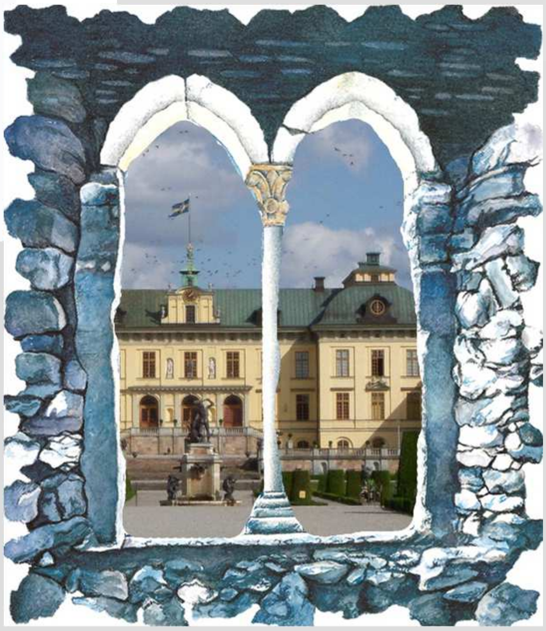
BIWAES 2015

9th Biennial International Workshop Advances in Energy Studies

Istituto Italiano di Cultura ”C.M. Lerici”

Stockholm, Sweden, May 4 – 7, 2015



Energy and Urban Systems

Scientific editors: Olga Kordas, Sergio Ulgiati

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KTH VETENSKAP OCH KONST

TU Graz
Graz University of Technology

UNIVERSITA' DEGLI STUDI DI NAPOLI PARTHENOPE

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Foreword
Energy and Urban Systems

Editors: Olga Kordas, KTH Stockholm, Sweden and
Sergio Ulgiati, Università Parthenope di Napoli, Italy
Associate Scientific Editors: Marco Casazza, Università Parthenope di Napoli, Italy and
Hans Schnitzer, TU Graz, Austria

The BIWAES series started in 1998. The 8th edition was held in Mumbai, India, in the year 2012, in collaboration with the Indira Gandhi Institute for Development Research. Since 1998, the Workshop was organized in Italy (4 times), Brazil, Austria, Spain, India.
The present Workshop edition brings together worldwide intellectual skills and talents with the aim to perform a critical assessment of environmental security and development of energy technologies suitable to meet the increasing world energy demand in the next decades, with special focus on urban systems.

Sustainability of Urban Systems

Cities are by definitions places of convergence and divergence, storage and redistribution. Convergence of people, traditions, materials, and energy; divergence of innovation, products, culture, information. Socially and environmentally concerned analysts, planners, managers and policy makers cannot ignore the opportunities that may arise from a sustainable and well-managed urban environment. Concepts of "sustainable community", "city metabolism", "transition city", "resilient city", "smart city", among others, by placing the focus on the social dimensions of development, on the ecological and economic aspects at the same time as well as on the innovative technologies and tools that are day-by-day becoming available, are gaining the attention of policy makers, managers and stakeholders.
As society moves from fossil fuels towards increased use of renewable energy and materials by implementing "green" technologies, and eco-conscious designs in buildings, neighborhood services, whole cities infrastructure and organization, also lifestyles change accordingly as a consequence and as a driver of new production and consumption patterns. In this context a sustainable urban community can be defined as an organization of people, institutions, activities and processes aimed at fulfilling the basic needs of the present and future generations, without disregarding the needs of the other species in the same area, within the constraints posed by the available natural capital and ecosystem services.
The ideal city does not exist. A city is not a set of buildings and streets, but instead a self-organizing system, capable to make choices and correct mistakes (or make new ones). Citizens are an important part of the system, with the role to provide a direction to the self-organization process. If we are still able to enjoy the beauty of the architectures, the sense of community, the participatory processes and still willing to plan the future development of the city towards new ways of living, then also a discourse about resources has a meaning. Instead, an urban system, simplified and only communicating through the traffic and the lights of supermarkets, loses its perspectives and guidance role.

Perspectives on urban studies and policies

Concepts of city sustainability are not new. It is not new that the metabolism of complex systems is continuously supported by outside sources. Similarly to human metabolism, cities and national economies are largely dependent on local and imported resources in support of both quantitative and qualitative growth. However, modern cities are experiencing shortages of energy, water, clear air, social relations and cohesion, social inclusion, and ultimately lack of participatory governance of city complexity. Cities must face the challenge of reorganizing their infrastructures and lifestyles to cope with the decreasing availability of resources, highly dependent on markets and environmental conditions. The priority in policy making is to identify suitable policies to reorganize the urban life in the presence of apparently unavoidable shrinking of the resource basis. Such reorganization will make cities less energy and material demanding, although still providing high quality standards of life. This cannot occur without investments and without important and shared choices about lifestyles.

What is new is that at present 50% of total world population live in cities; that 50% today means about 3.5 billion people (still growing); that the resource basis seems to be insufficient (or perhaps unfairly distributed) to support an acceptable standard of life to a large fraction of urban and rural population; and, finally, that the concentration of resources required to support cities places a huge load on surrounding environment. An energy and resource policy for planet Earth cannot ignore the way urban systems consume resources, grow and decline, compete, release waste and generate life support to urban population. As all living systems, cities are made with smaller interacting parts, are driven by outside resources, and self-organize by developing internal connections among components and external links with the environment as a source and a sink.
Similar to the metabolism of human body, cities extract from the biosphere the resources they need, and generate information in the form of culture, know-how, laws, economy, lifestyles, while at the same time releasing airborne, waterborne and solid emissions. As a consequence, a discourse on a city's sustainability translates into a discourse about internal and external connections and the rate resources are exchanged and processed.

What is also new is that for the first time in the history of our planet, modern transportation and communication technologies are generating an interconnected web of energy, resources, culture and information, in cities and throughout the world, capable to spur awareness and support efforts towards sustainable resource use, social cohesion and equity, inclusion and happiness. The opposite may also become true if resources and networking opportunities are not properly used through proactive attitudes and policies.

Energy, Sustainability and Equity

Energy and environmental security are major problems facing our global economy. Fossil fuels, particularly crude oil, are confined to a few regions of the world and the continuity of supply seems at present governed by dynamic political, economic and ecological factors, more than by actual availability in underground reservoirs. Increased growth and demand for welfare by developed and developing countries are placing higher pressure on energy resources. In particular, a large fraction of “new consumers” in developing countries, mainly concentrated in megacities, already reached a purchasing power high enough as to be able to access to commodity and energy markets worldwide, thus boosting energy consumption and competition for all kinds of resources. Such a trend, although in principle may represent a progress towards diffuse welfare and wealth as well as much needed equity, is at present contributing to a rush for the appropriation of available resources which are directly and indirectly linked to energy and may contribute to planetary instability if it is not adequately understood and managed.

A coherent energy strategy is required, to address energy supply and demand, security of access, development problems, equity, market dynamics, by also taking into account the whole energy lifecycle including fuel production, transmission and distribution, energy conversion, and the impact on energy equipment manufacturers and the end-users of energy systems. Issues of energy efficiency and rebound effect must also be taken into proper account. In the short term, the aim should be to achieve higher energy efficiencies and increased supply from local energy sources, in particular renewable ones. In the long term, redesign of life styles, further increase of alternative energy sources and shift to a more suitable and efficient mix of energy carriers are expected to contribute to solve or alleviate the problems generated by declining availability of fossil fuels. National economic accounting procedures are needed, capable to consider resource depletion and environmental degradation, and address questions concerning growth, carrying capacity, sustainability, and inter- and trans-generational equity.

Living within environmental boundaries

Concerned scientists and policy-makers cannot disregard the increased awareness of the energy problem among stakeholders (population, business communities, energy companies), in order to lead to redesign of societal structures and metabolism towards low energy lifestyles and attitudes. How this can be achieved is not an easy matter, since the present trend relies of past habits of low-cost energy use and insufficient awareness of environmental problems. It is evident that education must play a significant role in this regard.
According to the global need for addressing issues of access, safety, equity and diversification of resource use, special attention needs to be paid to:

- *Understanding of Environmental Constraints*

The environment is both a source and a sink. It represents a source of energy and resources used in the economies of humans and a sink for by products of economic processes. Energy use is more likely to be curtailed as the result of ecological considerations than as the result of actual resource exhaustion. In fact, although there is partial disagreement regarding the ultimate limitation of resources (i.e. the amount of resources that are actually available and the energy and economic cost of their exploitation), there is wide consensus worldwide about present exploitation of nature as a sink for waste release. As a consequence, there is an urgent need for incorporating environmental constraints into scientific research and policy actions.

- *Multidisciplinary integration of approaches*

It is obvious that there is still a need to evaluate new technologies. Much more effort is needed to reach quantitative and reliable conclusions regarding new technologies and energy sources. It is necessary to evaluate the feasibility and environmental effects of new technologies as much as possible during their developmental stages. Heated debate occurs worldwide about the use of different approaches, methods and tools and the domain in which the results of the various methods and tools are valid. Each of these methods reflects differences in perspectives, different questions, different goals, and different system boundaries. Rather than being a problem these differences are a strength, as the approaches are complementary and insights derived from the different approaches can be combined to increase insights into the complexities of reality and to generate policy within that reality.

- *Decision making supporting tools.*

Much needed are system modeling tools, decision support software, and techniques of multi-criteria evaluation leading to policy. Yet these approaches are still not at a level of maturity where they could be used by decision makers. We are still in the suggestion phase, still at the stage of trail observations and evaluations with an emphasis on indicators and normative standards that might lead to decision support tools. Much research and testing are still needed.

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A Roadmap towards Smart Cities

Hans Schnitzer*, Graz University of Technology, Inffeldgasse 13, 8010 Graz, Austria
hans.schnitzer@tugraz.at
Barbara Hammerl, CityLAB Graz, Reininghausstraße 11a, 8020 Graz, Austria
Barbara.Hammerl@stadtlaborgraz.at

Abstract

1. Background

The transition to sustainable energy systems has to start in cities. There is no way around and the facts are striking: cities cover about 1% of the world's surface, but consume 75% of the energy and cause 80% of the emissions of global greenhouse gases. And the cities keep growing. Today, about 50% of the world's population lives in cities, and 60% are expected by 2025. Before one starts to design a roadmap towards a Smart City, one has to know two cornerstones: the place where one starts from and the situation where one wants to end up. More than this, one needs indicators that can show whether the direction is right and how fast one progresses. Target point and indicators are specific to the city examined - as is the starting point - and have to be elaborated in tight cooperation with all stakeholders.

"Smart Cities" require both, innovative green urban technologies and a shift in paradigms of urban planning and development. The core challenges of creating future-oriented, sustainable cities include the integration of technological areas, the participation of citizens and relevant players (multi-stakeholder inclusion) and interdisciplinary process control beyond departments ("smart governance").

2. Vision generation

The definition of the target point is the result of a cooperative vision process. It should be discussed in a radical way with as few limitations as possible, current legislation and financing problems are to be left out. After a general definition, detailed visions can be elaborated for specific thematic issues. These visions are guided by what they aspire to achieve. In the City of Graz, we have chosen seven+one: energy supply, economy, ecology, mobility, buildings, metabolism and society plus urban planning as the comprehensive challenge. Multidisciplinary working groups with public administrators, researchers, civil organizations, entrepreneurs, NGOs and citizens defined targets and indicators for these issues. In detail, the working groups had to discuss the following issues:

1. Define the vision of the sector
2. Build a set of indicators
    - ✓ "hard" indicators that can be quantified "soft" indicators, descriptive only
3. Draw a roadmap
4. Specify the main actors and assign duties to them
5. Define the supporting (mega-)trends and most likely barriers

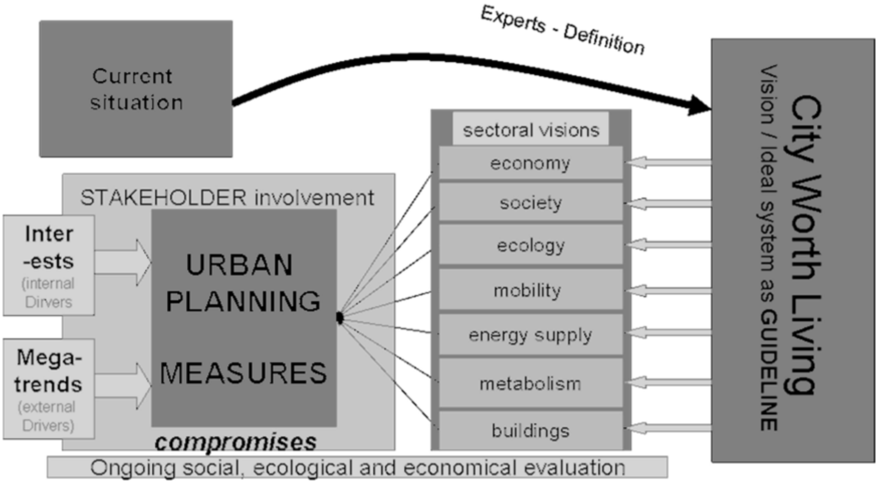

Fig.1: From sectoral visions to urban planning measures

The energy issue is a specific one. It is rather a crosscutting field than its own. Energy plays an important role in all the other thematic fields, especially in buildings, mobility and economy. While it is rather easy to set goals and define roadmaps for the energy supply scenarios, energy efficiency is very much depending on the services and goods needed for all sectors. The same is partially true for other infrastructure systems. Resource flows will depend on how existing infrastructure systems in energy, water, sanitation, solid waste, transport and other sectors respond to pressures for change.

3. Design of a roadmap

We do not know how a Smart City will look like, but there are several rules that have to be followed in order to achieve the results desired. Table 1 shows the criteria that have been developed in a participative process in the City of Graz [Hoffer K.U., 2014].

Hard indicators can be expressed in numbers (e.g. 15 kWh/y m² as the energy demand for heating, € as debts of the city). For the social roadmap, such indicators like “feeling safe” and “feeling well” are relevant, but difficult to measure. Moreover, indicators should possibly be included into architectural and city planning competitions and used as a yardstick for the selection process between development alternatives.

For the support of the teams while generating the vision and roadmap, we have developed a simple list of criteria. This list (see Table 1) contains some items that should increase (grow HIGH) or decrease (become LOW).

Table 1: LOWs and HIGHs for a Smart City

LOWs	HIGHs
SHORT DISTANCES: urban activities of everyday life are close together.	**HIGH ECONOMIC PRODUCTIVITY:** strong enterprises create meaningful jobs and fresh knowledge.
LOW GHG-EMISSIONS: energy and materials used in Graz are free of net CO_2emissions.	**HIGH INTERACTION:** Graz interacts with its international partners and its neighbours on a continuing basis.
LOW WASTES: waste air, waste water and waste have no negative influence on the environment, neighbourhood or nature.	**HIGH (Bio-) DIVERSITY:** all inhabitants and users meet a very attractive urban living space including the bountiful nature.
SMALL FOOTPRINT: the inhabitants' demand in Graz is in line with the bio-capacity of the earth.	**HIGH PERSONAL FREEDOM:** Graz encourages its inhabitants to follow their own style of smart living.
LOW EXTRA COSTS: all (investment) decisions are taken on the basis of lowest life-cycle costs.	**HIGH EVOLUTIONARY CAPABILITY:** Graz will transform itself and has the capability for changes and evolution.
LOW HEALTH THREATS: There will be no emissions that jeopardize the health of people living inside or around the area.	**HIGH RESOURCE EFFICIENCY:** Resources are used as effectively[1] as possible. People's demands are covered by services and not by products as far as possible.

The roadmap toward a Smart City will be different in every case as there is no single form of appearance of a Smart City, but the procedure for designing it can be very similar. Efficient ways of cooperation, participation and open innovation processes are key success factors regarding the roadmap development. Coordinating the different interventions and projects, facilitating learning between them at various times, and deciding how and whether they should be integrated will become the key challenges for the urban future. There are cultural backgrounds that will make some steps more easy or difficult in different countries, but a successful approach will always base on a jointly defined vision and participatory processes. Developing socially robust urban infrastructures require the creation of broad coalitions that integrated the interests of key stakeholders with relevant expertise.

4. Location of actors and driving forces

A roadmap towards a Smart City has to be based on the early involvement and participation of as many actors as possible and has to include the power of driving forces as well.

Politics or the city administration alone cannot push the development. There is a need for the involvement of all citizens, but especially of business. Yet business will only invest if there is a chance for profit.

We generally consider global trends as driving forces. There is first of all the increasing number of people migrating towards cities where they expect jobs and income. People get older and live longer, but simultaneously the elderly change their lifestyle: the new sixties are the former forties. Another global trend one has to consider while planning a smart city is the growing importance of a sharing economy [Rifkin J., 2014]. People are switching from buying good to paying for their respective services. The own car loses importance compared

[1] Effective (contrary to efficient) use means achieving a desired effect by means of low energy and material input (efficiency describes the relation of useful output/input).

to flexible mobility choices. Business approaches with nearly Zero Marginal Costs gain importance.

5. The Smart City process in Graz

Graz is Austria's second largest city. By 31.12.2014 the number of inhabitants was 275.526 [Präsidialabteilung, 2015] (main residence), corresponding to a population density of 2,058 ih/km². Together with surrounding communities, the number of inhabitants in the Graz region amounts to 420,000. After a long decrease, over recent years, there has been an increase in people actually present of approximately 1% per year. Reasons for the growth of the city and region of Graz are a positive increase in the number of births and a positive migration balance: in the years between 2004 and 2007, the city of Graz grew due to an increasing number of births and continuous migration into the city by 3,000 to 3,600 people per year. Long-term trends also show a continuous growth of population in the city of Graz and communities in the urban hinterland: current predictions foresee an increase in population to approximately 490,000 by 2050 (districts of Graz and Graz surroundings). The forecast dynamic population and economic growth development represents a special challenge for the development of the City of Graz[2].

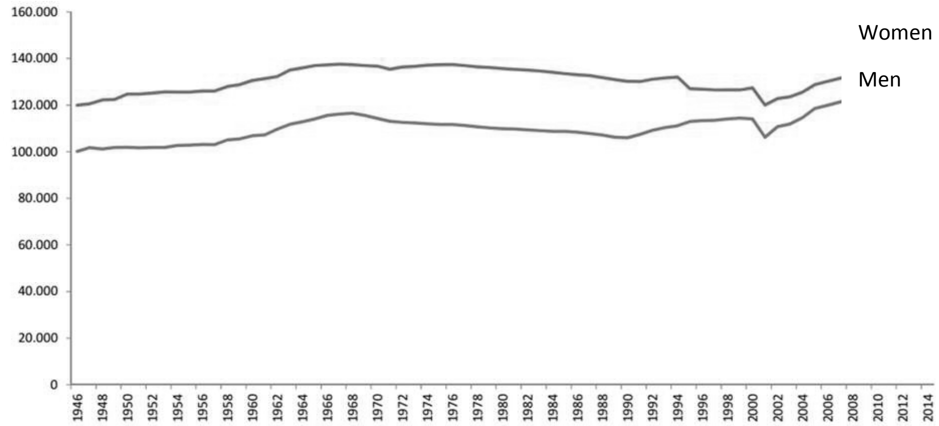

Figure 2: Development of population in Graz

In the course of the "I live Graz" project, the before mentioned 7 + 1 sets of indicators necessary for achieving a Smart City were recorded. In the action field Urban planning, strategies for the future urban development of Graz towards a "zero emission" city were elaborated.

Vision developed until 2020 / 2050:

2020: Graz has established itself as a "Smart City innovation technology and service center" with an international vocation and is evolving to become one of the top-ten medium-sized European cities. Implementation of the target area “Graz Mitte”, the first Smart City urban quarter has been completed. Any action is orientated according to SC strategies, which serve as a general guideline. A special interrelation between cultural, business and scientific competences acts as a driving force for a dynamic, modern and creative development, as well as a basis for high urban quality of life.

[2] http://www.stadtentwicklung.graz.at/cms/beitrag/10195417/4631044/

2050: Graz has become a dynamic, prosperous and leading medium-sized European city, in which the highest quality of life has been achieved. Thanks to consistently pursuing Smart City strategies, awareness raising and active participation, the city has managed to reduce resource and energy consumption and pollutant emissions almost to Zero Emission City level. 100% of total energy required is produced by local renewable energy sources. As a research, quality and business location, Graz has become an international benchmark for value creation by means of urban technology.

Indicators developed

In order to sort and apply urban development strategies and indicators, four strategic action levels were introduced on a local level: The city as a region ("City Region"), target areas, the quarter and buildings/projects.

Application of strategies, indicators and measures can thus be scaled according to "flying altitude". This ensures high-grade quality development, as well as quality assurance and monitoring measures. On the overall city level, three Smart City target areas, (Grazer Messe (Graz fair), Mur West (i.e. west of the river Mur), Graz Mitte (city centre), were defined as future zones of innovation for smart and sustainable urban development interventions. In the action fields Economy, Society, Ecology, Mobility, Energy, buildings and metabolism the aim is to define pilot projects for Graz, integrated according to the applicable strategic action level and implemented as agreed. This multi-project strategy could trigger a new era in urban development in Graz. Besides economic and ecological sustainability indicators, social topics shall also be taken into account and dealt with, in order to have jointly developed measures widely accepted by users. Social sustainability targets shall be supported by an accompanying quarter management.

Action Plan Target Area Graz Mitte

Elaboration and implementation of smart urban development strategies and processes:

- Smart urban development
  will be implemented on a conceptual level by steering the urban development and development process of the Graz Mitte target area on an interdisciplinary basis.
- Civic participation in Smart City life
  Regular information of specific target groups among the citizens of Graz, the establishment of a Smart City platform, quarter management, and e-participation are core elements.
- Economic aspects
  Implementation of innovative financing models and resource-efficient business models.
- Legal framework
  In order to maintain SC quality criteria, urban development agreements will be concluded with potential investors/land owners.
- Awareness raising, training and education
  In cooperation with local initiatives, platforms and organizations, events, meetings, workshops, training courses and further education courses will be organized for various target groups.
- Holistic approach and guiding principles/guidelines
  The holistic perspective ensures that the necessary individual Smart City solutions are integrated into in a higher-ranking strategy. Starting from an as-is analysis of the target area, general target categories including urban development indicators will be defined by applying the 7+1 indicators.

6. Conclusions

Roadmaps towards smart cities have to be designed in a cooperative process with as many stakeholders as possible. It is essential to first define the target and state clearly where the process is going to lead in the end. Goals will be non-technical ones in general and mainly relate to quality of life. Issues like energy autarky or CO_2-neutrality are never goals but instruments to reach other goals.

7. Literature.

Hoffer K.U. (edt.): I LIVE GRAZ - smart people create their smart city. Final Report, Klima & Energie Fonds Vienna, 2014

Präsidialabteilung der Stadt Graz: Bevölkerungsstatistik der Landeshauptstadt Graz. 2015

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Energy Metabolism of Urban Systems

Mario Giampietro*, Institució Catalana de Recerca i Estudis Avançats & Universitat Autònoma de Barcelona, Barcelona, Spain

Abstract

Urban systems are special cases of socio-ecological systems (SES) generated by the sustained interaction of two distinct typologies of complex adaptive autopoietic systems: human societies and ecosystems. SES are: (i) open systems capable of expressing specific structural and functional patterns by operating under conditions of thermodynamic non-equilibrium; (ii) hierarchically organized in nested structures observable only across multiple spatial-temporal scales; (iii) systems reproducing themselves using coded information; and (iv) metabolic systems in which the structural part (consisting in the fund elements making up the system) metabolizes flows (e.g., energy) in order to express the set of functions required for maintenance and reproduction. Finally, human societies are reflexive, in the sense that they are quicker than natural ecosystems in adjusting their own identity according to the circumstances.

Within this general framework, urban systems can be perceived as specialized organs of human societies characterized by: (i) an extremely high spatial density of both fund (humans, technology and infrastructure) and flow elements (energy and material); and (ii) an extremely high level of openness (cities are heavily dependent on the import of biophysical flows and export of wastes). Extreme means orders of magnitude larger than in rural areas.

MuSIASEM (Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism), an innovative system of accounting building on the flow-fund model developed by Georgescu-Roegen, is proposed to characterize the metabolic pattern of urban systems. This approach establishes a bridge between the quantitative characterization of socio-economic functioning (flows per hour of human activity) and the quantitative characterization of spatial organization (flows per square meter in different categories of land uses). The establishment of a direct link between information relevant to the socio-economic perspective and that relevant to the biophysical/ecological perspective strengthens the policy relevance of this type of analysis.

These innovative concepts and ideas are illustrated with examples, including: (i) the spatial metabolic pattern of energy of Barcelona; (ii) a grammar to assess the performance of urban waste management systems generating unconventional fuels; and (iii) an attempt to develop a taxonomy of typologies of urban informal settlements (slums).

Shaping options and mechanisms for decentral energy systems at different scales: an agent-based perspective

Verena H. van Zyl-Bulitta [1*], Christopher J. Watts [2], Alexander Mahr [3], Katharine N. Farrell [4]

[1] University of Leipzig [2] CRESS, University of Surrey [3 4] Humboldt University of Berlin

Corresponding Author e-mail: verena@bulitta.com

Keywords: agent-based modelling, decentral energy system scenarios, grid stability

We assess the comparative dynamic stability of system design options for a series of central and decentral energy system scenarios for the German energy market. Increasingly diversified and regionally extended electricity market structures bring new complexities and risks. Our investigation compares several possible combinations of market exchange mechanisms, energy distribution network structures and supplier / user interactions, using an agent-based model (ABM) that reflects both actor and system properties and possibly also roles. We distinguish between technological, trading, and legal controls, highlighting the interplay between physical and societal systems and the bridging roles of markets and technology, and consider implications for both local and global grid stability.

Options for model components and ontologies are developed using Georgescu-Roegen's (1971) economic process theory of flows and funds (Farrell and Mayumi, 2009). We then investigate how Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM, Giampietro et al., 2013, 2014), a related analytical tool for cross-scale analysis, could be linked with ABMs. MuSIASEM allows for specification of the micro-level relationships to be modelled and agent-based modelling can then be used to simulate the emergence of higher-order phenomena arising from the micro-level interactions between the selected components. Impacts on the German energy system, as a whole and for different scenario options are considered with respect to (i) storage and distribution, capacity provision and constraints and (ii) potential for flexibility in both storage and capacity.

Taking a bottom-up perspective of energy distribution networks, we ask, specifically: what could stable mechanisms for the coordination of distribution look like when peak loads are reflected in pricing? How would exogenous and endogenous driving factors, such as capacity and sustainability objectives impact on the dynamic stability of different market designs, and vice versa? This reflects the German energy transformation discourse (BMWi, 2014) concerning whether energy only markets or capacity markets should be fostered. With this approach we take the decentralised energy system proposition to the smallest possible scale, considering, for example, options how incentives for grid-stabilising strategies through small-scale storage options might work in practice. The spatial (mobility and movability) and temporal dynamics (flexibility) of energy system components are to a large extent defined by their technology, system design and connectivity options. Hence, it is important to devise appropriate structures to map decentral energy system components and interactions in the model development process.

Our investigation adds to previous work on combining other methods with ABM for energy systems (Chappin, 2011; van Dam, 2009), such as on complex systems for energy networks by Beck et al. (2008), or electricity (Zhou et al. 2007) and emissions trading markets (Weidlich, 2008). The modelling of predictive control by Negenborn (2007) uses strategies of control agents for transportation and power networks. Gaube and Remesch (2013) use ABMs and data on spatial patterns of energy consumption from a socio-ecological systems perspective for the city of Vienna. Kok (2013) describes the "Eco grid" as a multi-agent system, where coordination replaces centralised control structures. Those structures are prone to computational complexity and can quickly reach limits due to communication overload (Witt, 2013). Taking a socio-technical perspective, we use Witt's (2013) structure of energy systems and interactions with other supply systems, spanning socio-economic, physical, and ICT infrastructural domains.

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Food production, city-countryside relationship and energy resilient urban systems

Patrizia Ghisellini, Alma Mater Studiorum – University of Bologna, Bologna, Italy.

Marco Casazza, Parthenope University of Napoli, Napoli, Italy.

Corresponding Author e-mail: patrizia.ghisellini@unibo.it

Abstract

Food is the primary energetic need for mankind. It provides energy and nutrients, but its acquisition requires energy expenditure. This fact is particularly important, when considering the urban environment, since human communities organized within cities almost exclusively rely on the import of resources to meet their daily basic needs. Field-to-fork chain and its energetic cost depends on the organization of the food production and transformation processes, which, in turn, can be influenced by the city-countryside relationship idea and the organization of both the urbanization process and the agricultural production. A solution might come from the urban agriculture development and management. A short review of the state-of-the-art about urban agriculture, energy and urban resilience is given, together with an historical overview of the of the city-countryside relationship idea development, which still influences the evolution of urban agriculture. Some conclusions are drawn on the basis of the given findings.

1. Introduction

Food is the primary energetic need for mankind. Today, approximately a billion people are chronically malnourished, while our agricultural systems are concurrently degrading land, water, biodiversity and climate on a global scale (Smith 2013). So, the challenge of guaranteeing food security[1] for 9 to 10 billion people by 2050, and doing it sustainably, is considerable. Inappropriate soil and water management and the overuse of external inputs represent an economic loss for the farmer and a significant burden for the environment and subsequent impact on human health, as they contribute significantly to ground water and surface water pollution, GHGs emissions, the build-up in soil contaminants, such as heavy metals and organic pollutants. Predictions of a "perfect storm" of food, water and energy shortages by 2030 have therefore been made[2]. The order of magnitude of a human's energetic needs, which must be supplied from food, is of 10^2 W calculated on a daily basis (Casazza 2012). Actually the world agriculture produces about $1.3*10^2$ W per person per day, according to the most recent estimates[3], thanks to the introduction both of agricultural technologies and of chemical fertilizers. We can state that, in a very real sense, we are literally eating fossil fuels. In the last century, energy usage in agriculture increased from 10^7 to $5*10^{11}$ W for machinery, and from $3.6*10^5$ to $8*10^7$ t for production of fertilizers (Smil 2000). While nearly 40% of the terrestrial photosynthetic capability has been appropriated by human beings just for agriculture (Vitousek et al. 1986), the Green Revolution increased the energy flow to agriculture by an average of 50 times the energy input of traditional agriculture, and, in the most

[1] The World Summit on Food Security in 2009 defined food security as existing 'when all people at all times have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life.

[2] Beddington, J., 2009. *Food, Energy, Water and the climate: a perfect storm of global events?*. Available online at: http://www.letemps.ch/r/Le_Temps/Quotidien/2014/03/19/Sciences%20&%20Environnement/ImagesWeb/perfect-storm-paper.pdf (Visited on 24th March 2015)

[3] FAO, IFAD, WFP. 2002. *Reducing Poverty and Hunger, the Critical Role of Financing for Food, Agriculture, and Rural Development.* Available online at: http://www.fao.org/docrep/003/Y6265e/y6265e00.htm (Visited on 24th March 2015)

extreme cases, by 100 fold or more[4]. Nonetheless, while energy input has continued to increase, a corresponding increase in crop yield hasn't been observed[5]. This energy requirement does not include the energy to produce the machinery, or to transport, process and package the resulting food.

Whilst agriculture is a prime user of energy, it is also a major contributor to climate change, which may make food security even more difficult to attain. Climate change, through increasing variability of the weather, may also undermine the stability of whole field-to-fork chain. However, the potential impact is less clear at regional scales (Challinor et al. 2014), but it is likely that climate variability and change will exacerbate food insecurity in areas currently vulnerable to hunger and under-nutrition. Furthermore, in other areas, climate change may impede agriculture's access to water and may affect food prices across the world. There needs to be a considerable investment in adaptation and mitigation actions toward a "climate-smart food system" that is more resilient to climate change influences on food security (Wheeler and von Braun 2013).

Urbanization, which is a continuous shift process of the country's population to built up areas, is critical with respect to food production and consumption patterns. Most people, in fact, live in towns, cities and conurbations. The expansion of the city is not only the result of urbanization but also, and perhaps to a larger degree, the result of the diffusion of population, away from large urban centers, into smaller and less densely populated development clusters in the city region. It is known that food security has always been a key resilience facet for people living in cities (Barthel and Isendahl 2013). On the other side, we can discover an history of the idea of urbanization process, based on two enduring binaries: society-nature and city-countryside. These have been conceptualized in three different ways, under the framework of urban metabolism research: the first is the human ecology of the Chicago School, which treated the city as an ecosystem in analogy to external, natural ecosystems; the second is industrial ecology, where materials flow analyses of cities are developed, in order to conceptualize the 'external nature' as the source of urban metabolism's raw materials and the destination for its social wastes; the third is urban political ecology, a reconceptualization of the city as a product of diverse socio-natural flows (Wachsmuth 2012). This conceptualization came easier in China and in some parts of Europe, where walled urban environments developed along the centuries while this is not true for Countries such as Japan or England, where cities were rarely either walled or autonomous. Furthermore, the idea of city vs. countryside or city and countryside depends on the relative development of agricultural vs. pastoral practices and on the use of private property conceptualization (Smith II 1986).

Within the framework of urbanization process development, this paper deals about the energy-related aspects of urban agriculture, its consequences on urban resilience, its economical effects, making also some considerations about the history of city-countryside relationship idea.

[4] Giampietro, M., Pimentel, D., 1994. *The Tightening Conflict: Population, Energy Use, and the Ecology of Agriculture*. Available online at: http://www.dieoff.com/page69.htm (Visited on 24th March 2015)

[5] Pimentel D., Giampietro, M., 1994. *Food, Land, Population and the U.S. Economy. Carrying Capacity Network*. Available online at: http://www.dieoff.com/page55.htm (Visited on 24th March 2015)

2. Urban agriculture, energy and urban resilience

Food provides energy and nutrients, but its acquisition requires energy expenditure. Nowadays the consumption of fossil energy in agriculture can be divided in two categories: direct and indirect. Direct consumption of energy refers to the consumption of fuels for operating machineries, irrigation pumps, heating greenhouses and the moving loads, the consumption of electricity for drying crops, heating and illumination. Indirect consumption of fossil energy refers to the energy spent in the industrial sector for the production of the technological inputs used in agriculture. This indirect consumption includes the production of fertilizers and pesticides (in the chemical sector), the fabrication of machinery (in the mechanical sector) and the fabrication of other infrastructures. For this reason, it is normal to find a discrepancy between the estimates of energy consumption of the agricultural sector found in national statistics and the estimates based on the accounting of direct and indirect fossil energy consumption, which include also the embodied energy in the technical inputs (Arizpe et al. 2011).

Modern cities almost exclusively rely on the import of resources to meet their daily basic needs. Food and other essential materials and goods are transported from long-distances, often across continents, which results in the emission of harmful GHGs (Grewal and Grewal 2012). This problem, even if with a different dimensions, already existed in more ancient times. A simple example with respect to the city of Rome in the beginning of the imperial period illustrates the problem of external food dependency. Let us consider wheat caloric content ($1.69 * 10^7$ J/kg), ancient mean wheat productivity (referred to 2.000 years ago), of 1.5–2 t/ha (Jacobsen and Adams, 1958), the 1-year cycle as reference (we have 1 harvest per year for wheat). On the other side, it is known that an adult man body requires a mean daily food energetic intake of 2.200 kcal (Doughty and Field 2010). The ancient city of Rome (in the early imperial period) had a surface of $7,0 * 10^7$ m^2 and about 1 million inhabitants. The energetic (metabolic) need for feeding the inhabitants of the ancient city of Rome in 1 year was $3.36 * 10^{15}$ J (this number is obtained multiplying the energetic need of 1 man for 1 year for the number of inhabitants of the ancient city of Rome). Considering the available data, it is possible to derive that a surface of $1.13 * 10^9$ m^2 (equivalent to 16 times the surface of Rome at that time) would have been necessary for feeding the ancient city of Rome. This simply means that the city of Rome had to rely on external resources for food production and for the survival of its inhabitants. This was energetically costly. The main energy cost was related to food storage and transport (e.g.: granaries, transportation through ships and carriages, working animals and even slaves). On the other side, two case studies from widely different historical and cultural contexts – the Classic Maya civilization of the late first millennium AD and Byzantine Constantinople – demonstrate that urban farming is a pertinent feature of urban support systems over the long-term and global scales. Urban gardens, agriculture, and water management, as well as the linked social–ecological memories of how to uphold such practices over time, have contributed to long-term food security during eras of energy scarcity (Barthel and Isendahl 2013).

At a time when most of the world's population lives in cities, new issues of physical and financial access to food are raised, together with the recent emergence of a 'New Food Equation', marked by food price hikes, dwindling natural resources, land grabbing activities, social unrest, and the effects of climate change. The present diffusion of technologies and the globalization of the markets have reduced further the distances between cities and global food systems, increasing, in some terms, their resilience to possible food shortages, mainly due to their connectivity to higher and global food markets (Barthel and Isendahl 2013). However, since cities today mainly rely on food imports transported from long-distances and, often, across continents, the result is an increasing exposure of cities to sudden severance of supply lines, caused by oil peak scenarios and by higher emissions of harmful greenhouse gases (Grewal and Grewal 2012). These processes are contributing both to marginalize the local agricultural production and to deeply weaken the virtuous energetic and material cycles between the cities and their rural hinterlands (Elmqvist et al. 2013; Marchetti et al. 2014). This, in turn, increases the environmental pressure in the supply chain both within the cities and worldwide. Nonetheless, the reintegration of agriculture within the urban environment has a great potential. In fact, it has been demonstrated that urban food production improves the quality of urban environment (by reducing urban heat island, mitigate urban stormwater impacts) and lower the energy embodied in food transportation (Ackerman et al. 2014). Furthermore, the establishment of local food systems leads to organizational efforts either at the local level or in the form of geographically centralized networks, which allow energy expenditures linked to distribution to be minimized (Mundler and Rumpus 2011). It also improves both the local and the global environment, by building a green infrastructure, which improves the quality of urban environment (by reducing urban heat island, mitigate urban stormwater impacts) and lower the energy embodied in food transportation (Ackerman et al. 2014). Positive side effects, while considering an energetic perspective, can also be recorded in the case of rooftops planted with plants, which also contribute to the house thermal insulation and reduce the energy required for cooling the house (Orsini et al. 2013). The reintegration of agriculture within the urban environment has a great potential, since it makes cities much more food resilient. Agriculture has been incorporated into urban expansion plans for different cities, such as Kinshasa, Dar es Salaam, Dakar, Bissau and Maputo. In Lagos and Ibadan, state governments have embarked on urban greening programmes involving tree and grass planting in strategic public open spaces including road islands and road setbacks as well as roundabouts. Although the aim is to promote city aesthetics, this practice of policy support has indirect benefits to building resilience for climate change (De Zeeuw et al. 2011).

3. The city-countryside relationship idea

Landscape is a connecting term, which combines incommensurate or even dialectically opposed elements: process and form, nature and culture, land and life (Cosgrove 2006). Frederick LePlay's triad of place, work and folk was graphically expressed by the Scottish architect, ecologist and regionalist Patrick Geddes as the 'valley section', where human activities arise out of organic connections with the land and express themselves in an evolving series of settlement landscapes[6]. A similar idea was powerfully expressed in Martin Heidegger's 'Building, dwelling, thinking' (Heidegger 1978). A specific aspect of landscape is related to the urban-rural relationship. Over the last two centuries, the ideology underpinning city-country relationship in urban planning has radically changed, favoring a progressive emancipation and disconnection of the 'city' from its 'countryside' (Elmqvist et al. 2013). From a spatial point of view, this ideology has been articulated in two aspects. The first is still developing under the new concept of 'urban-rural fringe', which started to be discussed from 1937, as "the built-up area just outside the corporate limits of

[6] Steele, T., 2003. Patrick Geddes: Geographies of the Mind, the Regional Study in the Global Vision. Available online at: http://www.haussite.net/haus.0/SCRIPT/txt2000/04/reclus_geddes_X.HTML (Accessed on 23rd March 2015).

the city" (Pryor 1968). The second one has been related to urbanization channeling. More specifically, the idea of ever growing cities were already developed in the mid 1800s, together with the concept of green belts. The green belt concept goes back to the time of the garden city movement and before. In 1848, Edward Gibbon Wakefield promoted Colonel Light's scheme for Adelaide, Australia, which was based on the understanding that, with the growing size of the city, access to its central area became more and more difficult, owing to increasing traffic congestion. This, in turn, led to the idea that "once a city had reached a certain size, a second city, separated by a green belt, should be started" (Frey 2000). The model of urbanization has been put under discussion, together with its socioeconomic, ecological, cultural and political model (Marchetti 2014), since it omitted both the ecological and social dimensions from the urbanization processes (Elmqvist et al. 2013). The emergence of the city and the countryside as autonomous social entities is mainly a reflection of the diffusion of the modernist ideology, developed at the beginning of the last century from the Chicago School of urban sociology (Barthel and Isendahl 2013), which relied both on the ecosystem theory (Clemens 1916) and on the evidence that the city of Chicago, at that time, well represented the symbol of the city, as the centre of innovation and progress. In fact, at the end of 19th Cent., the industry started to overrun Chicago (as well as other cities), changing its previous feature of commercial center surrounded by rural hinterlands. Moreover, with the development of railroad transportation, in the middle of 19th Cent., Chicago became also an important node in the US railroad network, allowing the transportation of food over great distances[7]. The innovations in transport sector have been decisive both in contributing to the development of the ideology of cities separated from their life-support system (countryside) (Wirth 1938) and in excluding the rural aspects of life from the city (Elmqvist et al. 2013). The exclusion accelerated particularly after the World War II, with the industrialization and specialization of agriculture (Mok et al. 2014). This process has been particularly favored by the availability of cheap fossil fuels, which allowed an increasing surplus of food to be produced and a continuous urban growth worldwide. On the other side, urbanization leads to a continuous expansion of cities towards their rural hinterlands, while the reduced local availability of food (within the cities) has been mitigated by increasing food imports.

Nowadays, in order to talk about the layers of global flows of people, technologies, ideas, money, and ethics that will play a role in shaping the future of food, the term "foodscapes" is used. The urban food question is forcing itself up the political agenda in the Global North because of a new food equation that spells the end of the 'cheap food' era, fueling nutritional poverty in the cities of Europe and North America (Morgan 2014). Future research should investigate how cities can integrate social-practice based approaches into urban planning and design for resilience and sustainability, and how mainstream policy tools such as taxation, financial incentives, zoning incentives, land use regulation or educational programs, can be deployed to foster sustainable and just everyday urban practices (Cohen and Ilieva 2015).

4. A few economic considerations

Urban farming is a source of income for many urban poor, and it allows reducing the costs of food purchase, since it is estimated that those urban poor spend between 60 and 85% of their income just to feed themselves (Redwood 2008). Experiences cited

[7] It was a railroad center serving the upper Midwest as a shipping hub for lumber, meat, and grain: http://www.countriesquest.com/north_america/usa/history/industrialization_and_urbanization/growth_of_cities.htm

In the USA savings from the development of urban agriculture range from $475 (for individual gardeners) to $915,000 for an entire community garden program[8]. As a matter of fact, with few exceptions, a clear negative correlation between participation in agricultural activities and level of welfare has been noted (Zezza and Tasciotti 2010). The slum dwellers, who grow their own food, can provide food for their families and thereby reduce the costs of food purchase (Orsini et al. 2013). Urban farming creates job opportunities (Agbonlahor et al. 2007) and stimulates the growth of enterprises in the related activities (e.g., farming inputs, food processing, packaging, marketing, etc.) (Orsini et al. 2013). Although urban agriculture does not appear to be the major urban economic activity, in a number of countries, there is a significant share of the urban population that relies on the production of crop and livestock products for their livelihoods (Zezza and Tasciotti, 2010). Urban agriculture is eminently an activity practiced by the poor, and, with the rise of food demand in cities, small-scale farming gradually shift from subsistence farming to commercial farming (Dossa et al. 2011). Urban agriculture both offers employment and is a catalyst for new businesses, as in the case of food justice projects that regards areas with high employment rates (Ferreira et al. 2013). For example, in the USA some community food projects financed by the USDA contributed to the creation of 2,300 jobs and over 3,600 micro firms and 35,000 farmers were trained within community projects on sustainable agriculture, business management, and marketing[8].

4. Conclusions

Agricultural production is not “the antithesis of the city”, but is, in many cases, a fully integrated urban activity. It is important to notice that increasing local food production carries both advantages and social complications. A food system cannot operate in an independent local vacuum, but is integrated within global systems, incorporating both “more alternative” and “more conventional” members and processes, which have to be carefully evaluated (Bellows and Hamm 2001). Nonetheless, the reintegration of agriculture within the urban texture brings many benefits. Among them, a reduction of energy consumption and an increased resilience of the urban communities, together with a sensible beneficial effect on economy of local communities. Responses to this new biophysical and social geography of food, merged with both philosophical and planning aspects - known under the name of foodscapes - are increasingly emerging at the local level, particularly in industrialized countries, where municipal governments are recasting themselves as food system innovators. Innovative forms of green urban architecture aimed at combining food, production, and design to produce food on a larger scale in and on buildings in urban areas are under study (Specht et al. 2014). Urban agriculture, whose return has an interesting parallel with the medieval city, with its inner gardens, should be developed in the future, supported by a different city-countryside relationship idea, closer to 'city and countryside', trough policies and education and a deeper analysis of environment benefits.

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[8] Golden, S., 2013. Urban agriculture impacts: social, health, and economic: An annotated bibliography. Available online at: http://www.sarep.ucdavis.edu/sfs/UA%20Annotated%20Biblio-%20Golden%20Reduced%2011-15.pdf (Accessed on 25th March 2015)

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Developing methods and tools for local target-oriented action selection processes in the transport system

Markus Robèrt, PhD

Industrial Ecology, SEED, Royal Institute of Technology, Stockholm

Abstract

The concept of local action selection processes has emerged with the aim of creating informed decisions and consensus around alternative accessibility improvements in the transport system through a process of dialogue between public authorities and other stakeholders (e.g. the Swedish Transport Administration, public transport providers, municipalities, transport planners, etc.).

This study sought to create a more structured approach for integrating national policies for emission targets in Sweden and the transition to more sustainable transport alternatives in local action selection processes. At present, Swedish counties and municipalities deliver status reports on three indicators of regional/local progress towards the national transport targets: greenhouse gas emissions, mileage per travel mode and modal split. Based on target levels for these three indicators, quantifiable and tailor-made target scenarios were created for each local area involved in the local action selection process. Once these target scenarios were established, they helped facilitate proper prioritisation during the development of efficient and tangible action plans. The so-called CERO methodology for target-oriented travel planning at organisation level (companies, municipalities, agencies, etc.), which was originally developed in a doctorate at KTH, was refined in this study to handle scenario generation and preparation of action plans at regional and local level. In addition, a simulation tool (SIM-CERO) was developed to support the quantitative basis for scenario generation and decision making.

1 Introduction

The transport sector accounts for about one third of Sweden's greenhouse gas emissions and emitted approximately the same level in 2012 as in 1990 (Tärnroth, 2013). The majority of these emissions come from passenger cars and heavy vehicles. Passenger traffic in the period increased but despite this, emissions have decreased by 14% compared with 1990, due to fuel efficiency standards for cars having improved over the period.

The Swedish Parliament has established 16 national environmental quality objectives. Eight agencies are tasked with auditing and validation responsibility for one or more of these environmental quality objectives. The Swedish Transport Administration, together with the Swedish Transport Agency, is responsible for long-term planning of the transport system and is required to work to ensure that environmental quality objectives within the area of transport and infrastructure are achieved. For the transport sector, the objective specifies a vehicle fleet independent of fossil fuels by 2030 (Trafikverket, 2012), which is part of the basis for a road map for Sweden with no net emissions of greenhouse gases by 2050 (Naturvårdsverket, 2012). A milestone defined for the environmental quality objective of reduced climate impact is that emissions in Sweden should be 40% lower in 2020 than in 1990. A status assessment indicates that this target is not on track, i.e. the planned measures will not fulfil target conditions for the transport sector by 2020.

Indicators for monitoring the transport sector consist of:
• Greenhouse emissions
• Mileage by car and public transport
• Number of trips distributed between different travel modes

These three indicators are used to measure progress towards the national transport targets and are reported annually to assess progress at regional level in Sweden.

1.1 Action selection study: A concept to trim the transport system

Local action selection processes involve preparatory work for the selection of measures in accordance with government planning for transport infrastructure. Local action selection processes should identify the package of measures based on the so-called "four-step principle" that together create the best effects and solutions to the problem. All infrastructure investment in Sweden must be preceded by an action selection process.
Agreement to introduce an action selection process for the traffic situation in the cities of Solna, Sundbyberg and Stockholm Västerort has been reached between the municipalities, the Swedish Transport Administration, the County Administration Board and the public transport provider (SL). The agreement on cooperation concerns the parties involved in implementation of the process where the problem areas and targets are defined.
The action selection process is based on the results of "Systemstudie nordväst" (Transport Administration, 2010) and the Regional Action Plan for Mobility Management (Transport Administration, 2012). The background to these studies was the strong growth in the area and the accessibility problems in the road network. A functional demarcation for "The dense city" ("Täta staden" in Swedish) has been defined for the area where the action selection process will be carried out (Figure 1). However, the traffic flows in Solna, Sundbyberg and Stockholm Västerort may originate outside the defined area and thus transport efficiency measures can also be applied in other parts of the Stockholm county region.

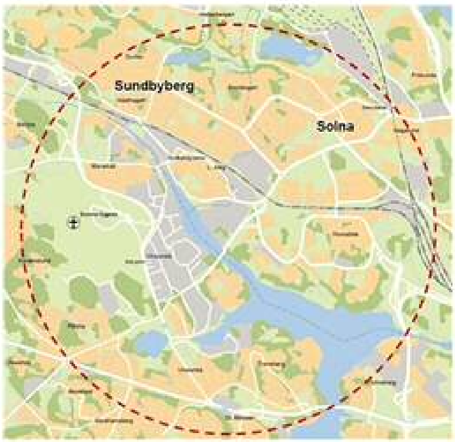

Figure 1. The area defined for the action selection study "The dense city".

The planning horizon for the action selection study was the year 2030 and the purpose of the study was to make parties adopt a strategic collaborative approach in order to identify joint solutions for infrastructure measures that could best solve traffic and accessibility problems on the one hand, and meet national climate targets on the other. The action selection study may involve different combinations of measures to implement coordinated action between actors at different times. The study provides a basis for subsequent agreement on implementation of the actors' respective areas of policy packages.

Due to the far-reaching planning horizon for this action selection study (2030), a clear motive was to integrate the national transport policy objective of a fossil fuel-free transport sector by 2030. Furthermore, the milestone set for the year 2020 of a 40% reduction in CO_2 should be achieved. Specific objectives of the action selection study developed in this project were to: a) break down the 40% target to locally adapted target scenarios for selected local destinations within “The dense city", and b) develop a methodology whereby target indicators are not only used as monitoring indicators, but also as a basis for constructing target scenarios.

2. Method

2.1 Status description: Simulating traffic volumes to target destinations

The methodology in the action selection study is based on the so-called CERO model developed in doctoral research at KTH (Robèrt, 2007, 2009, 2009), where the indicators are used to create a shortlist of alternative efficiencies in order to facilitate priorities and avoid sub-optimisations between alternative measures that may be relevant in the area. The model is based on backcasting (Robinson, 1982; Dreborg, 1996), a target-oriented perspective often applied in strategic planning in complex systems. CERO supports organisations through customised and economically optimal strategies to achieve long-term climate targets through more efficient travel. The most easily accessible way is modelled explicitly based on employees' travel behaviour and willingness to change that behaviour. To date (March 2015), CERO processes have been implemented in over 50 organisations in Sweden (32 municipalities, seven county councils (Robèrt and Jonsson, 2014), and some 15 large companies.

In order to quantify traffic volumes to selected destinations within the study area, a simulation tool (SIM-CERO) developed in a previous research project, in which a number of private actors conducted CERO processes internally for their respective organisations (Robèrt, 2015), was adapted and refined. In that project, a prototype of the simulation tool was designed in order to create a regional action plan for Kista. The purpose of the tool is to provide organisations, public authorities and planners with the ability to test different combinations of specific policies and produce an estimate of what degree of mode shifts, trip reductions and, consequently, greenhouse gas reductions, might be expected, particularly given the type, size and location of the organisation. Furthermore, generation of alternative simulated scenarios can improve the dialogue between different stakeholders in the process of providing better market-oriented traffic planning in certain key areas in line with sustainability targets.

An alternative approach to simulating traffic volumes would be to conduct traffic measurements or travel surveys in the area to create a quantitative basis for decision making. This would be more precise and accurate according to the local circumstances, but also far more resource intensive, time consuming and costly. SIM-CERO is based on a large database developed through the 50+ CERO analyses conducted in Sweden.

When simulating travel volumes to an organisation (or imaginary organisation), the following three organisation characteristics need to be known, in order to match with appropriate organisation travel data in the CERO database:

- Type of organisation to be simulated (business type, municipality, county, other)
- Geographical location (urban/town/rural)
- Size of organisation or work area (number of employees)

SIM-CERO is designed as an online, interactive planning tool where the above three basic settings can be specified by the user. Based on these settings, a travel choice model can be estimated from similar organisations, where log-normal distributions of commuting distances are estimated. Based on the parameters of the log-normal distributions, SIM-CERO produces a synthetic set of employees in the geography around a given point and distance to work in the traffic network, given the assumption that these distances follow the same probability distribution as for actual employees in similar organisations.

Based on the simulated distance to work and given the three criteria above, the next step for SIM-CERO is to simulate mode choice (car, public transport, cycling and walking). This is again based on the CERO database for similar organisations. A number of specific utility functions are estimated for each organisation type, geographical location and distance to work, so that the choice of transport mode is as consistent as possible with the actual travel behaviour revealed in the CERO database of similar organisations.

By combining these two parts, SIM-CERO simulates the total commuting volumes at a given geographical point (number of trips and miles), and calculates travel time (h), travel costs (EUR) emissions (kg CO_2), energy (kWh) and key figures for physical activity (kcal) of an organisation's employees, given the size and type of organisation and the geographical location of the transport network. The accuracy of SIM-CERO is gradually improving as the database increases in size (which occurs when more CERO analyses are conducted). At present, the precision is best for simulating businesses and municipalities in Stockholm County, which represent the majority of the data in the database. In future versions, SIM-CERO could also be developed to predict the effects of alternative policy measures. This will be possible when follow-up data are available from organisations implementing specific travel policies and action plans.

3. Results

3.1 Workshop 1: Anchoring the concept outline, method and process structure

The first workshop covered the following three elements:

a) Formation of working groups and definition of four target point areas within the dense city. The working groups on each of the four target point areas included representatives from the Swedish Transport Administration, SL, the County Administration Board and the three municipalities of Stockholm, Solna and Sundbyberg. Each working group was chosen jointly to create maximum involvement of public authorities at each target area and ensure local participation from each municipality.

The decision to focus on destination trips to the dense city was a consequence of a pre-study of travel volumes generated in and to/from the area, which revealed that trips with their destination in the dense city represented 52% of total trips in the area. Travel originating from the dense city with other locations as destination represented 25% of total trips, journeys within the dense city region corresponded to 8% and transit trips (through the dense city) corresponded to 15% (Schmidth, 2013). The four target point areas were selected based on where the traffic load is most urgent in the dense city area.

b) Definition of the objectives of the action selection process. The objectives were defined both as a quantifiable transport policy target deconstructed at local level and as improved accessibility in the area:

• "40% reduction in greenhouse gas emissions by 2020, with a long-term vision of a transport system independent of fossil fuels in 2030".

• "The purpose is to improve accessibility and to create conditions for an attractive and dense urban city district".

The project groups agreed on the following parameters as indicators of the quantifiable objective in accordance with the established indicators for the monitoring of transport policy objectives described above:

• Emissions (CO_2-equivalents)
• Vehicle mileage (km)
• Number of trips by car

c) Anchoring the methodological approach to the workshop process. Participants were given the opportunity to provide feedback on a proposal to work according to a target-oriented backcasting approach based on the CERO model, where a clear link to the national transport policy objectives permeated the action selection process. Project participants were given a brief presentation of the CERO methodology (Chapter 1), and a review of the results from the pre-study and the traffic analysis for the area. The project groups supported the proposed methodological approach and agreed that according to the four-step principle, they would focus primarily on step 1 and 2 measures in the development of a target-oriented action plan for the area. The four-step principle is an established model for infrastructure investments in the Swedish Transport Administration which states that each infrastructure investment should follow this order of priority:

Four-step principle
Step 1: Measures that may affect transport needs and choice of transport mode.
Step 2: Measures that improve the use of existing infrastructure and vehicles.
Step 3: Limited rebuilding measures
Step 4: New investments and major rebuilding measures

Figure 2 shows the sequential order of the process work, where an action plan for each area is systematically selected through a stepwise 'funnel' approach and the group defines overarching principle objectives (transport policy goals) in the initial step. In the next step, the target scenario is defined. It forms an essential basis for decision making and prioritising between measures that are finally are grouped together and packaged to form the action plan for each area. Each action plan must be anchored in all organisations involved and assigned a schedule for implementation.

Figure 2. The four-step process of developing a local action plan for each target point in the dense city. Each step is a successive concretisation of the initial step where the principle target is defined.

3.2 Workshop 2: Developing target scenarios

By applying SIM-CERO, 1000 commute trips were generated to each of the four target points within the defined area of dense city. Based on simulated traffic volumes to each target area, a shortlist of potential 1% CO_2 efficiencies was generated according to the CERO methodology. Based on this shortlist, each of the four working groups developed target scenarios for each target point. This exercise was aiming at filtering out the most effective and locally optimal policy packages for each area having a bearing on the principle emission reduction targets. Efficiencies in the shortlist were categorised as: a) local efficiencies, designed for commute trips that take place entirely within the dense city region and b) regional efficiencies, designed for commute journeys starting outside the dense city region. The reason for this categorisation is to separate measures that can be implemented by local decisions in the municipalities from measures requiring county-wide decisions. Each group was assigned homework to complete the target scenarios before Workshop 3 and to evaluate the action selection process so far. Table 1 presents a target scenario for one of the areas (Arenastaden), where local and regional efficiencies were selected in different proportions in order to jointly achieve the transport policy target of 40% CO_2 reductions by 2020.

Table 1. Example of a target scenario defined for one of the areas in the local action selection process (Arenastaden).

Efficiency category	Type of efficiency	Target substitution rate	% CO_2-reductions	Reduced private car kilometres (Mkm)
Local efficiencies	Increase public transport	16 car trips (21% of local car trips) switch to public transport	0.5	56
Local efficiencies	Increase cycling	27 car trips (18% of local car trips) are replaced by cycling	1	96
Local efficiencies	Infrastructure and city planning	27 car trips (18% of local car trips) are replaced by densified city planning	1	96
Regional efficiencies	Increase electric vehicle share	10 cars (1% of regional car trips) are replaced with electric vehicles	1	0
Regional efficiencies	Increase public transport	220 car trips (1% of car trips) are replaced with public transport	20	1940
Regional efficiencies	Increase renewable fuel share	7 car trips with fossil fuel cars (0.25% of car trips) are replaced with renewable fuel cars	0.25	0
Regional efficiencies	Increase cycling	70 car trips (7% of car trips) are replaced with cycling	7	679
Regional efficiencies	Infrastructure and city planning	100 car trips (10% of regional car trips) are replaced by densified city planning, telecommuting, travel planning	10	970

3.3 Workshop 3: Selecting measures to achieve target scenarios

The next step in the workshop process was, based on the target scenarios developed for each target point (Table 1), to select specific combinations of measures for each of the efficiencies described in the target scenario. Designing target scenarios for each geographical area in the action selection study facilitates prioritisation of measures that address each of the specific efficiencies listed and thus limits the risk of sub-optimisation in the development of target-oriented action plans. As an example, in the target scenario for Arenastaden (Table 1), the most comprehensive package of measures developed was to support the transfer from car to public transport regionally, as this efficiency corresponds to 20% CO_2 reduction and would improve accessibility in the area. This efficiency is also clearly consistent with the defined purpose of the improved accessibility objective in the action selection process, i.e. to create conditions for attractive and dense urban planning. Lower priority measures included those that increase the share of renewable fuels, which only corresponds to 0.25% CO_2 reduction in the target scenario. Another factor contributing to lower priority of this efficiency was that it did not assist the purpose of improving accessibility and creating the conditions for an attractive and dense urban city district.

Each group was also responsible for assessing how well each cluster of measures would fit together and for setting a deadline and naming the organisations responsible for implementation of each of the different measures that would form the action plan. Developing an action plan towards a target scenario is an iterative process, where a gradual assessment is made of whether the respective efficiency target in the target scenario is sufficiently supported by measures. Figure 3 provides a flowchart of the successive and iterative work of critically examining each of the efficiencies in the target scenario, in relation to how well it is supported by the selected measures. One useful technique invented in the workshop process was that the four working groups were able to criticise each of the target scenarios and associated action plans. This group exercise proved to be a useful part of the workshop process where the collective expertise was utilised in a peer-review process. When the target scenario was regarded as not sufficiently supported by measures, more measures were successively added. Finally, each action was categorised as based on the following questions so that it would take place at the right time in the planning process at the respective organisations responsible:

- Which geographical destination area does the measure address (area 1, 2, 3, 4)?
- Is the action primarily local or regional?
- What is the primary objective of the measure (public transport, cycling, car use, electric car, parking, trimming, densification, other)?
- Are there policy/planning documents and reports that support the measure?
- Does the measure counteract accessibility problems and barrier effects in the area?
- Start date and end date for completion of the measure?
- Organisation responsible for each measure (County Administration Board, Traffic Management, TRV, municipality, other)?

Figure 3. The action selection process is an iterative process where all actions are connected to the defined target scenarios. The second stage involves assigning responsibilities to different organisations, scheduling implementation of each measure and finally anchoring the total action plan.

3.4 Continuous series of seminars to maintain momentum in the process

To ensure continuity in the action selection process, a chain of tuning seminars was established so that the project participants could report on the status of the action plan for each destination area. The format of Workshop 3 was maintained in these seminar sessions, where the joint expertise in all four groups provided feedback to each measure selection process for the four destination areas. The presentation of each group's target scenario and action plan was also aimed at creating a 'challenge', where the project participants would think critically during the progress of the work between seminar sessions. The approach of allowing project groups to defend the adequacy of selected measures in relation to the target scenarios developed was much influenced by an approach developed and used successfully in teaching at KTH and other universities to maximise the benefits and responsibilities for groups presenting work in plenary sessions (Elmgren & Henriksson, 2011).

3.5 Involve companies in the action selection process at each target destination

A central part of the implementation process is to clarify and visualise the incentives and motives for the companies in each area to develop travel policies and their own "travel plans" (for references see Rye, 1999; Robèrt 2007; Newson 2000). CERO processes have been established in some 15 major companies in Sweden, including the business area of Kista, where the five largest companies (Ericsson, IBM, Microsoft, Atea and Oracle) have been invited to take part in a stakeholder-driven process to contribute to climate targets and reduce car dependency in the business area. Four of these companies have conducted follow-up analyses of their action plans and have demonstrated emissions reductions and reductions in traffic volume of over 20% during the period 2012-2014 (Robert, 2015). Research also shows that from a social perspective, an active travel planning agenda for large business districts contributes to a smoother energy transition, increased mobility, less carbon footprint, better local environment, reduced costs, fewer accidents and healthier employees (Robert, 2007). The aim is now for the project groups to identify the largest companies in each target area and highlight the benefits to companies from involvement in the process.

4. Discussion further research

A number of valuable comments on the format and methodology of the action selection process were collected when all groups had completed the target scenarios and compiled a first draft of the action plan for each target area. A small focus group of seven participants answered a number of interview questions addressing various issues to elaborate upon in the subsequent discussion.

A structured and target-oriented approach needs more resources to drive the process forward

When the project participants were asked what they most appreciated in the new format of action selection studies, all mentioned that the new format was more performance-oriented and structured than the previous processes. Several participants reported added value from a greater insight into the quantitative relationship between measure-impact in relation to defined targets. Furthermore, the group work with individual responsibility between plenary presentations at specific dates was perceived as a motivating and efficient structure for utilising group dynamics and collective know-how when assessing the impact of selected measures. One risk pointed out by a couple of project participants was whether the internal budget of each organisation could ensure an opportunity to establish continuity in the implementation phase of all measures in the action plans. One respondent recommended long-term follow-up whereby the continuous project meetings and process seminars continued once a month or once a quarter, to ensure that the action plan maintained momentum over time.

Detailed cost-benefit analyses and traffic modelling required for work to achieve priority
Another issue raised by the focus group was a need to conduct more rigorous socio-economic cost-benefit analyses for each measure. This was argued to be essential information when prioritising between measures and deciding which fitted best together. An ingredient that would most likely strengthen the format of the action selection study conducted in the dense city would be to complement the basis for decision making with traffic modelling predictions to produce socio-economic indicators. One problem with this would be that traffic modelling predictions are often too ‘blunt’ to evaluate mobility management measures, in particular combined effects from clusters of measures at a local level. Here is a clear need for further research from a process development perspective and from a purely technical traffic modelling perspective.

The relationship between the national transport targets must be balanced against local accessibility targets
One difficulty pointed out by a few participants was the conflict between local accessibility targets and national climate targets. In particular, a couple of municipal representatives regarded improved local accessibility and densification of buildings as the main priority for local action selection studies. Contributing to achieving national transport targets was regarded more as a national concern and therefore of secondary importance for the local transport planning process. A useful technique in this situation was to define more key parameters, other than CO_2 emissions, in order to demonstrate how each measure could be evaluated even from an accessibility perspective in the form of a) reduced car travel (number of trips and vehicle mileage) and b) transfer to other modes than the car. In general, both these parameters are consistent with the two climate targets and with improved accessibility.

Transport policy objectives need to be adapted specifically to local conditions
An important conclusion by one participant was that local adaptation of transport targets is needed before they can be used as an overall target for all destinations in the process work. Consideration also needs to be given to local emission levels, reflecting how each district relates to the national average. An improvement in future action selection processes would be to define differentiated emission targets for each respective area based on present conditions, which would also set the standard for the local target scenarios developed. The need for differentiated target setting was evident when comparing the prerequisites for reaching target fulfilment of a 40% CO_2 reduction in the four areas of interest in the action selection process. One municipality also had a more far-reaching target of becoming totally independent of fossil fuels by 2020, which created a special position for the target scenario at that particular destination.

System boundaries: To include both passenger and freight transport at the cost of increased complexity
One participant stated that it was unfortunate that the group agreed on limiting the scope of the action selection process to commuting and that it would be desirable to also include freight transport. Setting the system boundary to focus solely on commuting was decided based on the fact that commuter trips were by the far most dominant when different types of personal trips were analysed for the area and that the agreed focus of this action selection process was primarily on type 1 and 2 measures according to the four-step principle. However, the argument for incorporating goods transport into the process is justified by the fact that the emissions from heavy

vehicles increased by 44% in Sweden in the period 1990-2012 (EPA, 2012).
Consequently, there is strong reason in the next phase of the action selection process to generate target scenarios and action plans specifically for freight transport in the area. However, the implementation of measures directly or indirectly counteracting traffic volumes from commute trips with private cars (as was the scope in this action selection process) also has positive repercussions for freight transport, since these journeys take place during the most troublesome peak hours in the traffic system when emissions per km are greatest for freight transport too.

Teach the teachers and provide external support with anchoring at the project participants' organisations

One person reported that the interactive internet-based planning tool applied in the process was difficult to understand and use and that it would need to be more intuitive in order to facilitate anchoring of the action selection process back home in each partner organisation. Effects calculated, the relationship between target scenarios and adherent measures and the impact on measures in relation to traffic volumes must be more clearly displayed in order for the project participants to succeed in ‘selling’ the package of measures to decision makers and executives. This problem was mentioned by several participants, who expressed a desire to call in the workshop process manager on anchoring occasions when the package of measures would be agreed upon. The stated need for an ‘outside’ person who can convince others about the content of the action plan and the methodology behind the results is of course a dilemma and perhaps more emphasis should have been placed on ‘teaching the teachers’ (project participants). From an anchoring perspective, it is crucial that all project participants feel involved and ‘accomplices’ to the target scenario and action plan they have developed, and that they are capable of presenting and explaining every detail step by step.
One project participant said that "the group members would need support with promoting and anchoring the benefits of the action selection process internally in order to obtain priority higher up in their respective organisations". More resources could possibly be spent on just ensuring the understanding and teaching ability of project participants. One solution would be for workshop leaders to carry out a site visit to each participant’s organisation to support internal anchoring and training of colleagues, so that a larger group of employees at each workplace were familiar with the action selection process and the outcome of the study, methodology, results and design of the action plan and its defined target scenario. This would also be useful in the situation noted by one participant: Employees are often replaced during the process of the work, which can be serious because it can lead to knowledge gaps and lack of motivation where no-one ultimately feels personal responsibility or has insights into how the work is produced. One project participant claimed that compulsory participation throughout the process of implementation would be needed in order to limit this problem.

5. Conclusions

To cope with national climate targets, municipalities, traffic administrations and other stakeholders need to take great responsibility, even at a local scale. There is currently a large number of climate targets defined in Swedish municipalities, some of which are far more ambitious than the national objectives (e.g. Sundbyberg aims to be free of fossil fuel emissions by 2020). However, action plans for achieving these objectives at the local level are rarely defined and put into practice. Action selection processes as a concept have a very important role to play in that they are implemented in the sensitive stage where efficiency and trimming of the transport system is being considered. The three types of indicators established for monitoring the environmental quality objectives for the transport sector should be used not only for monitoring but as key parameters in the design of target scenarios. If target scenarios and subsequent follow-up parameters are not entirely consistent, there is a risk that the current gap between the overall national objectives and regional, municipal and local action selection processes will persist. Local changes in traffic volumes, modal shares and emission figures need to be measured and reported to ensure that progress towards environmental quality objectives actually occurs at the rate and extent required in relation to targets.

Based on the project participants' assessment of the format and outline of the action selection study, the overall conclusion is that it succeeded in its aim of creating a clearer structure for the actions chosen based on a quantified overall principle target. It also succeeded in generating tailored action plans for each of the four defined target point areas, based on emission targets deconstructed from the national transport target. Furthermore, a number of potential areas for development and improvement of methodology and design of the action selection study were identified, such as the use of explicit socio-economic cost-benefit analyses as an additional target indicator, the need for local adaptation of transport targets and a number of educational and engineering improvements to the workshop format that were developed and applied in the action selection study.

It will now be interesting to follow the long-term implementation work of the action plans for each of the four areas and the future role of all participating organisations that contributed to development of the action plans. The success of this will be strongly dependent on how much time and resources are dedicated to maintaining momentum in the implementation process and the ongoing work.

It is most likely highly important to decide at an early stage that the action plans at each target point will be followed up in the near future, so that each organisation that contributed to the work gets feedback on the impact of time and resources spent in the project. Quantitative monitoring results are also necessary if good examples and experiences from the project are to be spread to other action selection studies needed in Sweden (and globally) to jointly contribute to the national traffic and environmental quality objectives.

It is important to develop methods and tools to monitor the impact of mobility management measures from a holistic perspective, where synergy effects could be obtained by matching the right proportions of measures together. Trying to quantify the effects of one specific measure at a time is impossible, since synergies between actions can be crucial for the final impact of the measures. Monitoring should involve macro-level traffic measurements and micro-level analyses of some of the largest employers in areas where target-oriented action plans have been implemented.

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A Comparison of the Metabolic Pattern of Urban Informal Settlements in Rio de Janeiro and Cape Town

Victoria Emilia Neves Santos, Federal University of Rio de Janeiro (UFRJ), Rio de Janeiro, Brazil; Raul Figueiredo Carvalho Miranda, Federal University of Rio de Janeiro (UFRJ), Rio de Janeiro, Brazil; Zora Kovacic, Universitat Autònoma de Barcelona, Barcelona, Spain; François Diaz-Maurin, Universitat Autònoma de Barcelona, Barcelona, Spain; Mario Giampietro*, Institució Catalana de Recerca i Estudis Avançats & Universitat Autònoma de Barcelona, Barcelona, Spain

Abstract

An estimated 860 million people worldwide live in slums or urban informal settlements, constituting about one third of the world urban population. The number of slum dwellers has been rising steadily in recent years, and this trend is expected to persist into the foreseeable future. In spite of the obvious importance of this type of human settlement, a systemic understanding of the structural and functional organization of slums is lacking. This makes it difficult to design and implement effective development programmes to improve the living conditions of these communities. In our view, the systemic failure of development policies is due to the lack of recognition of the slum as a complex self-organizing system in its own right (different from urban formal settlements). Indeed, slums are by their very nature characterized by a spontaneous and adaptive self-organization that makes them difficult to model and plan. In addition, slums worldwide are highly heterogeneous and fast changing, which makes the use of a standard blueprint in development policies completely useless.

We use a flexible innovative method of accounting based on complex systems theory and the flow-fund model of Georgescu-Roegen in order to effectively characterize the (energy) metabolism of slums. We apply this approach to two case studies: Khayelitsha, a shanty town near Cape Town, South Africa and Vidigal, a favela in Rio de Janeiro city, Brazil. In these applications we map the circulation of biophysical flows (energy, water and waste) in relation to the size of funds (human activities and land use) and characterize the level of openness of the system. The metabolic pattern of slums typically depends on characteristics observable at different levels and scales: (i) structural characteristics (housing area per capita, typology of buildings and their density); and (ii) functional characteristics (household life style and mix of economic activities taking place both in the slums and in its socio-economic context).

The development of an effective methodology for the profiling of the metabolism of slums is an important first step towards the improvement of development policies. In fact, a taxonomy of different typologies of slums associated with expected metabolic patterns can enhance the process of collective learning by exchanging solutions across slums operating in different parts of the world but sharing the same structural and functional typology.

Energy consumption and output nexus in Indian states: A panel analysis with structural breaks

Md Zulquar Nain*[1, 3], Sai Sailaja Bharatam[2], Bandi Kamaiah[3]

[1]Department of Economics, MANUU, Hyderabad, India
[2]Institute of Public Enterprises, Hyderabad, India
[3]School of Economics, University of Hyderabad, India
Corresponding Author Email: alignain@gmail.com

Abstract:

This study examines the relationship between energy consumption and output in Indian states, for the period 1980 to 2009. The variables considered are net state domestic product (NSGDP) and electricity consumption as a proxy for output and energy consumption respectively. Using recently developed panel econometric techniques, the present paper accounts for cross-section dependence, heterogeneity and structural breaks when analysing the energy-output (income) nexus. The cointegration results indicate a long-run equilibrium relationship between energy consumption and income. The results of panel Granger causality test reveal that there is bi-directional causal relationship between the variables but it is heterogeneous across the states, causality running from energy consumption to income is more often than from output to energy consumption. Overall, the results suggest that electricity conservation policies in general may hamper the process of economic growth in Indian states. Nevertheless, we suggest that instead of integrated policy approach for all Indian states, state specific policy should adopted because such policies may have less or no adverse impact on growth process of the particular state as causality is heterogeneous across the states.

Keywords: Energy consumption, Output, Indian States

1 Introduction

The causal relationship between energy consumption and economic growth has been widely discussed in last three decades started with the seminal work by Kraft and Kraft (1978), for developed countries and developing countries within the framework of bivariate as well as multivariate. The studies have covered single as well multi-country scenarios across developed and developing countries. The outcomes of the studies however presented mix evidence on the causal direction between energy consumption and output (income). The relevant literature in this connection has been surveyed in Lee, 2005, 2006; Yoo, 2006; Chontanawat et al. 2006; Payne, 2009, 2010a, 2010b; Ozturk, 2010. An investigation of the energy consumption–output (income) nexus provides insights into the role of energy consumption in economic development in the present scenario, where developing countries are facing policy dilemma to tackle the environmental issues and sustain high growth at the same time. Thus conclusions of such an analysis are also relevant for the design of energy policies to mitigate global warming, to achieve conservation goals without substantially impeding the growth process.

In the literature four possible relationships between energy consumption and output (income) have often been described namely growth, conservation, neutrality, and feedback hypotheses. According to the growth hypothesis, energy consumption plays an important role in economic growth both directly and indirectly as a complementary input with labour and capital in producing output and, so, contributes to growth. The growth hypothesis is confirmed if causality runs from energy consumption to output (income), whereby the economy is considered energy dependent. In such a scenario, countries have to be cautious while adopting the energy policies as any negative shock to energy supply may adversely affect economic growth. On the contrary, the conservation hypothesis implies that a reduction in energy consumption will not adversely impact the output (income). The conservation hypothesis is supported if causality runs from output (income) to energy consumption. In such countries energy conservation policies may be adopted, without hampering economic growth by curtailing energy consumption and improving energy efficiency to reduce greenhouse emissions. The neutrality hypothesis said to be exist if there is no significant relationship between energy consumption and output (income). In another words, the neutrality hypothesis holds, if causal relationship between energy consumption and output (income) is absent. Similar to the conservation hypothesis, energy conservation policies would not adversely impact economic growth. Finally, the feedback hypothesis asserts that energy consumption and economic growth are interdependent and serve as complements to each other. The feedback hypothesis is said to be valid if there is a bidirectional causal relationship between energy consumption and output (income).

Analyzing the economy as a whole may provide insights on the current state of debate on the nexus between energy consumption and output (income). However, in a federal economy, states have different characteristics making it imperative to investigate the nexus across states. The differential growth performance of states is often be attributed to state specific factors or endowments (see Besley and Burgess, 2004; Kochhar, et al., 2006; Kumar, 2010; Aiyar and Mody 2011; among others). Among developing countries, the Indian situation provides an interesting case for the study of energy consumption output (income) nexus for several reasons. As Bhattacharya and Sakthivel (2004) pointed out, though average growth rate of gross domestic product increased in the 1990s, as compared to 1980s, the regional disparity has widened and regional inequity has risen.

Further, energy resources are also unevenly distributed among the states. Coal, the most important source of energy in India is mainly concentrated in eastern and south central parts of the country. The states of Jharkhand, Odisha, Chhattisgarh, West Bengal, Andhra Pradesh, Maharashtra and Madhya Pradesh account for more than 99% of the total coal reserves in the country. Geographical distribution of crude oil follows a similar pattern. The maximum reserves are in the Western Offshore (44.46%) followed by Assam (22.71%), whereas the maximum reserves of Natural Gas are in the Eastern Offshore (34.73%) followed by Western offshore (31.62%). In case of other resources also the situation is same. Thus, the uneven distribution of energy resources among states has paved the way for a marked heterogeneity in resource availability, justifying the need to analyze the causal relationship between energy consumption and output (income) at the state level.

With the exception of the studies by Mukherjee (2008) and Sen and Jamasb (2012), the studies in India have examined the energy- output (income) relationship at the national level (see for example, Nachane, Nadkarni and Karnik, 1988; Murry and Nan, 1994; Cheng, 1999; Ghosh, 2002, 2009 among others). Mukherjee (2008) using a principle component analysis for a set of 18 Indian states with specific sectoral variables like percentage of households in the States having electricity out of total number of electrified households, share of irrigated area in the States, industries consuming electricity, railways consumption of electricity etc studied energy intensity of the states. The study favoured an alternative methodology can bring out a better understanding of Energy-GDP. Sen and Jamasb (2012) included state industrial GDP, adjusted for inflation at 93-94 prices as one of many other variables in their work. Using panel data of 19 Indian states for the period 1991-2007 found that Indian electricity reforms at state level are yet to depict palpable results. They conclude that only and after completing a baseline level of reformation process at state level, electricity reforms in India explicitly cannot have an impact on the sector or on the economy as a whole.

The present study is motivated by the fact that there are no studies in the context of Indian states which have examined the issue of causal nexus between energy consumption and output (income). Accordingly the present study employs panel data techniques to addresses the issues of panel cointegration and panel causality in the presence of structural breaks and heterogeneity in the states.

The rest of the paper is organized as follows. In section 2, present data used for the analysis and sets out the method of analysis and the testing procedure. The results are presented in Section 3. Finally, the fourth section concludes.

2 Data and Econometric Methodology

2.1 Data

Data of electricity consumption and Net State Domestic Product (NSDP) is collected from CMIE and the Handbook of Statistics published by Reserve Bank India respectively for the period 1980-2009. NSDP is brought to 2004-05 constant prices base through multipoint splicing. We have used electricity consumption as the proxy for the energy consumption as it is the most direct usable form of energy and has largest share in the total energy consumption in India[1]. All variables are converted to logarithm before being used in the analysis. The pattern of NSGDP and electricity consumption over the period is shown in Figure 1 and Figure 2 respectively.

2.2 Methodology

New panel techniques which not only take account of heterogeneity of the individuals, but also presence of structural breaks are applied in this paper.

2.2.1 Panel Unit Root tests

Recently researchers have focused on using panel data techniques as it overcome the size and low power problems of traditional time series techniques and so is the case, to test the stationarity properties of the variables. Most commonly used unit root tests for panel data in the literature are Levin et al. (2002), Im et al. (2003), Breitung (2000), Maddala and Wu (1999), and Hadri (2000). The Hadri test is the panel version of the KPSS (Kwiatkowski, et al., 1992) test, which takes stationarity as the null, whereas other tests take nonstationarity as the null.

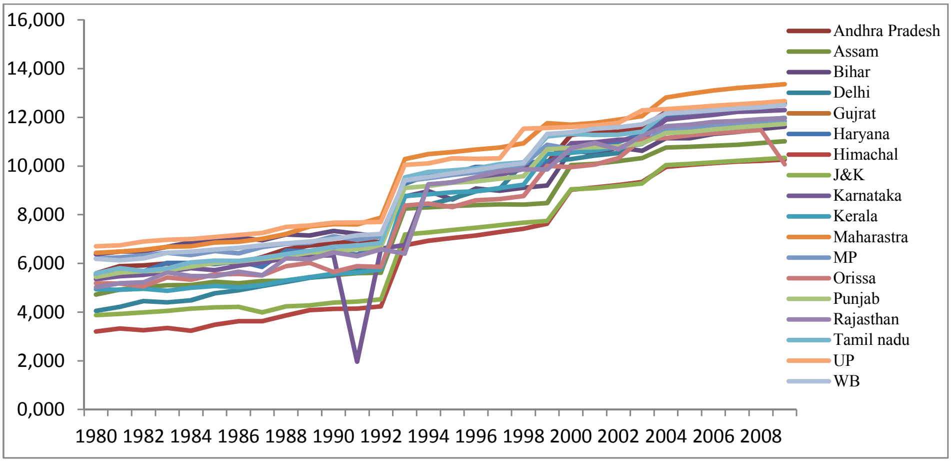

Figure 1: NSGDP of states

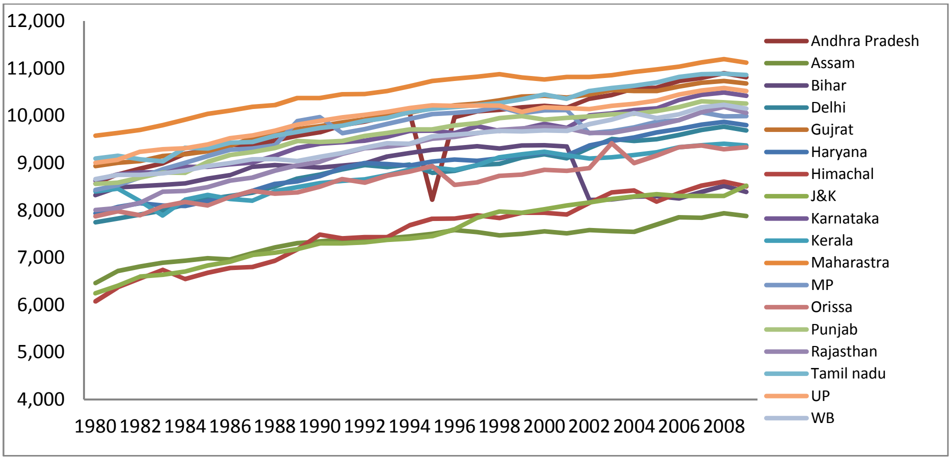

Figure 2: Electricity consumption of states

A commonality of these tests is the assumption that the units are cross-sectionally independent. However, the assumption of cross-sectional independence is rarely achieved in practice, especially in our present problem where, cross-section units are part of a federal system and have different economic and geographical characteristics. Further, these tests do not take account of structural breaks. Structural breaks correspond to parameter shifts that are caused by policy regimes (such as in our case new economic policy adopted in 1990s and electricity reform policies) shifts or significant events (such as economic and financial crises) and ignoring or erroneous omission of structural breaks may lead to deceptive inference about the order of the integration of the variables [Perron,1989; Bai and Carrion-I-Silvestre, 2009, Basher and Westerlund 2009]. We have used, Carrion-i-Silvestre et al. (2005) panel staionarity test, which takes care of the above mentioned problems of cross-sectional dependence and structural breaks. Carrion-i-Silvestre et al. (2005) test is a generalisation of the Hadri (2000) test for a case with multiple structural breaks. To test the null hypothesis of stationarity with multiple structural breaks, the following regression model is defined:

$$y_{it} = \alpha_i + \sum_{k=1}^{m_i} \theta_{i,k} DU_{i,k,t} + \beta_i t + \sum_{k=1}^{m_i} \gamma_{i,k} DT_{i.k,t} + \varepsilon_{i,t} \quad (1)$$

Where, α_i and β_i is constant and coefficient of trend respectively with $i = 1,...,N$ units and $t = 1,...,T$ time periods. The dummy variables $DU_{i,k,t}$ and $DT_{i,k,t}$ are defined as, $DU_{i,k,t} = 1$ for $t > T_{b,k}^i$ and 0 otherwise and $DT_{i,k,t} = t - T_{b,k}^i$ for $t > T_{b,k}^i$ and 0 otherwise, where $T_{b,k}^i$ denotes the k^{th} date of break for the i^{th} individual, $k = 1,...,m_i,\ m_i \geq 1$.

The above specification allows that structural breaks may have different effects on each individual time series and may be located at different date. The number of structural breaks may also vary individual to individuals.

Given the estimated OLS residuals $\hat{\varepsilon}_{i,t}$ of equation(1), the LM test statistics is given as,

$$LM(\lambda) = N^{-1} \sum_{i=1}^{N} (\hat{\omega}_i^{-2} T^{-2} \sum_{t=1}^{T} \hat{S}_{i,t}^2) \quad (2)$$

Where, $\hat{S}_{i,t} = \sum_{j=1}^{t} \hat{\varepsilon}_{i,j}$ denotes partial sum process and $\hat{\omega}_i^2$ is consistent estimate of the long-run variance of $\varepsilon_{i,t,}\ \omega_i^2 = \lim_{T \to \infty} T^{-1} E(S_{i,T}^2),\ i = 1,...,N.$

2.2.2 Cointegration tests

If the variables are found to be integrated, the long-run equilibrium relationship between them could be examined by tests of cointegration. In this study we have considered panel cointegration tests with and without structural breaks, As pointed out by Basher and Westerlund (2009), in the presence of breaks conventional tests of cointegration are no longer valid as these tests cannot be used to discriminate between cointegration with structural change, and absence of cointegration altogether.

2.2.2.1 Panel cointegration test without structural breaks

We used Pedroni's (1999)[2] test for panel cointegration for a case of without structural breaks. Pedroni (1999) suggest seven test statistics that can be used to test for cointegration in panel framework. These are panel ν-statistics, panel rho-statistics, panel PP-statistics(non-parametric), panel ADF-statistics(parametric), group rho-statistics, group PP-statistics(nonparametric) and group ADF-statistics(parametric). The common time effects removed by demeaning the data before performing the cointegration tests as suggested by Pedroni (1999).

2.2.2.2 Panel cointegration test with structural breaks

For establishing cointegration with structural breaks, the present study used the test suggested by Westerlund (2006), who suggested the LM-type panel cointegration test for the null hypothesis of cointegration that accommodates multiple structural breaks. The test is able to account for an unknown number of breaks, which may be located at different dates for different units. To perform the tests we adopted the following specifications.

$$\ln gdp_{it} = d_{it}{'}\alpha_{i,j} + \beta_i \ln ec_{i,t} + \varepsilon_{it} \quad (3)$$

Where, gdp_{it} and ec_{it} represents net state domestic product and electricity consumption for ith state in tth time period. Index $j = 1,..., m_i + 1$ denotes structural breaks, d_{it} is vector of deterministic component s and α_{ij} is the corresponding vector of parameters, which indicate m_i structural breaks in booth level and trend. There exist at most m_i such breaks or $m_i + 1$ regimes, which are located at the dates $T_{i1},...,T_{im}$, with $T_{i1} = 0$ and $T_{i,m+1} = T$. Here, ε_{it} assumed to be stationary which means it can be both heteroskedastic and serially correlated. Further, with the cointegration vector permitted to differ across regimes and individuals, the long-run variance of ε_{it} is also permitted to vary across individuals. The null hypothesis and alternative hypothesis for all individuals in panel are;

$H_0 : \phi_i = 0$ for all $i = 1,..., N$ against the alternative hypothesis

$$H_A : \phi_i \neq 0 \text{ for } i = 1,..., N_1 \text{ and}$$

$$\phi_i = 0 \text{ for } i = N_1 + 1,..., N$$

The null hypothesis assumes that all individuals in the panel are cointegrated and alternative hypothesis allows ϕ_i to differ across the individuals. It means, alternative hypothesis indicate that cointegration for only a fraction of the panel such that $N_1 / N \rightarrow z$ as $\mathrm{N} \rightarrow \infty$, Where $z \in (0,1)$. This means the rejection of null indicates the presence of cointegration for some individuals in the panel.

The panel LM test statistics is defined as;

$$Z(m) = \sum_{i=1}^{N} \sum_{j=1}^{m_i+1} \sum_{t=T_{ij-1}+1}^{T_{ij}} (T_{ij} - T_{i,j-1})^{-2} \hat{\omega}_{i1.2}^{-2} S_{it}^2 \tag{4}$$

Where, $\hat{\omega}_{i1.2}^{-2} = \hat{\omega}'_{i1.1} - \hat{\omega}'_{i21} \hat{\Omega}_{i22}^{-1} \hat{\omega}_{i21}$ and $S_{it} = \sum_{k=T_{ij}+1}^{t} \hat{\varepsilon}_{it}^*$ where, $\hat{\varepsilon}_{it}^*$ is any estimate of ε_{it}. The test statistic is written as a function of breaks i.e. $m(m_i,..., m_N)'$ which indicates that the statistics is constituted for a certain number of breaks and its asymptotic distribution depends on the number of the breaks.

The tests of Carrion-i-Silvestre et al. (2005) and Westerlund (2006) which tests for panel stationartiy and panel cointegration respectively, suggest the use of Bootstrap methods in presence of cross-section dependence for robust inference, which is very likely to be present in this particular problem. The bootstrap method adopted in the present study is based on the sieve scheme of Westerlund and Edgerton (2007)[3].

2.2.3 Panel causality test

After examining the cointegration between the variables, the next step is to establish the causality among the variables. In a panel context, as pointed out by Venet and Hurlin (2001), it is possible to use both cross-sectional and time series information to test the causality relationship between variables. A larger number of observations in this framework becomes available, which increases degrees of freedom and reduces collinearity among the explanatory variables in turn, the efficiency of Granger causality tests improve notably. But in a panel data framework, the issue of potential heterogeneity of the states (units) must be addressed. Mainly there are two possible types of heterogeneity exist, one is due to distinct intercepts; this type of variation is addressed with a fixed effects (FE) approach another is causal variation across units, which needs more complex analytical response.

Holtz-Eakin et al. (1988) proposed the following model for the panel Granger test, which takes care of first kind of heterogeneity. Formally,

$$y_{i,t} = \sum_{k=1}^{p} \gamma^{(k)} y_{i,t-k} + \sum_{k=1}^{p} \beta_i^{(k)} x_{i,t-k} + \nu_{i,t} \tag{5}$$

With $\nu_{i,t} = \alpha_i + \varepsilon_{i,t}$, where $\varepsilon_{i,t}$ are i.i.d. $(0, \sigma_\varepsilon^2)$. $i = 1,...,N,\ t = 1,...,T$ and $y_{i,t}$ and $x_{i,t}$ are co-variance stationary. α_i represents the fixed individual effect, and coefficients $\gamma^{(k)}$ and $\beta^{(k)}$ are implicitly assumed to be identical for all cross-sectional units. The null for the proposed Granger tests is given as,

$$H_0 : \beta^{(1)} = \beta^{(2)} = ... = \beta^{(k)} = 0$$

This model ignores the heterogeneity of second kind which is more crucial in case of causality test that is heterogeneity related to the parameter $\beta^{(k)}$. As Pesaran and Smith (1995) point out, estimates under the wrong assumption $\beta_i = \beta_j\ \forall\ (i, j)$ are biased. Further as pointed out by Hurlin (2004), this approach may suffer from several shortcomings. First, this test involves estimators for $\gamma^{(k)}$ and $\beta^{(k)}$, but the fixed-effect estimators in dynamic models tend to be biased and inconsistent if N is large and T is relatively small (Nickell,1981). Second, when T is short, the Wald-type statistic associated with null hypothesis may not have a standard distribution (Venet and Hurlin, 2001). Last, the alternative hypothesis against the null hypothesis of above is that $\beta^{(k)} \neq 0,$ for some $k \in (1,...,K),$ i.e. x causes y for all cross-sectional units. This is quite a strong assumption (Granger, 2003).

Because of the above short comings we conduct Granger causality tests by following Dumitrescu and Hurlin (2012) approach, which adopts the specification of equation(5), but more general than Holtz-Eakin et al. (1988). In this approach, the coefficients $\gamma^{(k)}$ and $\beta^{(k)}$ incorporate heterogeneity among the cross sectional units. The null hypothesis to be tested is

$$H_0 : \beta_i^{(1)} = \beta_i^{(2)} = ... = \beta_i^{(k)} = 0,\ \text{for all}\ i = 1,...,N.$$

This is called “homogeneous non-causality” (HNC) hypothesis. It is different from the above as the alternative hypothesis against it allows for the causality from x to y for some but not all cross sectional units. This may be conducted in following steps. First, we compute for each cross-section unit i, the Wald statistic under the null that $\beta_i^{(1)} = ... = \beta_i^{(k)} = 0,$ denoted by $W_{i,T}$. Then in second step we compute the average of the Wald statistics calculated from the earlier step as follow

$$W_{N,T}^{HNC} = \frac{1}{N} \sum_{i=1}^{N} W_{i,T}. \tag{6}$$

following Dumitrescu and Hurlin (2012) has shown that, the average Wald statistics $W_{N,T}^{HNC}$ converges in standard normal distribution if T is sufficiently large that is

$$Z_{N,T}^{HNC} = \sqrt{\frac{N}{2K}} (W_{N,T}^{HNC} - K) \xrightarrow[T,N \to \infty]{d} N(0,1). \tag{7}$$

where $T, N \to \infty$ denotes the fact that $T \to \infty$ first and then $N \to \infty$.

If T is small, the last result does not hold[4]. But, Dumitrescu and Hurlin (2012) shown that if $T > 5 + 2K,$ we can still have the standardized average statistic $\tilde{Z}_N^{Hnc}$ converging in distribution as;

$$\tilde{Z}_{N=}^{Hnc} = \sqrt{\frac{N}{2 \times K} \times \frac{(T-2K-5)}{(T-K-3)}} \times \left[\frac{(T-2K-3)}{(T-2k-1)} W_{N,T}^{Hnc} - K \right] \xrightarrow[N \to \infty]{d} (N(0,1) \qquad (8)$$

with $W_{N,T}^{Hnc} = (1/N) \sum_{i=1}^{N} W_{i,T}$.

Dumitrescu and Hurlin (2012)[5]proposed a block bootstrap procedure to correct the empirical critical values of panel Granger causality tests so as to account for cross-sectional dependence.

3 Empirical results

3.1 Panel unit root tests

As a first step in the empirical analysis we have to determine the order of integration of the two variables. If they are I(1), then we can proceed to examine the long run relationship. To confirm this, panel unit root test without structural breaks and panel stationary tests of Carrion-i-Silvestre et al. (2005) which incorporates structural breaks is employed. Panel unit root tests of Levin et al. (LLC, 2002) and Im et al. (IPS, 2003) with common null of non-stationary have been employed. The results are reported in Table 1. The results reveal that variables follow I(1) process i.e. are integrated of order one.

Table 1: Panel unit-root test statistics without structural breaks: At level and first difference

Variables	LLC(*t*-adjusted test)		IPS(*t*-bar test)	
	Constant	Constant + trend	Constant	Constant + trend
NSGDP	0.519	0.874	5.079	-4.266
	(0.698)	(0.809)	(1.000)	(0.000)
EC	-6.348	-0.125	-1.041	-4.552
	(0.000)	(0.450)	(0.149)	(0.000)
∆NSGDP	-16.754	-12.717	-19.657	-19.143
	(0.000)	(0.000)	(0.000)	(0.000)
∆EC	-10.790	-9.323	-17.155	-18.025
	(0.000)	(0.000)	(0.000)	(0.000)

Note: In parenthesis are probability values

We employed stationary tests of Carrion-i-Silvestre et al. (2005) to overcome the limitation of cross-sectional independence and omission of structural breaks to confirm the order of integration. To conduct the stationary tests of Carrion-i-Silvestre et al. (2005), we allow for a maximum of two breaks, since our sample size is small, otherwise it may lead to imprecise break estimates. To address cross-sectional dependence, the Bootstrap critical values are calculated, which implemented using replications and a sieve order of $4(T/100)^{2/9}$.

We performed the test for two models with different deterministic specification. The first model allows both a constant and trend but no structural breaks. The second model generalizes the first model by allowing structural breaks both in constant and trend. Results are reported in Table 2. First panel of the table shows the statistics for each variable in levels and the second panel reports at first difference.

Table 2: Panel unit root test statistics with structural breaks: At level and first difference

Models	Tests	NSGDP		EC	
No breaks		constant	constant and trend	constant	constant and trend
	Value	18.564	3.982	17.465	8.105
	P-value[a]	0.000	0.000	0.000	0.000
	P-value[b]	0.000	0.230	0.000	0.000
Breaks					
	Value	14.185	10.519	13.655	8.578
	P-value[a]	0.000	0.000	0.000	0.000
	P-value[b]	0.000	0.958	0.000	0.938
		∆NSGDP		∆EC	
No breaks		constant	constant and trend	constant	constant and trend
	Value	-1.423	4.398	2.375	1.234
	P-value[a]	0.923	0.000	0.009	0.109
	P-value[b]	0.732	0.066	0.028	0.798
Breaks					
	Value	-0.537	11.831	0.883	2.403
	P-value[a]	0.704	0.000	0.189	0.008
	P-value[b]	0.756	0.330	0.120	0.970

Note: [a] The p-values based on the asymptotic normal distribution. [b]The p-values based on the bootstrapped distribution. ∆ represents difference at first level.

For each model, the first row contains the test statistics, the second row contains the asymptotic p-value, and third row contains the bootstrapped p-value. The test statistics for the first model, for each variable at level, suggests that for both specifications the null hypothesis of stationary be rejected, since asymptotic p-value is zero. However, in order to account for cross-section dependence we use bootstrapped p-value and results suggest that null hypothesis of stationary be rejected for each variable except for NSGDP where bootstrapped p-values is not equal to zero, when trend is included . Furthermore, for the variables in first difference, the results of each variable cannot reject the null hypothesis of stationary, for both models i.e. without breaks and with breaks. In summary, although there might be some deviations between the results, generally we find that the variables seem to be integrated of order one, I(1). Therefore, we can proceed to examine the long-run relationship between the variables under consideration.

3.2 Panel cointegration tests

After determining that variables are integrated of order one, we examine long run relationship between the variables by employing cointegration tests. We employed cointegration tests without and with structural breaks.

3.2.1 Panel cointegration tests without structural breaks:

Once we established through panel unit root tests and panel stationary tests that variables are integrated of order one, we first used Pedroni's (1999) tests to find panel cointegration. Pedroni (1999) proposes seven tests of two kinds, panel and group, that can be used in the absence of breaks in the data. The first four test statistics are based on the "within" dimension (panel statistics). If the null is rejected, then NSGDP and electricity consumption are cointegrated for all states. The last three test statistics are based on the “between” dimension (group statistics). In this case, cointegration among NSGDP and electricity consumption exists for at least one of the all states. Following recommendation of Pedroni (1999), we performed cointegration test after removing common time effect through demeaning the data. The results are reported in Table 3. From the table, it can be inferred that when trend is included in the model, the results suggest that there exists cointegration between electricity consumption and economic growth for all the states. On the other hand, when trend is not included, the results suggest conflicting inference. Some statistics reveal cointegration while others do not.

Table 3: Panel cointegration test: without structural breaks ((Pedroni, 1999))

Test Statistics	Without trend		With trend	
	Statistic	Prob.	Statistic	Prob.
Panel v-statistics	-0.157	0.562	2.936	0.002*
Panel rho-statistics	-1.902	0.028**	-1.919	0.027**
Panel PP-statistics	-2.682	0.003*	-3.107	0.001*
Panel ADF-statistics	-2.605	0.005*	-3.011	0.001*
Group rho-statistics	-0.287	0.387	0.749	0.773
Group PP-statistics	-1.904	0.028**	-0.937	0.174
Group ADF-statistics	-1.744	0.041**	-0.763	0.223

*, and ** denote statistical significance at the 1%, and 5% levels, respectively

3.2.2 Panel cointegration tests with structural breaks:

The conflicting result of Pedroni (1999) tests may be because of its restrictive assumption of cross sectional independence and not considering of structural breaks. To overcome these shortcomings of the Pedroni (1999) tests we employed the Westerlund (2006) panel cointegration test with multiple structural breaks. We followed the same procedure as panel stationary tests to perform Westerlund (2006) Z(M) test of panel cointegration with fully modified(FMOLS) residuals. The results of two deterministic specifications with constant and without constant are reported in Table 4(Panel A). Furthermore, considering cross-sectional dependence, we also used bootstrapped critical values as suggested by Westerlund (2006). The first row contains the test statistics, the second row contains the asymptotic p-value, and third row contains the bootstrapped p-value. The results show that when cross-sectional dependence is ignored, we may reject the null of cointegration, but once the cross-sectional dependence is considered we cannot reject the null of cointegration. Thus the Pedroni (1999) and Westerlund (2006) tests provide evidence that NSGDP and electricity consumption are related in long run. The Westerlund (2006) test also reports the estimated breaks by using Bai and Perron (2003) technique, reported in Table 4(Panel B).

Table 4: Panel cointegration test with structural breaks ((Westerlund 2006))

Model	Breaks	
Test Statistics	in constant	in constant and trend
Value	11.004	5.284
P-value	0.000	0.000
P-Value	0.704	0.796
Estimated breaks		
States		Break dates

Andhra Pradesh	1992, 1999
Assam	1992, 1999
Bihar	1992, 1999
Delhi	1992, 2002
Gujarat	1992, 2003
Haryana	1992, 2004
Himachal	1992, 1999
J&K	1992, 1999
Karnataka	1990, 1996
Kerala	1992, 1998
Maharashtra	1992, 2003
MP	1992, 1998
Orissa	1992, 2003
Punjab	1992, 1998
Rajasthan	1993, 1999
Tamil Nadu	1992, 1998
UP	1992
WB	1992, 1998

Note: [a] The p-values based on the asymptotic normal distribution. [b]The p-values based on the bootstrapped distribution.Δ represents difference at first level. The maximum number of breaks allowed in break model is two.

Two statistically break points are found for all except for the state of UP. If we see historically, for most of the states first break occurred in 1992, which seem very reasonable, as it is the following of 1991, when India adopted the reform. In other states also, first break is found near to the year 1991, so first break may be attributed to reform implemented in the year of 1991. In most of states, the second break coincided with the reform adopted in electricity regulation. For example in case of AP and Delhi, electricity reforms were adopted in the year 1999 and 200 respectively and break dates are found in 1999 and 2002 respectively for the both states.

3.3 Panel Causality test:

As the results provide evidence that the NSGDP and electricity consumption are cointegrated, it is appropriate in the next step, to examine the direction of causality. The panel causality test developed by Dumitrescu and Hurlin (2012) is employed. In panel context, one of the major issues is heterogeneity, which has been taken care by the Dumitrescu and Hurlin (2012) panel Granger test. Further, critical values are reported after allowing cross-sectional dependence. The results of this test are presented in Table 5. First panel of the table shows statistics of the panel whereas; the lower panel gives state wise results.

Table 5: Panel Granger causality tests

Panel Statistics	consumption doesnot cause NSGDP			NSGDP doesnot cause consumption		
Tests/Lag orders	K=1	K=2	K=3	K=1	K=2	K=3
Wbar statistic	4.287	5.110	7.917	1.986	2.168	8.836
Zbar statistic	9.861*	13.194*	25.55*	2.958**	0.713	30.324*
Zbar tiled statistic	8.379*	5.252*	6.516*	2.367**	-0.103	7.81*
Individual Wald Statistics						
States/Lag order	K=1	K=2	K=3	K=1	K=2	K=3
AP	1.531	3.646	3.757	9.129*	4.238	96.139*
Assam	1.654	3.200	4.788	3.456***	1.833	2.282
Bihar	0.714	1.562	4.611	3.225***	4.704***	12.577*

Delhi	4.8676**	4.266	4.914	0.445	0.595	13.610*
Gujarat	6.4243**	7.2148**	6.8449***	0.994	1.286	3.620
Haryana	10.043*	10.766*	8.704**	0.021	3.320	3.778
Himachal Pradesh	4.007**	5.530***	13.025*	5.027**	3.574	3.010
J&K	4.347**	6.591**	7.627**	2.955**	3.639	3.829
Karnataka	6.071*	3.859	8.779*	0.380	0.128	0.168
Kerala	4.007**	4.689***	9.492**	3.429***	6.314**	0.828
Maharashtra	3.928**	5.5062***	5.000	0.557	1.547	6.529***
MP	1.645	1.394	27.943*	0.033	0.479	3.333
Orissa	0.805	0.763	0.569	4.907**	2.318	1.879
Punjab	5.165**	5.385***	6.628***	0.000	0.263	1.068
Rajasthan	4.408**	9.329**	9.509**	0.016	0.245	0.510
TamilNadu	6.571*	7.105**	6.503***	0.325	1.586	2.070
UP	4.522**	5.910*8	8.884**	0.064	0.497	1.235
WB	6.456*	5.262****	4.930	0.789	2.495	2.581

*,**, and *** denote statistical significance at the 1%, 5% and 10% levels, respectively

The Wbar statistic corresponds to the cross sectional average of the N standard individual Wald statistics of Granger non causality tests. The Zbar tiled statistic corresponds to the standardized statistic (for fixed T sample). We compute all these statistics for one, two and three lags for completeness and robust inference.

Both Zbar and Zbar tiled statistics are significant at 1% level there by rejecting the null of homogenous non-causality from electricity consumption to output (NSGDP) irrespective of the number of lags included. But the null of homogenous non-causality from output (NSGDP) to electricity consumption can be rejected only for the lag one and three at 1% and 5% respectively. Overall, the results indicate that energy consumption has more impact on the output than output on energy consumption. Thus the results suggest that there exists heterogeneous causality between energy consumption to output across the states, and hence it is necessary to look more closely at the individual state level.

Looking at individual Wald statistics it reveals that, out of eighteen, in nine states there is uni-directional causality running from electricity consumption to output. Out of these nine states, in five states the null of non-causality from electricity consumption to output can be rejected irrespective of lag length. For states like West Bengal and Uttar Pradesh, the null of non-causality from electricity consumption to output can be rejected at lag one and two and for Madhya Pradesh at lag three. Four states namely, Andhra Pradesh, Assam, Bihar and Orissa the results suggest that null of non-causality from output to electricity consumption can be rejected. In case of Orissa and Assam the null can be rejected only for lag one at 10% and 1% level of significance respectively. The null is rejected in case of Bihar irrespective of the number of lags though at 10% level of significance. On the other hand, for states, Himachal Pradesh, Jammu and Kashmir, Kerala and Maharashtra, the results provide evidence of bi-directional causality i.e. from energy consumption to output and vice-versa. A closer look reveal that among these four states null of non-causality from energy consumption to output is strongly rejected compared to the null of non-causality from output to energy consumption causation.

Overall, our results suggest that there is evidence for the causal relationship between energy consumption and output and it is heterogeneous across states. Out of eighteen, nine states show the presence of strong causality from energy consumption to output and in four states causality is the other way around. In four states there is bi-directional causality between energy consumption and output. The findings suggest that energy consumption has more impact on economic growth than what economic growth has on electricity consumption. One important finding is that most of the states where, manufacturing and service sector comparatively perform better, causation runs from energy consumption to output.

4 Conclusion

This paper examines the co-movement and causal relationship between electricity consumption and output in Indian states for the period 1980 to 2009. This is the first empirical insight for the causal nexus between electricity consumption and output for the Indian states in a panel framework. Further, the advanced panel techniques employed which not only take care of heterogeneity but cross sectional dependence and structural breaks. The panel cointegration and panel causality tests are conducted to answer the questions of co-movement and causal relationship between electricity consumption and output respectively. Our results suggest that there is a long-run steady-state equilibrium relationship between electricity consumption and economic growth measured by NSGDP for states, allowing state heterogeneity. These results are also robust to cross-section dependence between states as well as to structural breaks. Further, the results provide evidence of causality between electricity consumption and output for the panel but it is heterogeneous across the states. Overall, the results suggest that though there is bi-direction causal relationship between electricity consumption and output, energy consumption has more impact on the output than the other way round. Our finding is contrary to most of the earlier studies for India at aggregate level, such as by Cheng (1999), Ghosh (2002, 2009), and Chen et al. (2007) that found unidirectional causality running from economic growth to electricity consumption. This implies that high energy consumption tends to have high output. Thus, in general energy conservation may harm economic growth process in Indian states. It also implies a slow growth in Indian states may slow down the demand for energy, but it is the energy consumption which greatly affects the growth process. It is clear that, in general, energy is an important ingredient for economic development for Indian states. In general, formulation of energy policies that provide a sufficient supply of electricity is essential to boost productivity in India but, such policies may also lead to the environmental degradation problem. In light of this, we suggest that governments should formulate state specific policies and should encourage use and development of more advance and eco-friendly technologies by giving tax incentives or other incentives. Further, the Indian government should also formulate policies to attract domestic as well foreign investment in power generation sector so that it can reduce the growing supply-demand gap in energy sector and fully meet the ever increasing demand of energy in future. In turn, it would give impetus to economic growth without creating the problem of environmental degradation.

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Footnotes

1 Electricity accounted for about 57.57% of the total energy consumption (in peta joules) during 2011-12(CSO, 2013)

2 To save the space Pedroni (1999) test not described, interested reader may consult the reference.

3 See Basher and Westerlund (2009) for details

4 If T is small, the individual Wald statistics $W_{i,t}$ does not converge to a chi-squared distribution. Consequently, the average Wald statistics $W_{N,T}^{HNC}$ in equation (6) no longer has asymptotic property like (7) holds.

5 Further, this can also be applied for unbalanced panel data. For formal discussion see Dumitrescu and Hurlin (2012)

Global crisis: collapse with wars or prosperous decline?

Enrique Ortega[1*], Rosana Corazza[2], Miguel Bacic[3]

[1] Food Engineering School, [2] Geosciences Institute, [3] Economy Institute, Unicamp

Corresponding author e-mail: ortega@unicamp.br

Introduction

The hydrocarbon civilization offers progress with comfort while also bringing subjugation with poverty. Inequality in income and access to basic goods and public services is expanding. Several researchers, including **Piketty** (2014), have analyzed this social phenomenon and they say that in recent decades, the wealthiest have appropriated growing slices of richness. These findings contradict **Kuznets** (1955) who forecast that income growth in industrialized countries would advance to greater equity, after a period of increasing inequality.

The mainstream economy considers a *sine qua non* for achieving social equity a continuous economic growth; but numerous studies disqualify the idea of infinite growth. New scientific approaches address the uncertainty in the dynamics between nature and society. **Scheffer** (2009) theorize on the dynamics of ecosystems in the face of human pressures. Among his findings, he suggest that warning signals can be recognized before a tipping point, in which sudden and radical changes affect the system, leading to the collapse of its ecological and social features. This approach is important, because instead of a soft global transition to Sustainable Societies, we are seeing “militarized geopolitics” and “technological and financial innovation” to obtain quick profits, which reinforce the fossil-intensive paradigm that strongly tests the resilience of global ecosystems.

There is dangerous biosphere degradation, but there are scientific and political means that can aid in an ecological transition. It will be necessary to consider the contributions of **Odum** (1971 and 2007, 2001) that include a systemic diagnosis of global situation and suggestions for alternative policies, in order to empower the population in the process of redefining rural and urban areas and recovering of human culture. In that sense, the authors propose the creation of "Critical Eco-systemic Thinking Groups" in universities to discuss and report on the current risks. These centers would act in a network to promote communication with society. This may be a strategy for a deeper understanding of the global crisis and its effect on ecosystems and society to adjust our civilization to a Prosperous Way Down.

History

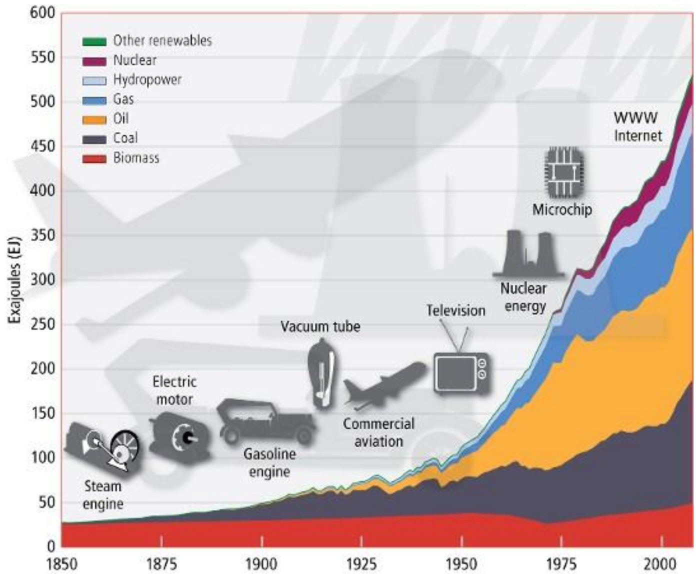
At the end of XIV century, the Iberian countries developed a commercial, military, technological and ideological project to expulse Arabs from the Iberian Peninsula and the conquest of America, Africa and Southern Asia and the theft of their wealth. The new flow of resources made possible the industrialization of Northern Europe using Chinese technology (**Goody**, 2006). Since then, humankind has known an unprecedented period of growth in assets and population and, in parallel, social and ecological losses.

The colonialist countries replicate its organization model wherever they expand with uneven distribution of economic benefits. The gap between rich and poor nations widens and also within the developed nations´ population, dissolving the ideal of equality and brotherhood in a society that now cultivates individualism and competition. As a result, the consensus for limits to growth and change of economic model is increasing.

Gradually, low-consumption lifestyles associated with a reduced use of energy and natural resources, with food production in communities or small farms, gave way to a "modern" pattern dependent on non-renewable resources (**Goldenberg**, 1998). The hydrocarbon civilization mobilizes carbon stocks accumulated over hundreds of millions of years in a very short time span, three centuries, thus, pouring many toxic gas emissions, effluents and solid waste into the biosphere.

Figure 1 illustrates global energy consumption from the XIX century to present day. These demands have grown by 2000% in a century and a half. The main source of energy at the beginning of this period was traditional biomass such as firewood, charcoal, crop residues, and straw, sources that could not meet the needs of an industrialized civilization.

Fig. 1. Growing Consumption, in EJ, since 1850 (Source: **Grubler** *et al.* (2012))



Limits or borders

Scientists have studied the biophysical limitations of human society and recently, a large group signed a much-quoted article published by Nature identifying the "excesses" of the hydrocarbon civilization (**Rockström** et al, 2009). The study reveals nine risk borders: Climate change, Biodiversity loss, Biogeochemical, Ocean acidification, Land use, Freshwater, Ozone depletion, Atmospheric aerosols, Chemical Pollution. The first four have already been exceeded; the risk is that beyond a boundary line there is no "safe operating space" for humanity. The authors emphasize the dynamic relationships underlying these limits: what happens in one "border" affects and influences what happens in the other border.

Future visions

The understanding of our reliance on the limits imposed by our biosphere should be part of our social, economic, and geopolitical world. There will be no escape from a dystopic future unless this fundamental interdependence is considered. In this sense, a critical review of the literature can be of great help, for example: **Odum**, 1971/2007 and 2001; **Meadows** *et al.*, 1972 and 1992; **Herrera** *et al.*, 1976; **Raskin** *et al.* 2002; **Millennium Ecosystems Assessment**, 2005; **Pachauri and Reisinger**, 2007, 2013. The outlines could allow discovering prospects for global society, and they could be dystopian or utopian.

On the dystopian side, there are previsions of environmental, social and economic collapses, conflicts on the use of resources, mass migration, famine, disease and epidemics, wars and massive deaths and, with the rising of militarization, the most radical outcome: human extinction. On the utopian side, there are two broad future views, not necessarily excludable.

On the utopian side, there are two broad future views, not necessarily excludable. On the one hand, there are concepts of a new society organizing production and consumption with a view of what we may call "a green golden age" (**Perez**, 2009, 2011, 2013): it depicts a society organized into broad globalization and a “green economy”. On the other hand, there is “Eco-Communalism” according with **Raskin** (2007). This view encompasses localism, face-to-face democracy, small-scale production, and economic autarky. In this current, it appears the perspective of the emergence of a patchwork of self-sustaining communities, in a plausible response in the case of recovery from a social-environmental-economic collapse.

Between these two views is the Odum´s view of a soft decline from our highly energy intense Hydrocarbon Civilization to self-sustained, low-energy, decentralized, empowered, diverse and enduring communities, nested within larger hierarchically organized systems. This is would be a smooth pathway to the transition towards a truly sustainable future.

Conclusion: how to promote the change

It is important to recognize that there is a profound absence of “good information” to be widely accessed by society. One should consider that if our Planet is going to experience deep transformations on its natural organization, for humankind to collectively adapt and survive, we should have to change our social and economic systems in a way that respect biophysical conditions. Sociologists, economists, anthropologists, politicians and activists must face the challenge of devising socioeconomic and institutional framing systems for sustainable societies. We need systemic, multi-disciplinary diagnosis of global situation with framing of alternatives to existing dystopias, in order to empower the population for redefining rural and urban areas and recovering of human culture.

The authors propose the creation of "Critical Eco-system Thinking Groups" in universities to discuss and report on the current boundaries and risks. These centers should act in a cooperative network to promote communication with organized sectors of society. This strategy might allow a deeper understanding of the global crisis and its effect on ecosystems, economy and society in order to generate integrated actions to adjust our civilization to a path of a Prosperous Way Down.

In the State University of Campinas (Unicamp), we have begun a series of activities, to face this challenge, hosted at the Ecological Engineering Laboratory. The main activity is a one-semester cycle of seminars on “The Prosperous Way Down”, organized by this paper authors. The main purpose of the seminars is to examine and critically discuss the Odums´ contributions from a Latin American perspective, and to offer an updated view focused on regional issues as a diagnosis, and make it available for a wider audience. Contacts with colleagues of other Latin-American universities, mostly in Argentina and Chile, are promoted by means of a YouTube channel (see the address below at the Literature). The next two steps will be: (a) a Workshop, at the end of Odums book´s Seminar, and (b) a Distance Learning course offered through the Unicamp´s Extension School for a broader audience.

As the knowledge transmitted currently at the universities does not address the ecological and political issues, it is necessary to break the inertia (the existing “shadow cone”) and begin to discuss the themes related to the coevolution between nature and mankind. A new political pedagogical project is necessary to incorporate Critical Systems Ecology in all the courses curricula and introduce a wide range of transdisciplinary projects in strategic topics.

An effort should be made to transfer these concepts into governments at various levels, in order to make possible assessing the impact of programs and projects in the context of global changes. By these means, it could be analyzed in a different form the problems of economic juncture, because usually the immediacy proposals increase the society problems in the medium and long term. Finally, private and public enterprises should produce reports considering the impact and the benefits into the nature-humanity system.

The use of emergy analysis could help in these efforts. The perspective of acting in a preventive way with comprehension of the functions of the biosphere and its economic subsystem can encourage political, scientific and technical solutions able to recover the planetary resilience to the natural limits that have been exceeded; this clearly means the choice of declining prosperous time instead of chaos and wars.

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Energy demand in the oil extraction system of Ecuador

Rony Parra[1]

1. Centro de Prospectiva Estratégica (CEPROEC). Instituto de Altos Estudios Nacionales (IAEN), Ecuador.

E-mail: rony.parra@iaen.edu.ec

In the oil system there is an energy component that is not accounted for in national inventories which is the consumption of energy in the extraction processes. In contracts says companies can use the energy resources within its concession area (oil and gas) for subsistence purposes at no cost. There is a state subsidy for energy supply of oil blocks for public and private companies.

In the oil infrastructure there is a demand of energy used for operation processes, mainly used for the separation of water and gas associated with the extraction of crude oil, pumping systems for transportation, for suction of oil and water reinjection and to supply of electricity to the camps. The management of oil blocks has not a homogeneous infrastructure in operation or in your energy system. Each block has a different design for energy supply.

Sometimes they have decentralized systems for each consumption center (each field has energy autonomy) and others is managed so decentralized for each operating company (the electricity generation is centralized and then distributed to each center consumption). In addition, there are backup systems to meet energy demands not considered and planned equipment stops.

The equipment for power generation are different depending on the availability of fuels, mainly electricity consumption in the oil blocks respond to a thermal system. Crude oil is consumed directly in each block before posting and delivery to the State, diesel produced in small refining plants built by each operating company or diesel bought to the public company EP Petroecuador and gas associated with the oil extraction after of a treatment process.

In 2012, 25 oil blocks were identified in operation, 12 blocks were operated by private companies, 12 public companies (EP Petroecuador and Petroamazonas EP) and 1 by the joint venture (Rio NAPO CEM - Block 60 - Sacha). Total production was 184 million barrels of oil, however they gave the state 176 million barrels of oil, indicating that in the domestic extraction processes were used 7 million barrels for energy production. These value is considerable and if we add the consumption of other fuels such as diesel and associated gas that also used in the processes, the figure is alarming.

The aim of this paper is to analyze and characterize the structure of the energy system in the public and private Ecuadorian oil extraction, identify energy consumption by type of process (pumping system, separation systems, use in camps and others) and by type fuels (crude oil, diesel, associated gas) for each concession block.

Then, the oil production and the fluid volumes (water and gas) in each block are identified, since this depends on the intensity of energy expenditure, and finally the energy payback rates and the subsidy granted by the State fuel for power generation in each concession block are calculated.

Pathways to decarbonize mobility in Europe

Christian Zulberti*, Daniela Di Rosa

Enel Foundation, Rome, Italy

*Corresponding Author e-mail: christian.zulberti@enelfoundation.org

Abstract

Transportation is responsible for approximately one third of the global greenhouse gas emissions, 70% of which is related to road transportation (IEA, 2013). With the objective of reaching ambitious CO_2 reduction targets, the European Union released a series of strategic documents aimed at deploying policies fostering sustainable mobility and enhancing sustainable development in the cities of the XXI century. Within this context, the deployment of electric vehicles is expected to play a crucial role in reducing greenhouse gas emissions.

Especially in urban areas, an increasing presence of electric vehicles may indeed have significant impacts on the displacement of pollutant emissions. To enable the diffusion of Electric Vehicles (EVs) and move towards low-carbon mobility, smart charging may be a suitable solution enabling the integration of electricity use and mobility needs. Among the European initiatives, those developed in Spain may be considered as a relevant case study for the EVs deployment in Europe. In particular, Enel Group developed the Electric Mobility Management (EMM) system which supervises the installed charging stations in Italy, Spain, Romania and Greece and monitors all the recharge processes in real time, providing end-users with information about the current status of each charging station and historical data about electricity consumption, allowing for the analsys and better prediction of network load.

Introduction

A considerable contribution of atmospheric pollutant emissions (mainly CO_2, CO, NO_x) in urban areas today is from on-road transport. The European Union (EU) has put in place legislation ([1]) to reduce CO_2 emissions from cars and vans, including targets for 2015 and 2020. The regulation requires the reduction of CO_2 emission for cars from a current average of 126 gCO_2/km to 95 gCO_2/km by 2021. Emissions targets encouraged manufacturers to diversify their fleets with lower emissions cars. As an indication, with a carbon intensity of the power sector of 330 gCO_2/kWh in 2010, a typical battery electric car would result in CO_2 emissions of around 66 gCO_2/km ([2]). This compares favourably to the 2013 average CO_2 emissions of new cars of 126gCO_2/km ([3]), as showed in fig.1, (Eurelectric, 2015).

[1] Regulation (EC) 443/2009 (CO_2 from cars), Regulation (EU) 510/2011 (CO2 from vans)
[2] Calculation: 1) EV: CO2/ km =[CO_2 g/ kWh (for the relevant area electricity)] X 2) [kWh/ km (for the particular EV)]. Assumptions: 1) estimated carbon intensity of the power sector of 330 gCO_2/kWh in 2010; European Commission Trends to 2050; 2) average consumption of a typical BEV assumed at 20 kWh/100km
[3] ACEA pocketbook http://www.acea.be/publications/article/acea-pocket-guide

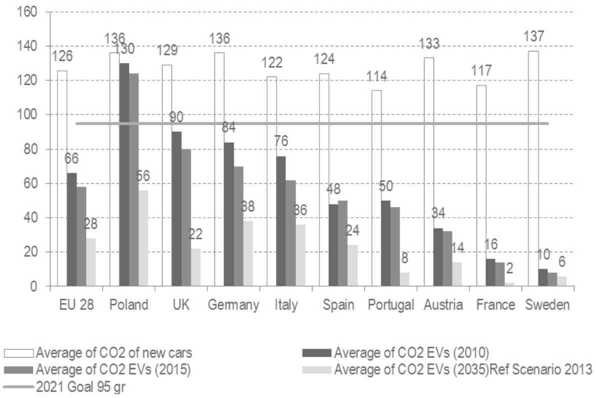

Fig. 1: Average CO_2 emissions (g CO_2/km) of EVs (2010, 2015 and 2035) vs average CO_2 emissions of new cars (2013) for the EU-28 and other EU countries (Eurelectric, 2015)

In this framework, as depicted in fig.2, electric and plug-in hybrid vehicles sales have been doubling each year, crossing the 400000 units barrier at the end of 2013 (CSEHRBW, 2014). In 2013, the sales of Electric Vehicles (EVs) in the EU represented the 0,4% of total sales, with about 50000 units sold, thus covering the 25% of the global market of this kind of vehicles.

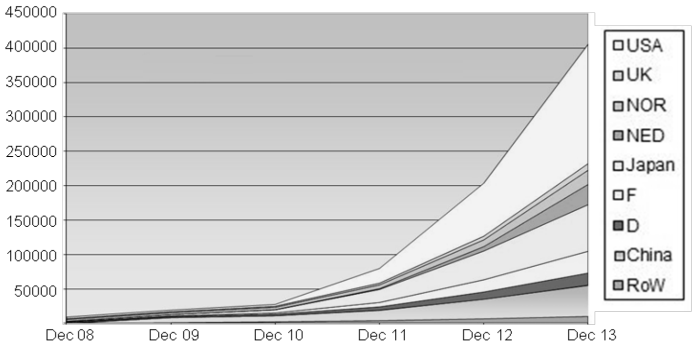

Fig. 2: Electric vehicles Sales Worldwide (Dec 2008-Dec 2013). Source: Centre for Solar Energy and Hydrogen Research Baden-Württemberg, 2014. BEV(Battery EV) + PHEV (Plug-in Hybrid EV) + REX(Range Extender) EV

Even if the total number of EVs still represents a small fraction of the overall number of vehicles, the above growth of sales prefigures a relevant future role of EV in reducing road transport emissions. Being completely emission free during the drive, EVs are particularly suitable to improve urban air quality, while the limited driving range is not a limitation for urban mobility, where short distances and low speeds are prevalent. Furthermore, higher potential benefits of reducing air emissions are found in highly populated areas (Ayalon et al., 2013).

Electricity is therefore considered as an extremely effective way of solving the EU's transport emissions challenge and in this frame developing smart charging could represent a great opportunity to facilitate EVs diffusion. With smart charging, the EVs time of charge can be coordinated to coincide with available renewable capacity such as wind at night, or solar at noon, bringing further benefits in terms of emissions reductions. If cars are coordinated to charge at times of lower electricity consumption, they can optimize the use of existing capacity and use less emitting power plants running outside peak hours – which would be needed to meet what are otherwise infrequent spikes in electricity demand. Moreover, to further enhance the efficiency of the power grid, EVs can be considered as moving energy storage systems, to be displaced in the portion of the grid that would need more flexibility.

Smart charging offers significant possibilities to EV stakeholders and local communities for wide-range market models and technology innovation, creating new business opportunities for electricity industry actors. DSOs and commercial parties need to develop and use innovative tools that can help to better monitor system operations, avoiding unnecessary grid upgrades. Mechanisms such as energy management systems, including optimal algorithms for loads and EV charging, back-end systems, automated meter reading, or smart meters with uses for grid operation are crucial to paving the way for smart charging (Eurelectric, 2015).

In this paper we describe relevant electric mobility initiatives focused in Spain and the benefits of the Electric Mobility Management (EMM) system developed by the Enel Group, aimed at enabling smart charging. In particular, section 1 is devoted to the description of the case study in Spain, while section 2 is focused on the initiatives developed by Enel Group. Finally, in section 3 we state our conclusions.

1. Spain

Spain is ranked within the first three European countries for car production. Given the strong presence of the car industry, Spain is also considered a favorable environment to explore alternative and emerging mobility technologies (fig 3). In fact, in Spain several associations play an active role in pushing the deployment of electric and hybrid vehicles (e.g. ANFAC - Asociación Nacional de Fabricantes de Automóviles y Camiones, and AEDIVE - Asociación Empresarial para el Desarrollo e Impulso del Vehículo Eléctrico, group the national companies whose business is related to the electric vehicles).

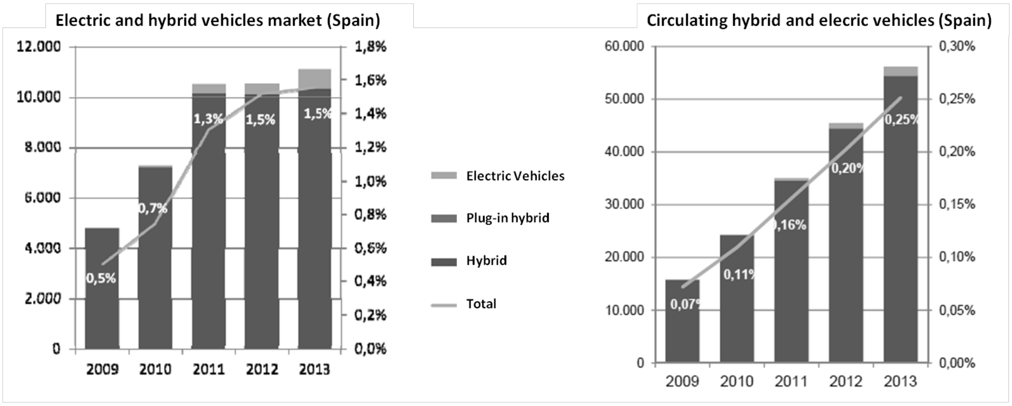

Fig. 3: Electric and hybrid vehicles market and share of circulating vehicles in Spain (Source: ANFAC, Asociación Nacional de Fabricantes de Automóviles y Camiones, 2014)

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In 2009 the Spanish government launched MOVELE, a plan for the deployment of electric mobility, managed and coordinated by IDAE (the Institute for the Energy Diversification and Saving) and the Ministry of Industry, Energy and Tourism. The main objectives of the plan are the introduction of 2000 electric vehicles in urban areas (of different categories, performances and technologies) and the installation of more than 500 charging points distributed in Madrid (280), Barcelona (191) and Seville (75). Moreover, the Spanish government allocated a budget (yearly renewed) to foster the purchase of full and plug-in hybrid electric vehicles. In 2014 about 10 M€ have been allocated for funding, with a maximum of 5500€ per single incentive, depending on the declared autonomy of the vehicle in terms of Kms per recharge. The Enel Group (through Endesa) was fully involved in the development of the MOVELE plan, having a strong presence in the three cities involved (Madrid, Barcelona and Seville).

When Madrid was chosen for the plan in 2009, there were only 24 on-street charging points. In 2014, with about 200 charging points in its metropolitan area, the City of Madrid set up a Public Private Partnership with two EV charging stations providers, allowing for the implementation of an interoperability pilot project (every user can recharge at every charging point) and the renewal of a significant share of the charging points (with a smart management system). Furthermore, the role of the charger manager was created, to foster the trading of the electricity specifically produced to recharge electric vehicles. During the next phases of the MOVELE plan, fast charging stations will be installed in appropriate locations (e.g. petrol stations, underground parking, commercial establishments, shopping centers etc.) and similar initiatives will be launched on regional base in the future.

Barcelona can also be considered a remarkable example for the deployment of charging points. EV charging stations from the Enel Group have been installed on street corners, including normal and Fast Charge. There are over 60 public charging stations on the streets of Barcelona. Moreover, there are several public underground parking lots equipped with charging infrastructure, so the city has available more than 200 charge points for the citizens. The branding of this EV infrastructure is in line with the city's banner - 'Smart City Barcelona', which is part of a citywide smart structure, a joint venture between Endesa and the City of Barcelona. Enel and Endesa aim to create a smart grid integrating the electricity system with the EV system, whilst providing an integrated solution for city services such as transportation, street lighting, car-park management and waste disposal.

2. Electric mobility enabling products – Enel Group case

Since its engagement in electric mobility back in 2009, Enel Group has developed EVs charging stations and an IT platform for the management of charging stations (smart charging), while enabling service providers to trade services with their customers.

As of today, Enel Group has currently deployed more than 2,000 charging stations in Italy and Spain, (see fig. 4), ranging from products to perform charging processes at home to public and highway fast charging stations. Enel Group has developed EMM, the "Electric Mobility Management" system, an eRoaming platform supporting the Group's charging points as well as those recharge facilities owned or operated by other players in Italy, Spain, Romania and Greece.

It is worth noticing that all the recharging stations, installed by Enel Group, are remotely operated by EMM system, which supervises all the stations and monitors all the recharge processes in real time, providing end users with information about the present status of each station and past data about electricity consumption. Through eRoaming platform, electric vehicle drivers are enabled to charge on facilities that are not owned nor operated by the utility they are customers of. The main benefit provided by this system is to enable electric vehicle drivers to charge their cars on around 5,000 facilities across an area spanning from Sicily to Lapland with each recharge being automatically billed to their utility customer accounts back at home.

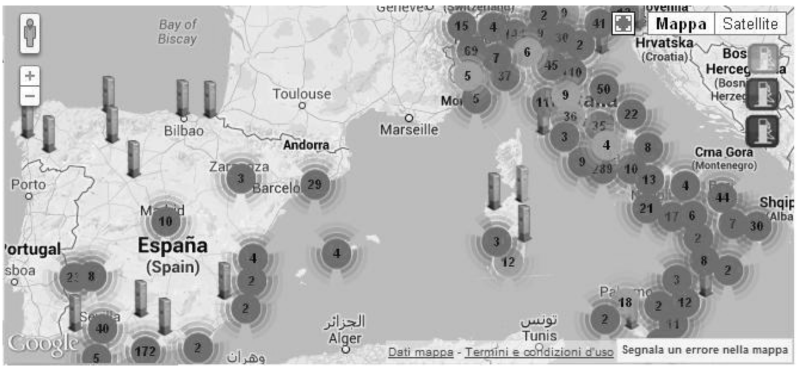

Fig. 4: EVs charging stations installed by Enel Group (Source: Enel Group)

Enel Group is a trail blazer in the deployment of necessary technology for charging infrastructure in order to minimize electricity grid investments, by allowing EV Customers to access Demand Response programs for EV charging. Due to white certificates incentives and corporate taxes discount linked to EVs purchase, fleet market will reasonably dominate electric mobility in Europe and a realistic Time To Market for such Demand Response programs for EV charging do exist for Fleet Operators as Service Customers. Therefore the corporate fleets are a very suitable use case fur such application since the fleet operators can take advantage of load modulation to reduce the running cost of the fleet. The architecture is designed around the concept of deploying a B2B service to be provided by EVSE (Electric Vehicle Supply Equipment) Operator/EVSP (Electric Vehicle Service Provider) to the Fleet Operator in order to minimize electricity bills, electrical investments and – wherever feasible – maximize the allocation of local Distributed Energy Resources.

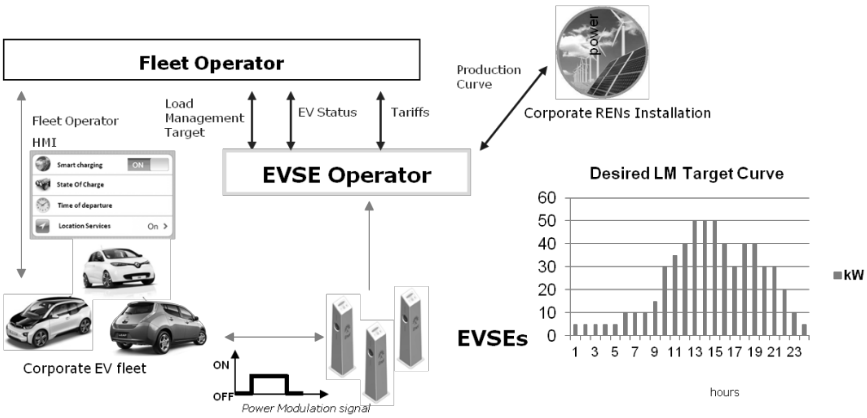

Fig. 5. Architecture of Electric Mobility Management system developed by Enel Group

3. Conclusions

EU strategic indications together with ambitious targets of CO_2 reduction represent an important driver to foster policies for the deployment of sustainable mobility solutions. In this context an extensive use of EVs, especially in urban areas, can significantly contribute to the reduction of local pollutants. EVs have in fact a direct positive impact on the air quality in urban centres, given that local pollutant emissions could be displaced and centralized (and better controlled) at the power plants.

In this terms electricity can be considered an appropriate energy vector to make transport more sustainable, and the pathway to move towards low-carbon mobility requires that EVs could be charged in a smart way, integrating electricity use and mobility needs. As seen in the cases described in this paper, smart charging can also create opportunities for the stakeholders involved, representing a key enabler in paving the way for mass-market EVs deployment. Similarly, a wider deployment of EVs can contribute to make the electric system more flexible, if cars are charged in a smart way.

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Energy Metabolism for New-type Urbanization: Methodology and A Case of Handan, China

ZHOU Hang[1], SHI Lei[1]*, SONG Haiyan[1], Ahmed Tazrin[1], LU Wei[2]

(1 School of Environment, Tsinghua University, Beijing, 100084, China ; 2 Institute of Spatial Planning & Regional Economy, National Development and Reform Commission P.R.C , Beijing , 100000 , China)

slone@tsinghua.edu.cn

Abstract

To cope with the resource and environmental challenges from transitional urbanization, China puts forth a new-type of urbanization strategy which aims to provide an alternative pathway for sustainable urbanization. We argue that urban metabolism for the new-type urbanization should be based on the life cycle perspective and provide a framework for energy metabolism by combining LCA method and LEAP model. To prove the effectiveness of the framework, we carry out a case study of Handan, a typical industrial city in China. In total, eight scenarios have been designed for the 13th Five Year Plan (2016-2020): industrial baseline scenario (IB); new energy use scenario (IN); industrial coal reduction scenario (ICR); industrial integrated control scenario (IIC); transportation baseline scenario (TB); new energy automobile development scenario (NAD); construction baseline scenario (CB); and green construction development scenario (GCD). The study then calculates the emissions of carbon dioxide, sulfur dioxide, nitrogen oxide, $PM_{2.5}$, and PM_{10} generated from energy consumption for every scenario to assess their impact on environment. Compared with the baseline scenarios, the energy saving and emission reduction potential of the other scenarios among three sectors (industrial, transportation and construction) are calculated in turn. The contribution of the industrial sector in energy saving and emission reduction has been found to be overwhelmingly dominant, accounting for 98%. The result shows that maximum energy saving can be obtained in IIC, which will be 13,810,000 tons for standard coal consumption with an efficiency rate of 10.65% and 27,900,000 tons for CO_2 emission reduction, with the reduction rate of 12.19% by 2020. In terms of the transportation sector, the NAD scenario shows the potential reduction of standard coal consumption to 79,454.4 tons with reduction rate of 16.92%, CO_2 emission reduction to 191,000 tons with reduction rate of 18.49% by 2020, SO_2, NO_x, $PM_{2.5}$, PM_{10} reduction rate of 18.31%, 14.74%, 15.23%. For the construction sector, the GCD scenario shows effectiveness in promoting energy efficiency. The results show the potential reduction for standard coal consumption to 667.0 thousand tons (over 50 years) with energy saving efficiency rate of 10.01%, CO_2, SO_2 and $PM_{2.5}$ emission reduction to 1,249,000 tons, 727 tons, and 812 tons respectively.

Key words: metabolism analysis framework; urban energy metabolism; LEAP model; life cycle assessment; scenario analysis

1. Introduction

Over recent years, the acceleration of urbanization has led to not only rapid economic development in urban areas, but also excessive waste of urban resources and energy. It is expected that the urbanization rate in China will reach 60% by 2020. Faced with the dizzy urbanization progress, China has put forward a new-type urbanization development model. The promotion of the new-type urbanization policies symbolizes that China has entered an important transitional period of development. The transition covers not only industrial economy, urban transportation and construction land use, but also environmental protection extending to general ecological awareness. The features of the new-type urbanization which were targeted for improvement are set out in Figure 1. Based on the transition concept, it has been a hot topic among scholars to conduct quantitative analysis of the environmental influence brought by new-type urbanization.

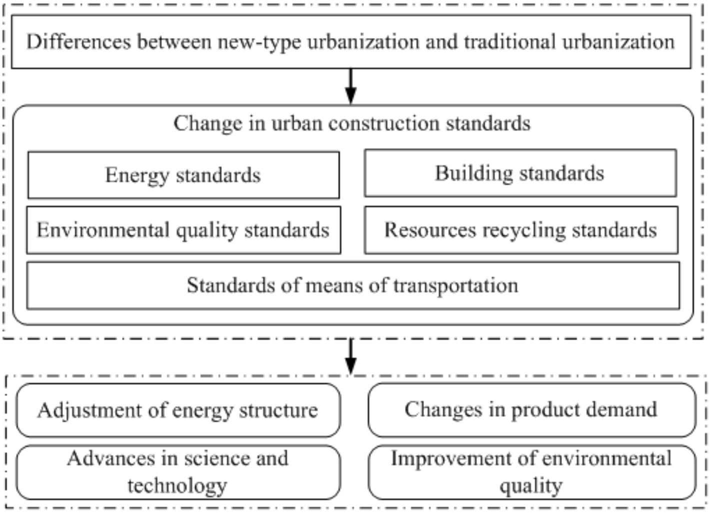

Figure 1： The features of the new-type urbanization which were targeted for improvement

Given that rapid urbanization leads to a surge in energy usage and environmental emissions, this has been the specific target of much research. For environmental emissions, Martinez-Zarzoso and Maruotti[1] analyze the impact of urbanization on CO_2 emissions in developing countries 1975-2003, with the result showing an inverted-U shaped relationship (Martínez-Zarzoso and Maruotti, 2011) What is more, Han et al[2] examined and compared $PM_{2.5}$ concentrations in urban and the surrounding regions and investigated the impact of urbanization on urban $PM_{2.5}$ concentrations at the Chinese prefectures (Han, et al 2014). For the transport industry, Poumanyvong et al[3] investigated the impact of urbanization on transport energy use for countries of different stages of economic development. For the relationship between the urbanization and environment, Ouyang[4] created an environmental impact assessment model-urban environment entropy model on the basis of the thermodynamics entropy principle to apply it in the comprehensive assessment of environmental impact of urbanization in the Pearl River Delta Economic Zone (Ouyang, T 2005). However, there are few studies on the influence brought by new-type urbanization from the perspective of urban scale, especially those concerning environmental influence. This study establishes a material - energy - environmental analysis framework under new-type urbanization. And then it quantifies the influence of new-type urbanization on urban energies and environment using LEAP and LCA models.

Currently, China's development model still displays extensive, linear features. The energy-intensive industries occupy a high percentage. The steel industry, the non-ferrous metals industry, the construction materials industry and the chemical engineering industry are four industries with high energy consumption. Their energy consumption occupies more than half of the total. How to scientifically formulate the energy conservation and emission reduction policies has become an issue of serious concern to Chinese energy development, of which urban energy utilization is the top priority. With Handan as a case study, this paper examines the energy metabolism of the typical Chinese city with use of urban metabolism framework under a new-type urbanization. Besides, it calculates the energy conservation and emission reduction quantity of Handan in combination with the energy policies promulgated during the 13th Five-Year Plan period so as to provide a basis for decision makers.

2 Urban energy metabolism framework for the new-type urbanization

In this paper, we provide a material - energy - environmental co-metabolism framework for the new-type urbanization (Figure 2), which discloses the relationship among material flow, energy flow, and environmental discharge flow from the perspective of urban scale. And it reflects that the material metabolism process consisting of material production – construction - material consumption - urban recycling coupling with energy metabolism process exerts certain influence on the environment.

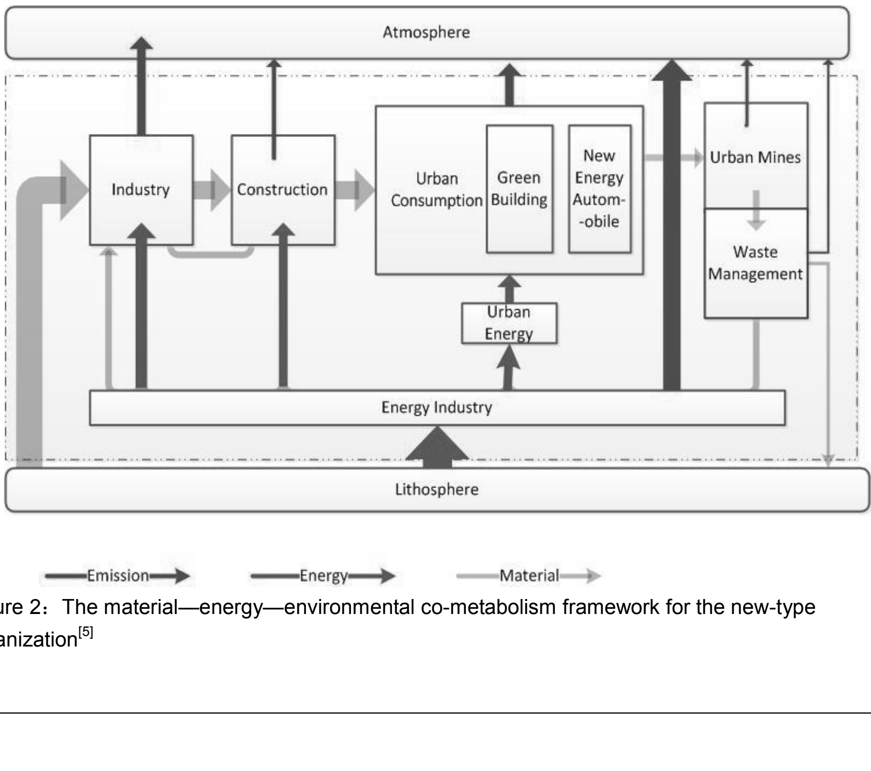

Figure 2：The material—energy—environmental co-metabolism framework for the new-type urbanization[5]

This research conducts an in-depth discussion concerning the relationship between energy metabolism and environment under the urban metabolism framework. The concept of energy metabolism is pioneered by Haberl[6], who argued that accounting for energy flows provides a detailed understanding of urban metabolism (Haberl, 2001)[7], a concept formerly discussed by Karl Marx[8] in 1883. At that time, there was a growing consensus that material and energy flows should have equal status in urban metabolism research and that both should be studied with equal intensity. In addition, Haberl established an energy metabolic method. Based on the results of energy flow research, some scholars proposed a modification of the method of ecological energy metabolism based on emergy, which stands for "embodied energy"[9] (Odum, 1971, 1976, 1983, 1987, 1996). Zhang[10] et al. (2010b, 2011a, b) analyzed the urban energy metabolic system from the perspective of network models to replace the black-box model to make a comparison on 5-17 sectors of Beijing and other Chinese cities. However, few scholars used the life cycle to analyze the urban energy metabolism. LCA can consider the associated environmental impacts from extraction to disposal[11] (Chester, 2010; Solli, Reenaas, Stromman, & Hertwich, 2009). What is more, LCA analysis uses the inventory part of materials flows analysis to assess the movement of materials through the urban system[12] (Barles, 2007a). We could consider LCA as a tool for quantifying the energy of urban metabolism. There are also software packages that have been developed to calculate LCA, which contain GaBi, developed by PE International. Since energy metabolism is a complex process in itself, the environment emission data of GaBi can be used to calculate the influence of every process of energy metabolism on the environment.

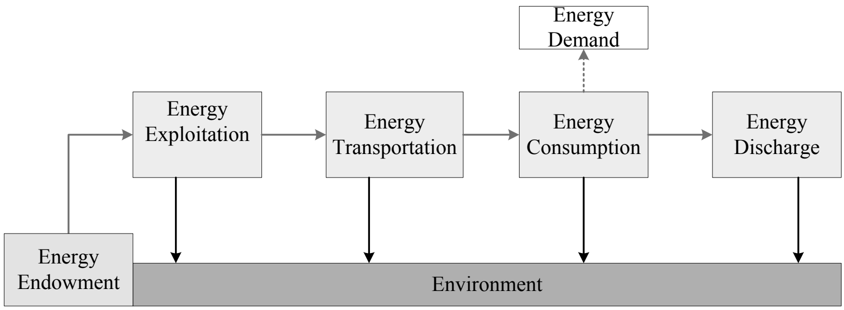

Figure 3: Life Cycle of urban energy metabolism

The energy of the urban economy conforms to the life cycle demonstrated in Figure.3: energy endowment – energy exploitation - energy transportation - energy consumption - energy discharge. Energy consumption contains 3 aspects: energy transition, energy consumption, and energy penalty. Energy penalty refers to the energy which has not been fully utilized, such as inefficient burning, or lost in the process of energy transmission. To reduce the complexity of calculations, in this study the energy penalty is not taken into consideration.

3. The energy status of Handan City

Handan City is located in the south of Hebei Province, boasting rich resources and forms of energies. It is one of the most famous national coke steam coal and iron ore production areas in China. By the end of 2013, the population of Handan totaled at 10.12 million RMB and the annual municipal GDP had reached 306.15 billion RMB, of which the income of the industrial enterprises above a certain designated size had increased by 127.36 billion RMB. Steel forms the No.1 dominant industry in the whole city. In 2013, the output of the cast iron, crude steel and steel materials reached 37.143 million tons, 44.846 million tons and 51.196 million tons, respectively; and the generated electricity amount reached 33.2 billion kilowatts. Based on the industrial structure of Handan City, the energy consumption situation of various departments in Handan City in 2013 is shown in Table 1. Industry is the major energy consumption department, whose annual consumption reached 86.002 million tons of standard coal, accounting for 98% of the total. The energy consumption of the agriculture, the transportation industry and the construction industry mainly accounted for 0.4%, 0.35% and 0.35% of the total, respectively. In 2013, the consumption of the raw coal accounted for 42.23% of the total. The consumption of the cleaned coal, the coke and the electricity accounted for 27.52%, 16.81% and 3.16% of the total, respectively. The types of industrial energy consumption in Handan City are shown in Figure. 4.

Handan City has rich coal resource. Coal accounts for a large amount in the primary energies. However, the recyclable primary energies, such as hydro-energy and wind energy, are quite rare. The processing and conversion of the primary energies takes up a large percentage in the energy consumption. Based on the situation and Handan Municipal Statistical Yearbook 2014, the energy metabolism chart of Handan City is drawn, including the conversion of the primary energies and the terminal consumption, and the terminal consumption of the secondary energies. The model chart is transformed into the LEAP model language. Energy metabolism model in Handan city is shown as Figure 5.

Table 1：Energy consumption of each sector in Handan in 2013

Sector	Energy Consumption (thousand tce)
Industrial	86002
Agriculture and water conservancy industry	253
Transportation (including roads and railways)	298
Construction	235
Wholesale, retail trade, and catering services	99
Other industries	476

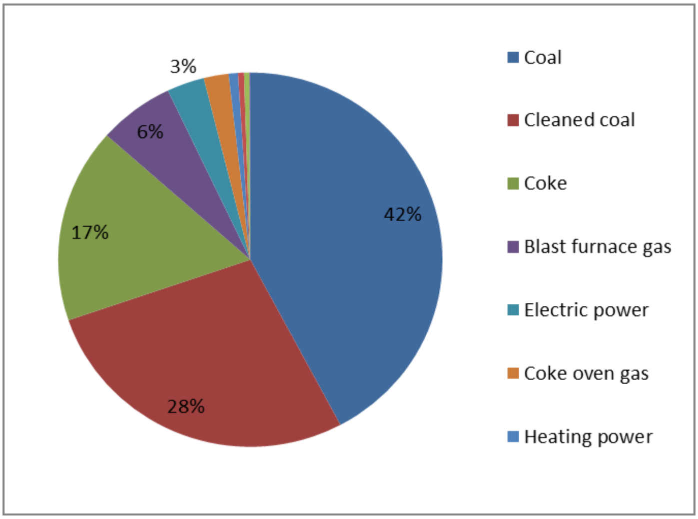

Figure 4： Energy consumption structure of Handan's industry in 2013

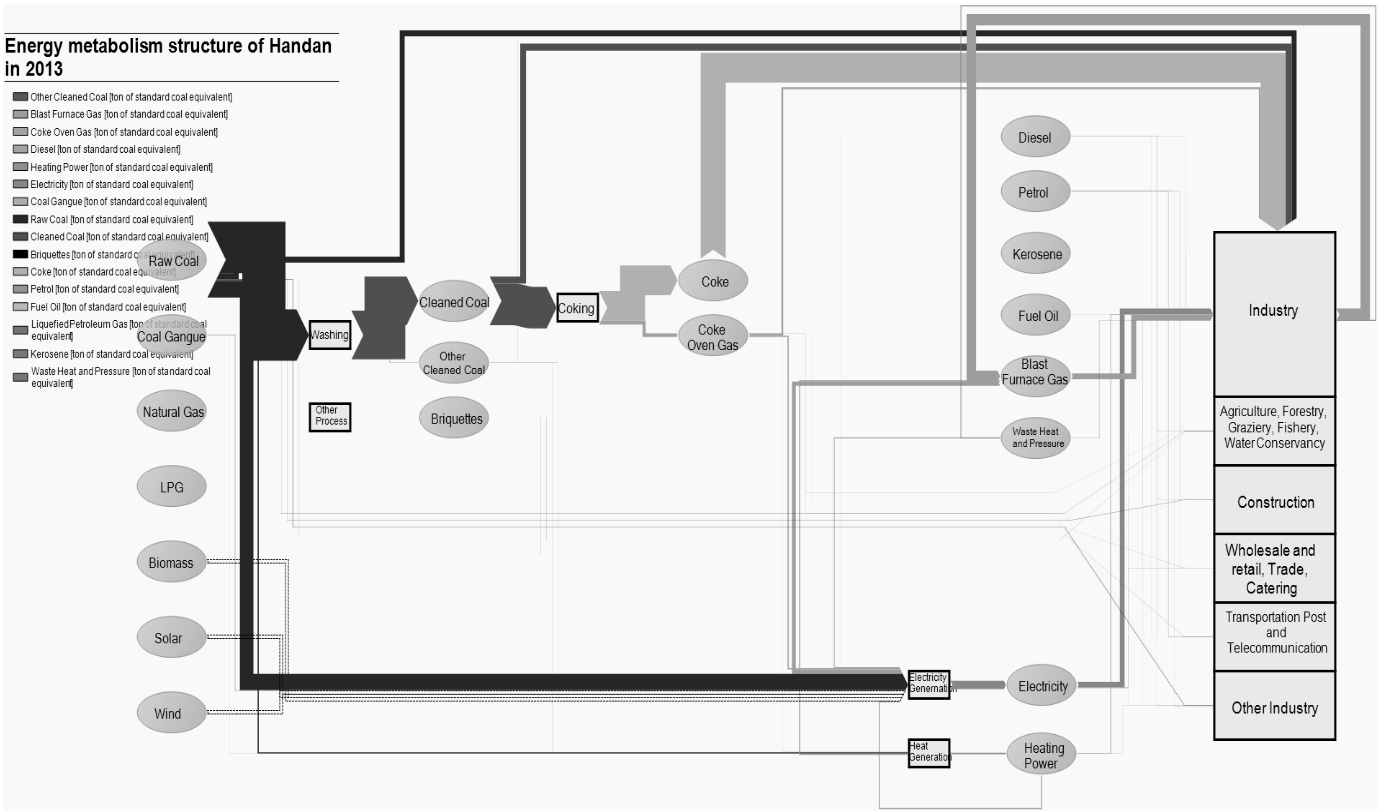

Figure 5： Energy metabolism status of Handan city in 2013

4. Scenarios design for Handan energy metabolism

4.1 LEAP model

LEAP (Long Range Energy Alternative Planning) is an energy-environment modeling tool that was first developed at the Stockholm Environment Institute (SEI). [13]Utilizing LEAP allows the energy-saving potential and pollution reduction potential to be obtained by comparing the results from a series of simulations for a specific year or period. This paper combines LEAP model and the Life Cycle Assessment (LCA) as quantitative analysis tools to calculate energy consumption and environmental emissions in the city of Handan, China, and posits recommendations for saving energy and reducing emissions based on the information gathered.

The LEAP model is a "bottom-up" model with clear computational principles.

Energy demand is calculated using the following expression:

Where ED_k is the total energy demand, *AL* is activity level, *EI* is energy intensity, *i* is the sector, *j* is the energy using equipment, and *k* is the fuel type. Different simulated scenarios result in various *AL* and *EI*, thereby reflecting the changes in energy demand.

Emissions are calculated using the following expression:

Where $EDEmission_p$ is environmental emissions. Different scenarios, again, result in various emission levels. Emission data is provided by LCA Software Gabi 6.0, which allows wider and more precise coverage.

LEAP is utilized by numerous research institutions, owing to its many notable advantages. Price et al[14], for example, used the LEAP model to estimate the CO_2 emissions of different scenarios in worldwide industry, transportation, and construction sectors. Zhang[15] et al used LEAP to assess the CO_2 abatement potential of China's iron and steel industry from 2000 to 2030 according to cost information. Yu[16] employed the LEAP model to analyze the CO_2 emissions at a regional level, with scenarios that involved the output of steel, flowage structure, equipment size, and sophistication of technology. Cui[17] et al applied the LEAP system to model CO_2 emission reduction potential in Xiamen, China. Another factor unique to this study is its extensiveness – the majority of LEAP researchers focus on CO_2 reduction potential, where this paper further includes NO_x, SO_2, $PM_{2.5}$, and PM_{10} data as well, in order to provide the most thorough analysis possible. The overall LEAP model structure is as follows (Figure 6).

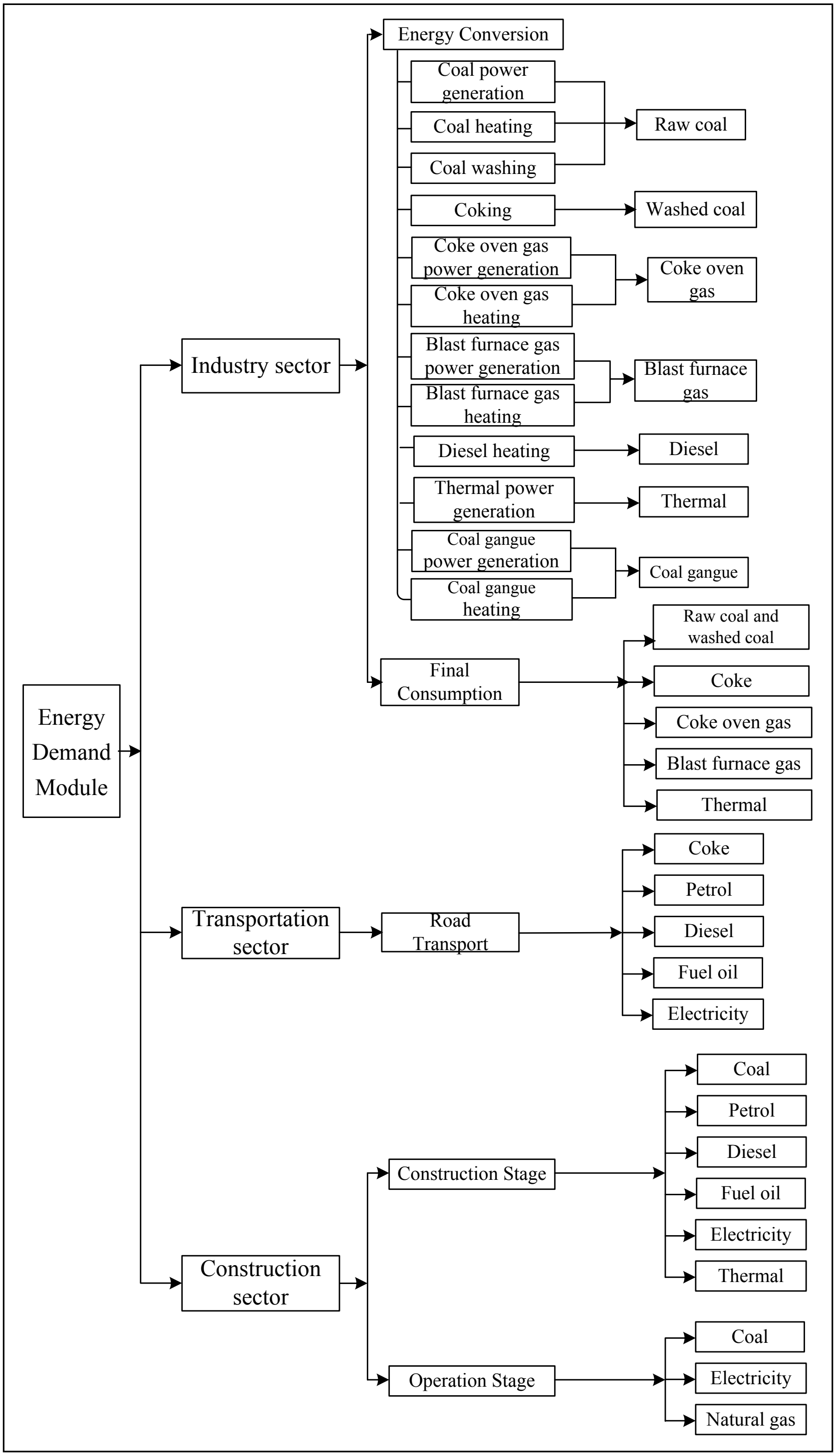

Figure 6: The overall structure of the LEAP-Handan model

4.2 LEAP scenario design

This study establishes 8 energy utilization scenarios in 3 sectors during China's 13th Five Year Plan (2016-2020). The industry sector includes industrial baseline scenario (IB), new energy used scenario (IN), industrial coal reduction scenario (ICR), and industrial integrated control scenario (IIC); the transport sector, includes transportation baseline scenario (TR), new energy automobile development scenario (NAD); the construction sector includes construction baseline scenario (CB), and green construction development scenario (GCD). Eight scenarios are in Table 2.

Table 2: Eight energy utilization scenarios during Handan's 13th Five Year Plan

Sector	Scenario	Content	Basis
Industry	IB	Linear extrapolation is performed according to the Handan yearbook's 2010-2013 data, assuming that since 2013, the industrial added value increased 8% each year and the industrial energy consumption increased 5% each year. The energy structure remained stable.	Handan yearbook's data (2010-2013); Government report in the 12th National People's Congress
	IN	Handan begins to develop new energy sources. Until 2015, new energy occupied 10% of the total installed capacity. By 2020, new energy occupies more than 15%. (Biomass power generation reaches 18 kilo watts, and solar power generation reaches to 500 megawatts.)	Handan development and reform commission on energy (Handan construction and development of new energy situation analyses)
	ICR	Beginning in 2014, reduction in steel use reached 5,000 tons. From 2013-2017, total coal reduction reaches 16,700 tons. (It is assumed that the added coal reaches 10,000 tons from 2018 to 2020.)	Handan city development and reform commission (Report on the impact of industrial structure adjustment on economic and social development), (New energy industry in Hebei province "12th Five Year Plan" development)
	IIC	Combining new energy plans and	—

		industrial coal reduction scenarios	
Transportation	TB	2020 energy data is gathered by linear extrapolation according to the Handan yearbook (2010-2013) data from the transportation sector. The energy structure remained stable	Handan yearbook's data (2010-2013);
	NAD	According to country policy, in 2020 new energy mobile use occupies 25%. The energy structure changed in the LEAP model.	Transportation sector： New energy vehicles speed up the popularization and application of the implementation opinions (draft)，(September, 2014)
Construction	CB	According to the Handan yearbook (construction sector,) linear extrapolation provides data for new completed residential areas. The energy structure remains stable.	Handan yearbook's data (2010-2013);
	GCD	By 2020, completed green residential buildings occupy 50% of the total, up from 2% in 2012. The energy structure changed in the LEAP model.	"The New Urbanization State Plan (2014—2020)"

4.2.1 New energy use scenario

Handan shows significant potential in the development and utilization of biomass energy and solar energy. Handan produced an average of 7,296,400 tons of dry straw from various crops in recent years, at a conversion potential to biomass energy of about 1,500,000 tce; Handan is also located in an abundant solar energy resource area, with average annual sunshine of 2200-2900 hours that can be used to generate power.

By the year 2013, the new energy power generation in Handan City had accounted for 2.67% of the total municipal electric power installed capacity. It is expected that, by the year 2020, the new energy power generation will have reached more than 10% of the total municipal electric power installed capacity. By the year 2015, the figure will have reached above 15%. Based on that, the LEAP model energy percentage and the environment influence are set.

By comparing the environmental impact (throughout the entire life cycle) of thermal power generation, biomass power generation, and solar power generation (Table 3), the influence of thermal power generation on the environment is demonstrably the largest. Solar power occupied 7.53% of the total thermal power generation, and biomass power occupied 9.38%. In effect, clean power generation deserves more attention for its ability to decrease overall environmental impact. As far as power generation period, there is almost no environmental impact of solar power generation; and the CO_2 emission of biomass power generation is, naturally, biomass, which is highly reusable. Any other emissions are negligible.

Table 3: Environmental impact throughout the life cycle of thermal, solar energy, and biomass power generation

Pollutant emissions(kg/MJ)	Thermal power generation	Solar energy power generation	Biomass power generation
CO_2	2.75E-01	2.07E-02	2.58E-02
SO_2	6.11E-04	7.30E-05	8.56E-05
NOx	1.12E-05	5.00E-05	5.25E-05
PM_{10}	9.01E-04	6.69E-06	7.02E-06
$PM_{2.5}$	5.35E-05	7.51E-06	7.21E-06

4.2.2 Industrial coal reduction scenario

Known characteristics of Handan's industrial structure show that the city is very dependent on coal resources, which accounted for more than 90% of total energy consumption. Basically, reduction of the dependence on coal energy is the best place to start improving Handan's environment. According to a document entitled "Decomposition of the Implementation Plan of Coal Reduction in Handan City", Handan will, in fact, take action including reducing the production capacity of steel and cement, eliminating coal-fired boilers, and other relevant measures. Coal use was reduced by 4.28 million tons in 2013, and 4.63 million tons in 2014, and will be reduced by a remarkable 20.26 million tons by 2017, 3.56 million tons more than the Province Issued Plan (16.7 million tons). During 2017-2020, Handan will continually implement coal reduction measures, and the coal reduction is predicted to be 10 million tons total for the three-year period. According to the emission reduction targets, we adjusted intensity factors in the coal industry in the LEAP model, including coal power generation, heating, coal washing, coking, and terminal consumption of cleaned coal and other cleaned coal.

4.2.3 New energy automobile development scenario

According to the life cycle of an automobile (Fig. 7), energy consumption can be divided into three stages: the fuel and preparation stage, vehicle use stage, and repair and recovery stage. Most energy statistics provided by the transportation industry only account for the vehicle use stage. According to the "Energy Saving and New Energy

Automobile Industry Development Plan (2012-2020)", Chinese new energy vehicle development will focus on electric vehicles. The production capacity of 100% electric vehicles and plug-in hybrid vehicles are expected to reach 20 million, respectively, and cumulative production will be more than 450 million. Both types of new energy vehicle are expected to comprise 50% of the total proportion by 2020. Energy consumption data at various stages of the life cycle of traditional fuel vehicles and new energy vehicles are shown in Table 4.The energy consumption of a plug-in hybrid vehicle is 56.72% of a traditional fuel vehicle, and a 100% electric vehicle’s energy consumption is only 36.82% of a traditional fuel vehicle.

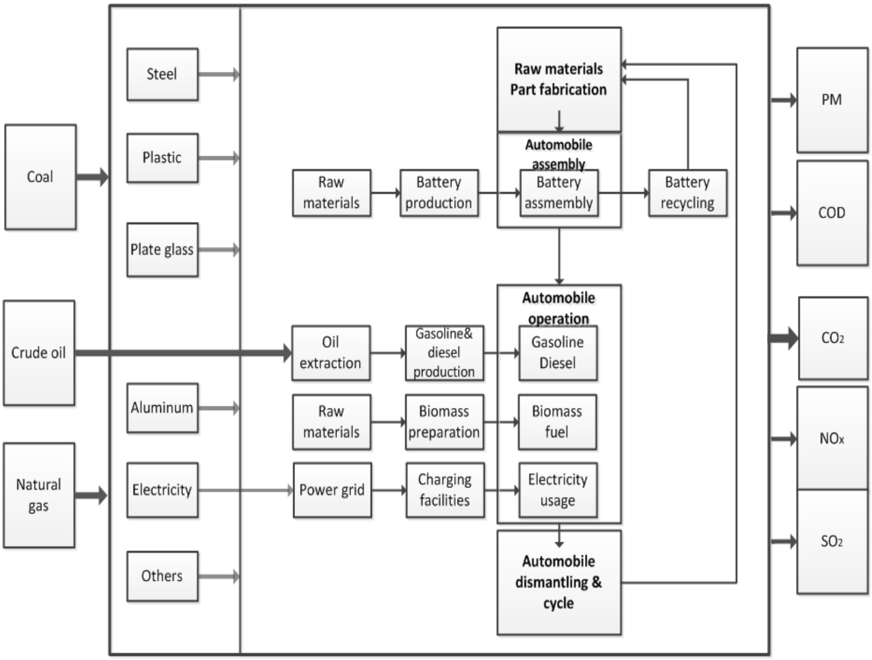

Figure 7: Life cycle of a vehicle

Table 4: Energy consumption throughout the life cycle of a traditional fuel vehicle, a plug-in hybrid vehicle, and a 100% electric vehicle

Vehicle types	Energy types	Energy consumption throughout the life cycle（MJ/vkm）		
		The fuel and preparation stage	Vehicle use stage	Repair and recovery stage
Traditional fuel vehicle	Total	0.760	2.327	0.550
	Coal	0.359	0	0.386
	Petrol	0.192	2.047	0.093
	Electricity	0.185	0	0.024
Plug-in	Total	0.606	1.32	0.692

hybrid vehicle	Coal	0.373	0.107	0.498
	Petrol	0.103	1.056	0.102
	Electricity	0.223	0.011	0.033
100% electric vehicle	Total	1.536	0.857	0.720
	Coal	1.348	0.765	0.536
	Petrol	0.029	0.004	0.082
	Electricity	0.128	0.074	0.038

According to the new energy and traditional energy consumption list[18], and the report "Implementation on Accelerating the Popularization and Application of the New Energy Vehicle (Draft)", new energy vehicles will reach 25% of the total.[19] We thus assumed, in accordance with all the above information, that the ratio of new energy automobiles in Handan city was 25% and that both plug-in electric vehicles and 100% electric vehicles accounted for 50% of new energy vehicles. We then adjusted the GDP energy ratio and energy intensity in the LEAP–Handan model.

Table 5: The major parameters used in the TB and NAD in LEAP-Handan model

Scenario	TB	NAD
Year	2013	2020
Coal（%）	3.69	4.92
Coal unspecified（%）	0.08	0.11
Gasoline（%）	77.47	75.97
Diesel（%）	13.51	13.25
Fuel oil（%）	2.71	2.66
LPG（%）	0.01	0.02
Heating power（%）	0.00	0.01
Electric power（%）	2.53	3.07

4.2.4 Green construction development scenario

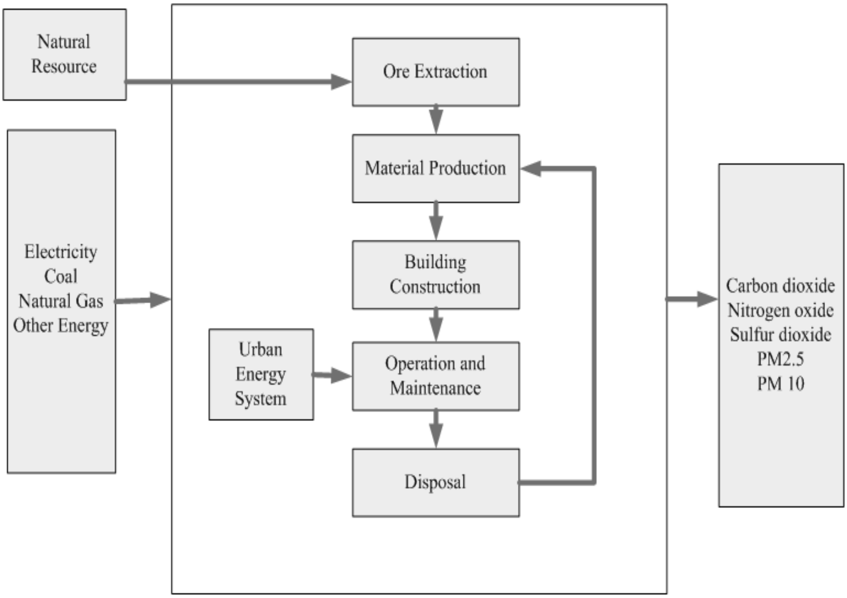

Figure 8: Life cycle of a building

The life cycle of a residential building can be divided into four stages (Figure.8): the material stage (including ore mining and material production) construction and installation stage, operation and maintenance stage, and demolition and disposal stage. Energy consumption in the material stage accounts for more than 20% of the total[20]. Operation and maintenance is about 70%, and the other stages are less than 2%[21]. Because construction is directly related to statistical data and operation stage is important. Thus, we take these two stages into consideration.

“Green building”[22] refers to architecture that is harmonious with nature, which maximizes the conservation of resources (energy, land, water, and materials,) in its entire life cycle, protecting the environment and reducing pollution in order to provide a healthy, comfortable, and efficient space for the humans who inhabit it. As far as energy saving, the energy consumed during construction of a green building is slightly larger than that of a traditional building; the operation of green building, however, uses only 80% of the energy that a traditional building does. Basically, green buildings are more energy-efficient over the course of their entire life cycle. Operation-level energy consumption for green buildings versus traditional buildings is shown in Table 6[23].

Table 6: Operation-level energy consumption for green buildings versus traditional buildings

Energy types	Green buildings	Traditional buildings	Green buildings / traditional buildings
Coal（heating）（kg/m^2）	4.65	7.18	0.65
Electricity（kw.h/ m^2）	21.63	22.57	0.96
Natural gas (m^3/ m^2)	1.278	1.278	1

According to energy consumption data and information from "National New Urbanization Planning (2014-2020)", green buildings will account for 50% of new housing areas in 2020. We thus assumed that the ratio of green buildings in Handan city is 50% in 2020, and adjusted the energy ratio and energy intensity of unit housing areas in the LEAP–Handan model accordingly.

Table 7: The major parameters used in the CB and GCD (construction) in LEAP-Handan model

Scenario	CB	GCD
Year	2013	2020
Coal（%）	38.05	45.65
Coal unspecified（%）	3.07	1.80
Coke oven gas（%）	0.17	0.10
Gasoline（%）	15.16	16.27
Diesel（%）	11.39	12.22
Fuel oil（%）	10.56	11.33
LPG（%）	0.17	0.10
Heating power（%）	4.21	2.46
Electric power（%）	17.20	10.06

Table 8: The major parameters used in the CB and GCD (operation) in LEAP-Handan model

Scenario	CB	GCD
Year	2013	2020
Coal（%）	53.41	48.90
Electricity（%）	28.89	31.43
Natural gas（%）	17.70	19.67

5.Results and discussion

5.1 Reduction potential of energy consumption

5.1.1 The tendency of energy consumption in 2013-2020

Industrial energy consumption can be divided into three parts: energy conversion, energy end-use, and energy penalty. Energy conversion is the process that primary energy is converted into secondary energy, for example the processes of raw coal converted into cleaned coal, used coal to generate electricity, used cleaned coal for coking, etc. Energy end-use means that energy is used directly, and in this paper we take this terminal consumption to mean being burned directly.

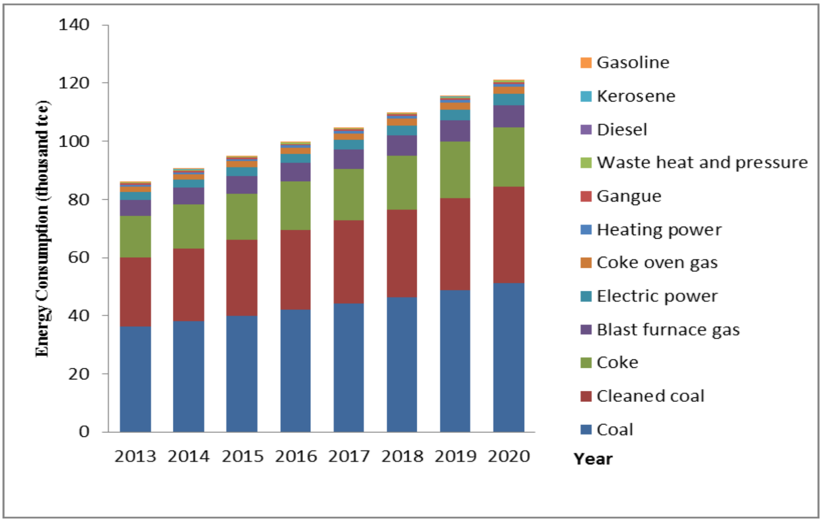

Figure 7: Expected energy consumption of Handan's industry in 2013-2020

In the process of energy transformation, the use of coal is up to 90 percent, which includes the conversion of raw coal and also the conversion of clean coal to coke. In the process of energy end-use, coke's quantity is the most, up to 42 percent of energy end-use. Figure 7 displays industrial energy consumption from 2013 to 2020.

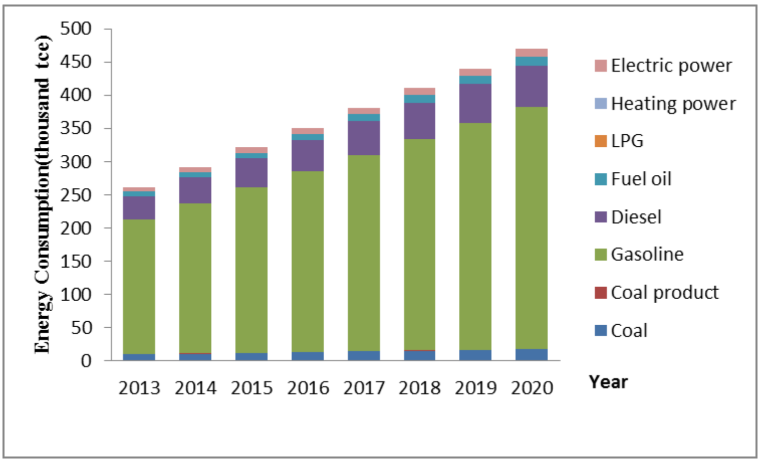

Figure 8: Expected energy consumption of Handan's transportation in 2013-2020

We would now like to discuss turn the construction industry in Handan. The figures from the Handan Yearbook show a downward trend in new buildings every year from 2010-2013. We project that this trend will continue to decrease from 2014 to 2020, and that total energy consumption will likewise decrease. This study mainly focuses on the two phases of a building's life cycle – the construction phase and the usage phase. During the construction period, coal consumes the largest amount of energy (38.05%) followed by electricity (17.20%) During the usage period, coal still consumes the most energy, 43.25% of the total. Figs. 9 and 10 show the projected energy consumption during the construction and usage period of a building in Handan between 2013 and 2020.

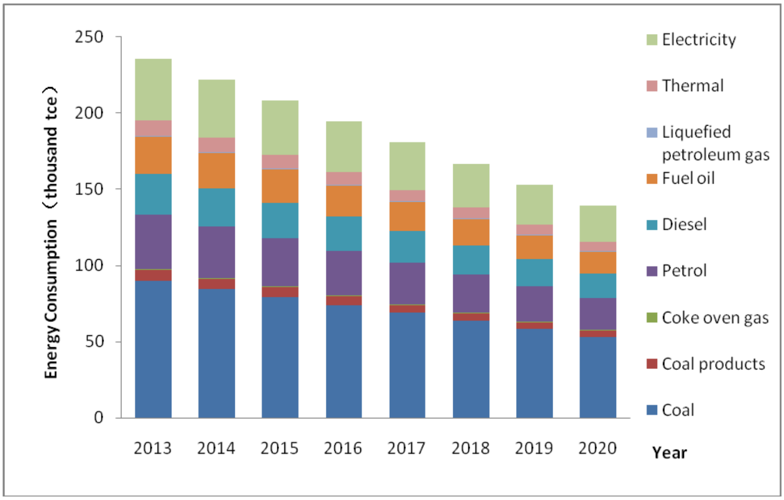

Figure 9: Expected energy consumption in the construction stage in 2013-2020

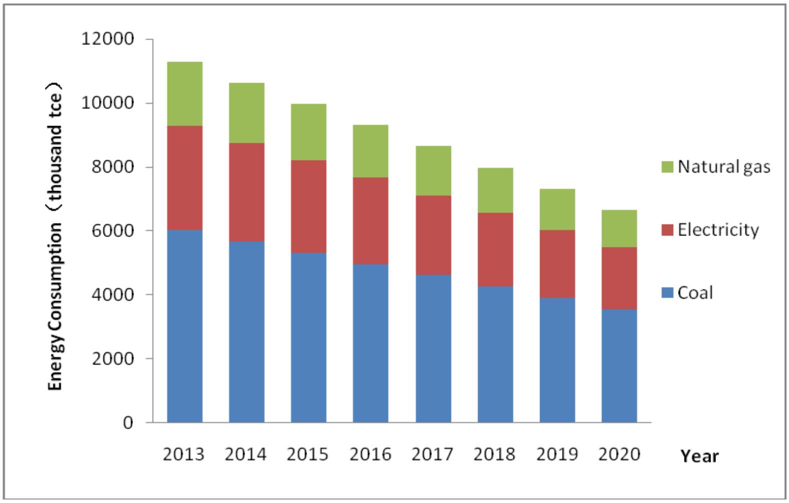

Figure 10: Expected energy consumption in the operation stage in 2013-2020

5.1.2 2020 Reduction potential of energy in different scenarios

In the industrial field, an integrated control scenario shows better energy saving performance. Under the integrated control scenario, energy dependency reduction in Handan peaks in 2017, saving 14.1 million tons of standard coal at an energy saving rate of 12.58%. In 2020, the potential for energy saving is 13.81 million tons of standard coal at a rate of 10.65% (Figure. 11, Table 9).

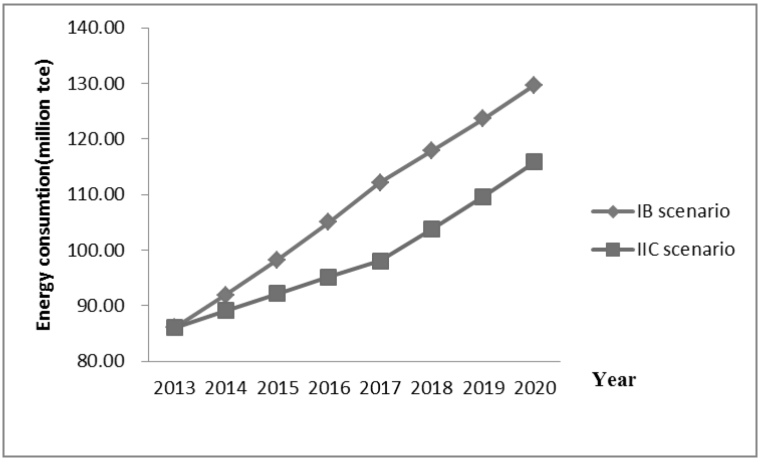

Figure 11: Expected energy consumption in IB and IIC scenario in 2013-2020

Table 9: Expected energy consumption in IB and IIC scenario in 2013-2020 (Unit: 10^6 tce)

Year	2013	2014	2015	2016	2017	2018	2019	2020
IB scenario	86.00	91.92	98.23	104.96	112.14	117.80	123.64	129.66
IIC scenario	86.00	89.12	92.18	95.17	98.04	103.70	109.63	115.85
D-value	0.00	2.80	6.05	9.79	14.10	14.10	14.01	13.81
Energy saving rate	0.00%	3.05%	6.16%	9.33%	12.58%	11.97%	11.33%	10.65%

As expected, new energy vehicles save more energy than traditional vehicles (Table 10). In 2020, the energy saving potential of new energy vehicles reaches 79.45 thousand tons of standard coal, at an energy saving rate 16.92%. New energy vehicle policies are imperative in Handan. This study recommends the proportion of new energy vehicles be set to 25% of the total vehicles, and stresses increased investment in new energy vehicles begin immediately.

Table 10: Expected energy consumption in TB and NAD scenario in 2013-2020 (Unit: thousand tce)

Year	2013	2014	2015	2016	2017	2018	2019	2020
TB scenario	261.84	291.51	321.19	350.86	380.54	410.22	439.89	469.57

NAD scenario	261.84	284.47	305.66	325.42	343.74	360.64	376.09	390.11
D-value	-	7.05	15.53	25.44	36.79	49.58	63.80	79.45
Energy saving rate	0.00%	2.42%	4.83%	7.25%	9.67%	12.09%	14.50%	16.92%

Green construction practices consume more energy during the construction phase than traditional construction (Table 11), but less during the usage period that is caculated as 50 years in this study (Table 12). 667 thousand tons of standard coal will be conserved by 2020 if green construction policies are implemented, at energy saving rate of 10.01%.

Table 11: Expected energy consumption in the construction stage in CB and GCB scenario in 2013-2020 (Unit: thousand tce)

Year	2013	2014	2015	2016	2017	2018	2019	2020
Traditional Construction	235.34	221.57	207.80	194.03	180.27	166.50	152.73	138.96
Green Construction	235.34	252.48	269.66	286.87	304.10	321.37	338.66	355.98
D-value	0.00	-30.92	-61.86	-92.83	-123.84	-154.87	-185.93	-217.02
Energy saving rate	0.00%	-13.95 %	-29.77 %	-47.84 %	-68.70 %	-93.02 %	-121.74 %	-156.17 %

Table 12: Expected energy consumption in the operation stage in CB and GCB scenario in 2013-2020 (Unit: thousand tce)

Year	2013	2014	2015	2016	2017	2018	2019	2020
Traditional Operation	11284.2	10624.0	9963.9	9303.7	8643.5	7983.4	7323.2	6663.1
Green Operation	11284.2	10472.1	9678.8	8904.5	8149.0	7412.5	6694.8	5996.0
D-value	0.0	151.9	285.0	399.2	494.5	570.9	628.4	667.1
Energy saving rate	0.00%	1.43%	2.86%	4.29%	5.72%	7.15%	8.58%	10.01%

5.2 Reduction potential of emission

5.2.1 The tendency of environmental impact in 2013-2020

This study assumes 5 distinct environmental pollutants (all assumed pure/untreated) during the process of energy consumption: carbon dioxide, nitric oxide, sulfur dioxide, $PM_{2.5}$, and PM_{10}. In 2013, CO_2 emissions were the largest of the 5 pollutants, at 152 million tons. NO_x emissions were 235 thousand tons. SO_2 emissions were 511 thousand tons, $PM_{2.5}$ were 81.2

thousand tons, and PM_{10} were 30.6 thousand tons. Emissions of all five materials increase as years go on, at a 5% increase. If no emission reduction measures are employed, the quantities of the same pollutants in 2020 will be: 229 million tons CO_2, 354 thousand tons NO_x, 771 thousand tons SO_2, 122 thousand tons $PM_{2.5}$, and 46.1 thousand tons PM_{10}.

5.2.2 Reduction potential of emission in different scenarios

The emission reduction potential and reduction rate for industrial scenarios are shown in Table 13 and Table 14. CO_2 emission reduction proved more effective under the new energy use scenario than coal cutting. By 2020, CO_2 emission reduction potential reaches 23.87 million tons at reduction rate of 10.43%. (The reduction rate of other pollutants is around 10%.) Coal cutting reduces overall emissions better than energy transformation. By 2020, the reduction potential of CO_2 emissions under a coal cutting scenario reaches 20.86 million tons at reduction rate of 9.12%. The “integrated control scenario” is a combination of new energy practices and cutting coal, and it shows the best reduction performance with CO_2 emission reduction of 27.9 million tons at reduction rate of 12.19%.

Table 13： Emission reduction potential in IT, ICR, and IIC scenarios in 2020

Emission reduction potential	$PM_{2.5}$ （10^3t）	PM_{10} （10^3t）	CO_2 （10^6t）	NOx （10^3t）	SO_2 （10^3t）
IT scenario	9.52	3.53	23.87	30.34	60.34
ICR scenario	14.55	5.15	20.86	39.79	77.88
IIC scenario	15.17	5.34	27.90	44.27	82.13

Table 14： Emission reduction rate in IT, ICR, and IIC scenarios in 2020

Emission reduction rate	$PM_{2.5}$	PM_{10}	CO_2	NOx	SO_2
IT scenario	7.77%	7.66%	10.43%	8.56%	7.82%
ICR scenario	11.88%	11.17%	9.12%	11.23%	10.10%
IIC scenario	12.39%	11.58%	12.19%	12.49%	10.65%

Energy reduction (and continual reduction potential) will reach a very high level by 2020 if new energy vehicle policies are adopted by the Handan transportation authority. CO_2 emissions reduction reaches 191 thousand tons at a reduction rate of 18.49%. $PM_{2.5}$ and PM_{10} emissions are reduced by 4.55 tons and 9.06 tons, both at reduction rate of 15%. SO_2 emissions reduction reaches 394 tons at an 18.31% reduction rate (Table 15).

Table 15： Emission reduction potential and rate in TB, and NAD scenarios in 2020

	$PM_{2.5}$ （t）	PM_{10} （t）	CO_2 （10^3t）	NOx （t）	SO_2 （t）
TB scenario	30.8	59.5	1030	22.8	2150
NAD scenario	26.3	50.4	842	25.2	1760

Emission reduction potential	4.55	9.06	191	-2.48	394
Emission reduction rate	14.74%	15.23%	18.49%	0	18.31%

We assume that green construction policies are implemented citywide. As mentioned earlier, pollutant emissions are greater during green construction than traditional construction – CO_2 emissions alone increases 451 thousand tons under green construction policies (Table 16). During the usage phase of a building's lifecycle, however, (50 years) green buildings consume less energy and emit less pollutant than traditionally-constructed buildings. (NO_x emissions, which remain stable, are the only exception.) Green buildings emit 1.76 million tons less CO_2 during their lifecycle, at a reduction rate of 14.76%. The reduction rates of $PM_{2.5}$, PM_{10}, and SO_2 are all near 17.50% (Table 17).

Integrating green construction and usage phases still shows remarkably reduced emissions and enhanced energy efficiency over traditional construction practices, despite apparent disadvantages at the construction phase alone. Total CO_2 emissions reduction reaches 1.249 million tons; $PM_{2.5}$ is reduced 81.2 tons, and SO_2 is reduced 727 tons (Table 18).

Table 16: Emission reduction potential and rate in the construction stage in CB and GCB scenario in 2020

Construction stage	$PM_{2.5}$ (t)	PM_{10} (t)	CO_2 (10^3t)	NOx (t)	SO_2 (t)
CB scenario	23.2	8.5	248	1.96	467
GCB scenario	49.0	23.5	699	2.88	1190
Emission reduction potential	-25.8	-15.0	-451	-0.92	-723
Emission reduction rate	-111.21%	-176.47%	-181.85%	-46.94%	-154.82%

Table 17: Emission reduction potential and rate in the operation stage in CB and GCB scenario in 2020

Operation stage (50years)	$PM_{2.5}$ (t)	PM_{10} (t)	CO_2 (10^3t)	NOx (t)	SO_2 (t)
CB scenario	610	65.8	11900	4490	8240
GCB scenario	503	54.2	10200	4490	6790
Emission reduction potential	107	11.6	1700	0	1450
Emission reduction rate	17.62%	17.62%	14.76%	0.00%	17.58%

Table 18: Emission reduction potential and rate in the construction and operation stage in CB

and GCB scenario in 2020

	$PM_{2.5}$ (t)	PM_{10} (t)	CO_2 (10^3t)	NOx (t)	SO_2 (t)
CB scenario	633.2	74.3	12148	4491.96	8707
GCB scenario	552	77.7	10899	4492.88	7980
Emission reduction potential	81.2	-3.4	1249	-0.92	727
Emission reduction rate	12.82%	-4.58%	10.28%	-0.02%	8.35%

5.2.3 The contribution rate of each consumption sectors

Because the industrial sector consumes more energy than any other sector of Handan analyzed in this study, we can conclude that energy policies regarding industry, specifically, will considerably reduce pollutant emissions and increase energy efficiency for the city as a whole. With the exception of $C0_2$ emissions, industry contributes nearly 100% of the total pollutant emissions; and its percentage of CO_2 emissions is still highest, at 95.09% of the total. The construction industry, the second-most contributor, emits CO_2 at 4.26% of the total (slightly more during the construction phase of green buildings.) New energy vehicles contribute only 0.65% to CO_2 emissions. Details regarding reduction contribution rate by sector can be found below in Table 19.

Table 19: Contribution rate to emission reduction of the three sectors

Sector	$PM_{2.5}$ (%)	PM_{10} (%)	CO_2 (%)	NOx (%)	SO_2 (%)
Industry	99.44	99.83	95.09	100.00	98.65
Transportation	0.03	0.17	0.65	0.00	0.47
Construction	0.53	0.00	4.26	0.00	0.87

6. Conclusion

(1) Urban energy metabolism dataset for Handan was built by combining LEAP and Life Cycle Assessment models (Software Gabi 6.0), and calculating energy consumption. We set eight energy utilization scenarios within China's13thFiveYear Plan (2016-2020): industrial baseline scenario (IB), industrial transformation scenario (IT), industrial coal reduction scenario (ICR), industrial integrated control scenario (IIC), transportation baseline scenario (TB), new energy automobile development scenario (NAD), construction baseline scenario (CB), and green construction development scenario (GCD). We then analyzed the energy-saving and emission reduction potential for CO_2,

NO_x, SO_2, $PM_{2.5}$, and PM_{10} emissions. Our conclusions based on these scenarios demonstrate the necessity for appropriate environmental regulations in Handan.

(2) In the heavy industry sector, different life cycle environmental impacts regarding thermal power generation, solar power generation, and biomass power generation were assessed. In the transport sector, automobile life cycle assessment was conducted as well as a comparison between the traditional vehicles, hybird vehicles, and 100% electric vehicles. In the construction sector, the life cycles of traditional buildings and green buildings were compared.
As far as saving of energy, analysis results show that maximum energy saving can obtained in IIC scenario, at 14,100,000 tons for standard coal consumption with efficiency rate of 12.58 % in 2017; and in 2020, 13,810,000 tons standard coal consumption at efficiency rate of 10.65%. The implementation of new energy policies in the transport sector results in energy-saving potential of 79,454.40 tons standard coal equivalent with efficiency rate of 16.92 % – thus, this study recommends increasing investments (in which new energy automobiles occupies 25% of the automobiles) in new energy automobiles. Data for the construction sector can be divided in two parts: construction and operation. Promoting green construction policies (in which green construction occupies 50% of new buildings,) has the potential to save energy up to 667 thousand tons standard coal equivalent at efficiency rate of 10.01%.

(3) As far as reduction of emissions, for the industry sector, the integrated control showed the best results: 27,900,000 tons CO_2 emission reduction at a rate of 12.19 % during the study period. $PM_{2.5}$, PM_{10}, NO_x, and SO_2 reduction rates were 12.39%, 11.58%, 12.49%, and 10.65% for the same period, respectively. In the transport sector, there was a 191,000 ton CO_2 emission reduction at a rate of 18.49% over the study period. SO_2, NO_x, $PM_{2.5}$, PM_{10} reductions reached 394, 0, 4.55, and 9.06 tons, respectively, at reduction rates of 18.31%, 0.00%, 14.74%, and 15.23%. In the construction sector, though green construction emissions are, in fact, higher than traditional construction emissions, there is a 1,700,000 ton reduction in CO_2 during the usage phase at a rate of 14.76%.The reduction rate of SO_2, $PM_{2.5}$, and PM_{10} were about 17.60% combined . The combined emission reduction of both phases, in a green building, brought CO_2 down by 1,249,000 tons, SO_2 by 727 tons, and $PM_{2.5}$ by 81.2 tons.

(4) The heavy industrial sector in Handan contributed more to energy consumption and emissions than other sectors because of the city's unique structure – industrial energy consumption in Handan reached a staggering 98% of the total. For this reason, the industrial sector must be the focus of the majority of energy-saving and emission reduction strategies.

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Modelling Sustainability of the Urban Mobility System and its impact on Energy System

Nibedita Dash[1] and P. Balachandra[2]

[1]Research Student Department of Management Studies, Indian Institute of Science, Bangalore, India
[2]Principal Research Scientist, Department of Management Studies, Indian Institute of Science, Bangalore, India

Abstract
Increasing urbanization, in terms of growth in population as well as geographical spread, in the developing has significant implications for the transport sector. The implications are manifested as two important indicators – increases in traffic volume and energy consumption. The energy resource constraints, threat of climate change and infrastructure inadequacies have transformed the above two into serious challenges and thus needing immediate attention of the planners and policy makers. Adding to the above challenges, recent times have witnessed creation of more sub-urban centres with dispersed activities and hence requiring increased travel needs with higher traffic volumes. However, there is inadequate research in understanding the casual interactions among various agents (or sub-systems) of an urban system in relation to transport system, its impact on energy system and consequently on the sustainability of the system as a whole.

In this paper, we have made an attempt to study such interactions by dividing the urban system into numerous sub-systems, linking these with mobility (or transport) sub-system and then analyzing its combined effect on energy system. The conceptual framework is developed on the premises that each subsystem will have an input, an output and an interaction phase and these can be modeled (or represented) through indicators. Further, these indicators have been mapped into three standard dimensions of sustainability, namely, social, economic and environmental. Appropriate indicators are chosen to represent the three dimensions as well as the above three phases. The framework has been validated for the urban system of the city of Bangalore in India. The extent of sustainability in each dimension is assessed by simulating the cause-effect relations among the indicators. Each subsystem is tested against sustainability within itself and in interaction with other subsystems. Overall measure of urban system sustainability is established by identifying the combined cause-effect relationship among indicators of each subsystem with the energy system. This paper contributes in developing new understanding of the underlying role of urban system dynamics on the sustainability of the mobility subsystem and thereby on the energy system.

1. Introduction

Indian cities face the huge challenge of meeting the rapidly growing urban mobility demand as a consequence of high urbanization in a low carbon and sustainable manner. To guide the cities to move towards the sustainable mobility path, the Government of India is implementing its National Urban Transport Policy (NUTP) that advocates planning for the 'movement of people, not vehicles'. The successful implementation of the Policy requires cities to develop robust sustainable mobility plans, which call for capacity and expertise that most cities lack. Given the lack of understanding in the nature of vicious loop of urbanization and motorization leading to 'sustainable' mobility plans, it becomes necessary to provide a framework that incorporates different dimensions of an urban system , their dynamics and how best that can be addressed.

The current pattern of urban transport growth in most developing countries is marked by an explosive growth of personal vehicles and declining share of public and non-motorized transport leading to traffic congestion, road accidents, air and noise pollution, growing dependence on fossil fuels and increasing CO_2 emissions. Indian

[1]Corresponding Author: e-mail: nivedita44@gmail.com; ndash710@mgmt.iisc.ernet.in
[2]patilb@mgmt.iisc.ernet.in

cities are no exceptions. Rapid urbanization, rising per capita incomes, growing aspirations and sprawling cities have resulted in transport demand increasing at a rate much faster than the rate of growth of transport infrastructure. Cities are witnessing an exponential increase in the use of personal transport and a steady decline in the modal share of public transport and non-motorized transport. There has been a growing realization, bothinternationally and nationally, that the current unsustainable trends in urban transport should be arrested and urban transport placed on a low carbon and sustainable path. Several international for a like the SLOCAT, the recently concluded United Nations Conference on Sustainable Development, 2012 (Rio+20), etc. have highlighted the challenges associated with meeting urban mobility demand in a sustainable manner.

In light of this realization that urban transport /mobility is unsustainable, the present work attempts to understand the underlying factors that affect mobility in a urban dynamic system and how best it can be represented using an indicator framework. We have validated this framework for the urban mobility system of Bangalore city in India. This framework could further form the basis to analyze sustainable policies across all domains of an urban system and provide direction to government initiatives like NUTP in making Indian cities sustainable.

2. Literature review

2.1 Sustainability and Residential Subsystem

In the context of sustainable mobility, the urban system may be considered as a closed system with many subsystems in interaction with mobility subsystem. In the present study, we have limited the scope to the study of interaction between residential and mobility subsystems. Many studies have shown the effects of the built environment on travel demand, and they have analysed the impact of city size, density and mixed land use in cities and towns, the supply of public transport and the structure of the urban system. Several aspects of the residential environment were taken into consideration, not only at the macro scale, but also at the micro scale (that is, neighbourhood and activity centre). These studies have explored the effect on travel behaviour of residential and employment densities within neighbourhoods or activity centres (Ewing *et al.*, 1994; Frank and Pivo, 1994), land-use mix (Cervero, 1989; Ewing *et al.*, 1996), micro-accessibility (for example, Kitamura *et al.*, 1997; Handy, 1992) and design (Hess *et al.*, 1999; Cervero and Kockelman, 1997). Comprehensive reviews on this can be found in Anderson *et al.* (1996), Badoe and Miller (2000), Crane (1999), Ewing and Cervero (2001), Handy (1996), Steiner (1994) and Stead *et al.* (2000). Levinson and Kumar (1997) found that after controlling for available opportunities, transport infrastructure and the socioeconomic and socio-demographic characteristics of the residents, there is a positive relationship for automobile and transit commuters between metropolitan residential density and average commuting distance.

2.2 Indicator Based Framework

Sustainability in the current study is addressed using indicator based framework. Indicators are tools that measure performance of any given system under which it is created and in the process of urban sustainability assessment there is a need for measurable indicators to ascertain sustainability quantitatively. Several approaches to assess urban sustainability based on indicators have been developed. Ugwu and

Haupt (2007) examined available techniques for evaluating different aspects of sustainability through the use of indicators. Munda, 2001; Li et al, 2009 ; Litman, 2009a; Litman, 2009b; Castillo, 2009; Mascarenhas et al., 2010; Miranda F, 2012; Yigitcanlar, 2010) have contributed by studying different approaches for selecting urban sustainability indicators and urban mobility indicators. There are many applications of a composite index or multivariate indicators to local or regional contexts as case studies (Ferrarini et al.,2001; Graymore et al.,2009; Kondyli,2010; Lee,2007; Mascarenhas et al.,2009; van Dijk and Mingshun,2005; Doody et al. ,2009; Donatiello G.,2001; Marzukhi, 2011;).

3. Framework Measuring Sustainable Index

Drawing motivation from these studies, the present problem is framed to consist of residential and mobility subsystems in an urban setup. Indicator based approach is used to determine the sustainability of residential and mobility system individually and the urban system as a whole. Each subsystem here is considered to consist of input, interaction and output phase. Each of these phases are considered for three dimensions of sustainability social, economic and environmental., each phase being represented by suitable indicators. Sustainability is determined for each dimension under each phase and then overall subsystem sustainability is ascertained adopting following steps.

3.1 Normalization

Usually the indicators considered for study are in different units of measurement. To enable comparison on the same scale it is required to convert them to a single unit of measurement. Thus, for each of the indicator included for each subsystem, a relative indicator is estimated by min-max method of normalization using the actual indicator value and the threshold values for the said indicator. The actual as well as threshold values of minimum and maximum areobtained from secondary sources.

$$RelativeValue = \frac{ActualValue - MinimumValue}{MaximumValue - Minimumvalue}$$

The actual value for a given indicator is obtained for Bangalore city and threshold values for the same indicator are obtained from values of different Indian cities. The city having a maximum value for a given indicator is used as an upper threshold for that indicator. Similarly, the city with lowest value forms a lower threshold for a given indicator. Thus, for every indicator, there would be three values – actual (Bangalore city), maximum (city with highest value) and minimum (city with lowest value).

The next step is to derive the composite dimensional index from appropriate indicators belonging to that particular dimension. Displaced ideal method is used for developing dimensional sustainability index for each subsystem. Finally the overall subsystem sustainability measure is obtained as a geometric mean of individual dimensional sustainability index values.

3.2 Displaced Ideal

Displaced ideal method is used to aggregate overall sustainability index for each dimension. It is based on the concept that a better system should have less distance from the ideal (Zeleny 1982). Additive inverse of the normalized Euclidean distance from the ideal gives

$$CompositeIndex = 1 - (\sqrt{}((1-h)^2 + (1-e)^2 + (1-y)^2)/\sqrt{3}),$$

where $(\sqrt{}((1-h)^2 + (1-e)^2 + (1-y)^2)/\sqrt{3})$ is the Euclidean distance from the ideal. $h$represents subsystem input sustainability index, *e* represents subsystem interaction sustainability index and y represents subsystem output sustainability index. Dividing the same with $\sqrt{3}$ normalizes it in three –dimensional space. Thus for country j, the lower the distance from ideal, the higher the index value (Mishra 2013).

3.3 Geometric Aggregation

Finally the overall subsystem sustainability is obtained as a geometric mean of individual dimensional sustainability index since geometric mean giver higher importance to the dimension having lower performance and hence penalizes unbalanced development. This helps in compensating good and bad indices under each subsystem.

The LA method of aggregation which implies perfect substitutability was criticized in literature for not being appropriate (Desai, 1991; Hopkins, 1991; Palazzi and Lauri, 1998;Sagar and Najam, 1998; Raworth and Stewart, 2003; Mishra and Nathan, 2008; Nathan *et al*., 2008; Herrero *et al*., 2010a). Perfect substitutability means, “that no matter how bad thehealth state is, it can be compensated with further education or additional income, *at aconstant rate*, which is not very natural” (Herrero *et al*., 2010a). According to Sagar and Najam (1998: 251), masking of trade-offs between various dimensions suggests that “a reductionist view of human development is completely contrary to the UNDP’s own definition.” Acknowledging this limitation, in the 20th anniversary edition of human development report (UNDP, 2010), the aggregation method shifted to geometric mean (GM).

Mathematically, Sustainability Index Geometric Mean =(h×e×y)1/3

Geometric mean does not allow for perfect substitutability, gives higher importance to the dimension having lower performance, and penalizes unbalanced development (Gidwitz*etal*., 2010; Herrero *et al*., 2010b; Kovacevic and Aguña, 2010).

Since the present work involves understanding sustainability, thereby improving the dimension with lower performance value to balance the lack of it, geometric aggregation is used as an ideal method of aggregation of each dimensional index to an overall index

3.4 Determination of Weights

Since energy use and emissions are direct outcome of an unsustainable system, urban sustainability is measured against energy subsystem. This helps in determining sustainability performance of each subsystem with respect to energy subsystem. In this case, the urban system is like a black box with each subsystem like residential, employment and mobility as input to it and energy subsystem as output. Efficiency of each subsystem against energy subsystem reflects the degree of sustainability of the concerned subsystem.

Construction of weights is performed using Data envelopment analysis(DEA). DEA is developed by Charnes et al (1978) has been universally recognized as a useful tool of performance assessment. The method calculates an entity's efficiency based on the maximum outputs that a decision making unit is able to produce with a given set of inputs or based on its ability to produce a given set of outputs using the least amount of inputs. The method is useful in assessing the performance of decision making units such as transit systems, schools, and hospitals for whom performance may not be measured only in terms of financial performance or profits earned.

Relative efficiency is measures as

$$Efficieny = \frac{weightedsumofoutputs}{weightedsumofinputs}$$

$$Efficiencyofeachcity = \frac{\sum w_0\, y_0}{\sum w_i\, x_i}$$

Where w_0 = weight assigned to output variable y_0
y_0= amount of output variables
w_i = weight assigned to input variable xi
xi = amount of input variables

Present work uses DEA CCR model developed by Charnes, Cooper and Rhodes (1978). For any special DMUs, the CCR model with constant return to scale can be formulated as follows to obtain a score of technical efficiency:

$$MaximizeW_0 = \sum U_r\, Y_{rjo}$$

$$Subjectto \sum_i V_i\, X_{ijo} = 1$$

$$\sum_r U_r\, Y_{rj} - \sum_i V_i\, X_{ij} \leq 0, j = 1, \ldots..n$$

$$U_r \geq \in, r = 1, \ldots.s$$

$$V_r \geq \in, i = 1, \ldots..m$$

4. Urban System Sustainability

The sustainability levels for each urban subsystem was obtained for each dimension of sustainability and the main observation was sustainability does not completely depend on input, interaction or output indicators, but on the dynamic interaction of these indicators.

Urban system sustainability is obtained as a weighted average of individual subsystem sustainability. It is given as follows

$$OverallUrbanSystemSustainability = \frac{w_1 * residentialsustainability + w_3 * Mobilitysustainability}{2}$$

W_1 = weight of residential subsystem

W_2 = weight of employment subsystem

5. Results-

This section summarizes all the results obtained for the formulated problem. Section 5.1 summarizes results from data envelopment analysis.

5.1 DEA Results

The tables below summarizes the result obtained from DEA analysis of residential and mobility subsystem against energy subsystem.

Table 5.1.1 Residential Subsystem Efficiency

Residential social subsystem efficiency	0.665
Residential economic subsystem efficiency	0.723
Residential environmental subsystem efficiency	0.316

The residential social subsystem is found to be efficient at 66.5 percent against the energy system, i.e., it lies at a distance of 0.66 from the efficient frontier. Similarly residential economic subsystem and residential environmental subsystem lie at a distance of 0.723 and 0.8 from the efficient frontier and are 72.3 percent and 80 percent efficient. Thus the social dimension is less sustainable compared to economic and environmental. Though economic and environmental still contain the capacity to be sustainable, with deteriorating values in future they might further affect sustainability.

Table5.1. 2Transport/Mobility Subsystem efficiency

Mobility social subsystem efficiency	1
Mobility economic subsystem efficiency	0.918
Mobility environmental subsystem efficiency	0.124

CRS efficiency for mobility subsystem at social dimension lies on the frontier and is completely sustainable at 100 percent. Economic sustainability of mobility in terms of cost per kilometer of travel for both public and private transport and fuel efficiency is sustainable at 91 percent. However the environmental sustainability is worst at 12.4 percent. Thus environmental dimension mobility subsystem must be improved to improve overall sustainability

5.2 Residential Subsystem Sustainability-

Table 5.2.1 Residential Sustainability Index

Dimension of Sustainability		**Dimensional Index Value at Input-Interaction-Output**	**Dimensional Index value-without weights**	**Dimensional Index value-with weights**
	Residential social input index	0.4		

Residential social sustainability index	Residential social interaction index	0.61	0.49	0.33
	Residential social output index	0.4		
Residential economic sustainability index	Residential economic input index	0.28	0.51	0.37
	Residential economic interaction index	0.45		
	Residential economic interaction index	0.73		
Residential environmental sustainability index	Residential environmental input index	0.2	0.84	0.27
	Residential environmental interaction index	0.43		
	Residential environmental output index	0.3		
Overall residential sustainability index			0.6	0.32

Residential social sustainability index is obtained at 0.49 and at 0.33 with weight consideration on a sustainability scale of 1. Similarly residential economic sustainability index and residential environmental sustainability index is 0.51 and 0.84 without weight consideration and 0.37 and 0.27 with weights respectively. Also overall residential sustainability index is determined as 0.6 and 0.32 with weight and without weight respectively. This clearly suggests residential subsystem affects sustainability in three dimensions and shows a clear difference in values when measures against energy system. Thus it may be concluded that for the present study residential subsystem is important when considering sustainability analysis of urban system.

5.3Mobility Subsystem Sustainability-

Table 5.3.1 Mobility Sustainability Index

Dimension of Sustainability		**Dimensional Index Value at Input-Interaction-Output**	**Dimensional Index value-without weights**	**Dimensional Index value-with weights**
Mobility social sustainability index	Mobility social input index	0.4	0.50	0.5
	Mobility social interaction index	0.47		
	Mobility social output index	0.65		
Mobility economic sustainability index	Mobility economic input index	0.46	0.47	0.43
	Mobility economic interaction index	0.63		
	Mobility economic output index	0.36		
Mobility environmental sustainability index	Mobility environmental input index	0.79	0.56	0.069
	Mobility environmental interaction index	0.34		
	Mobility environmental output index	0.68		
Overall Mobility sustainability index			0.51	0.5

Mobility sustainability index does not show much change for its values determined with and without weights. For both cases it is reported at 0.5 on a scale of 1. However it is noted that mobility environmental sustainability index is reported much lower at 0.069 suggestive that environmental dimension of mobility subsystem is unsustainable compared to the other two dimensions and is reflected when compared against energy subsystem. Thus social dimension and economic dimension of mobility are still considerable, the environment dimension like emission and use of natural resources are not much sustainable and in this case effort must be directed towards improving environmental sustainability of mobility.

6.Overall Urban System Sustainability Results

Table 6.Summary of Sustainability Indices

Urban Subsystem & Overall Sustainability Index	Dimensional Index value-without weight	Dimensional Index value-with weights
Overall residential sustainability index	0.6	0.32
Overall Mobility sustainability index	0.51	0.5
Overall urban sustainability	0.56	0.41

As observed overall urban sustainability is 0.56 without weight and 0.41 with weight consideration. This suggests in the present context of study, each subsystem considered plays a crucial role in overall sustainability analysis. With the current set of indicators considered for the residential subsystem, it shows a significant difference in sustainability index when considered with and without weight for each dimension and the overall all index value. But mobility subsystem does not show much difference for the current set of indicators chosen for this study, except the environmental dimension of mobility. Thus it is evident that an urban system may be sustainable in one of its subsystem, but may be unsustainable in other. But since each subsystem affects the entire urban system the un-sustainability in one subsystem is reflected in the overall urban sustainability.

6. Conclusion

The current study suggests that urban sustainability is a function of sustainability of each individual subsystem. Any change in sustainability in one subsystem is reflected in the overall sustainability index. Any change in one dimension of a subsystem can affect overall sustainability index. Also it observed that for the present urban setup residential subsystem is not sustainable when measured against energy subsystem and it must be further investigated in the analysis to improve the index value. Mobility subsystem though measures well in social and economic dimension for the present work, it must be further analyzed to see if the relationship is same over other similar types of cities with same indicators.

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Decomposition Analysis on Energy-related Carbon Emission of Transportation Industry in Beijing

Fengyan Fan[1,2] , Yalin Lei[1,2,*]

[1] School of Humanities and Economic Management, China University of Geosciences, Beijing, 100083, China

[2] Key Laboratory of Carrying Capacity Assessment for Resource and Environment, Ministry of Land and Resource, Beijing, 100083, China

Abstract: Transportation industry is one of the main driving forces of energy consumption, especially oil consumption. Urban traffic control is the key to building a low carbon emission city. In the process of Beijing's rapid development of urbanization, how to reduce carbon emissions, the potential factors identification of carbon emissions in transportation industry is an important prerequisite to control carbon emissions. Based on generalized Fisher index (GFI) approach, a decomposition model of energy-related carbon emissions in the transportation sector of Beijing is established. This model is adopted to analyze the influence of energy structure, energy intensity, transport efficiency, transport intensity, economic growth and population size on carbon emissions from 1995-2012 in the transportation sector of Beijing. Compared to previous studies, this method eliminates the decomposition residuals, in comparison with other five kinds of index decomposition approaches, Generalized Fisher index(GFI) has better decomposition characteristics (Ang, 2004). The results show that the trend of traffic carbon emissions in Beijing is upward, after 2003, the trend is evident. The main positive drivers of carbon emissions in transportation sector are economic growth, energy intensity and population size. Sustained growth in economic output of Beijing is the dominant factor in the growth of carbon emissions, the cumulative contribution reaches 334.46%; transport intensity is the main factor that restrains carbon emissions, and the inhibition shows an increasing trend. The contribution rate of transport efficiency on carbon emissions appears as flat "m", which plays a pulling effect on carbon emissions on the whole but an inhibition effect between 2001 and 2005. Energy structure plays a certain inhibition effect on carbon emission, however, the inhibition is not obvious. In order to further suppress the growth of carbon emissions in transportation Beijing government should not only adjust the mode of economic development and appropriately control population size but also improve operational efficiency and energy efficiency in transportation sector and optimize energy structure of consumption in transportation.

Keywords: Transportation industry; Carbon emissions; Generalized Fisher index(GFI); Decomposition analysis; Beijing

1. Introduction

Strengthen energy-saving and emission-reduction in transportation industry has become an inevitable choice to relax the tension of energy supply, the pressure of environmental capacity and build low-carbon ecological city. Beijing as an international metropolis, urban transport carbon emissions continue to grow along with the increasing expansion of urban space and the increased car ownership. The analysis of key factors affecting urban traffic carbon emissions and their influence degree has important significance for the promotion of low-carbon transport development in Beijing and other typical cities.

2. Literature Review

Increased traffic carbon emissions has become an important factor restricting the sustainable development of global economy, which has attracted worldwide attention. Many scholars have done some useful attempts on the influencing factors of carbon emissions in the transportation sector. Mishalani et al.(2014) presented a model of CO_2 emissions per capita as a function of various explanatory variables using data on 146 urbanized areas in the United States and analyzes the factors influencing CO_2 emission associated with passenger travel. Similarly, Lu et al. (2007), Lakshmanan(1997), Kwon(2005) et al. adopted different methods to analyze the influencing factors of traffic carbon emissions.

Currently, research on the influencing factors of transport carbon emissions in China and various provinces is less in academic field. Wang et al.(2011) applied LMDI (logarithmic mean Divisia index) method to find the nature of the factors those influence the changes in transport sector CO_2 emissions. Wang&Liu(2014) examined the impacts of individual travel behavior on carbon emissions from urban transport.

Overall, Index decomposition method are applied on traffic emissions factors by most current research. Ang et al.(2004) compared the generalized Fisher index (GFI) method with five widely known IDA methods and point out the generalized Fisher index (GFI) can eliminate the decomposition residuals, with better decomposition characteristics.

In the existing literature, scholars adopt different countries as research objects, analyzing the influencing factors of traffic carbon emissions, due to regional differences, the existing research conclusions cannot fully explain the actual situation in Beijing. At the same time, most of the scholars in the use of factor decomposition analysis does not combine industry characteristic. In view of this, based on the extended Kaya indentity, we adopted the generalized Fisher index (GFI) decomposition method to analyze the influencing factors of traffic carbon emissions during 1995-2012 in Beijing, in order to build low carbon traffic system, achieve sustainable economic and social development and provide data to support decision making.

3. Methodology

In this paper, we extended the KAYA identity and analyzed various factors on traffic carbon emissions in Beijing by using the generalized Fisher index method.

3.1The extended KAYA identity

The Kaya identity was proposed by the Japanese scholar Yoichi Kaya (Kaya, 1990) for the first time at an IPCC workshop. The expression is:

$$C = (C/E)(E/GDP)(GDP/P)P \qquad (3\text{-}1)$$

The Kaya identity related energy-related carbon emissions with energy (E), economic development level (GDP) and population (P). Its structure is relatively simple, so we added energy structure as a factor to the Kaya identity, combined with the characteristics of the transport sector, further expand Beijing's traffic emissions as:

$$C = \sum_i C_i = \sum_i \frac{C_i}{E_i}\frac{E_i}{E}\frac{E}{GDP_{tr}}\frac{GDP_{tr}}{V}\frac{V}{GDP}\frac{GDP}{P}P \qquad (3\text{-}2)$$

Among them, GDP_{tr} on behalf of GDP in the transportation industry; V represents traffic turnover; C_i/E_i is the carbon emissions of the ith fuel type, namely the carbon emissions coefficient; E_i/E represents the total energy consumption share of the ith fuel type, namely energy structure; E/GDP_{tr} is energy consumption per unit GDP in the transportation industry, namely energy intensity; GDP_{tr}/V represents the value of GDP brings by per unit transport turnover, reveals transportation efficiency to a certain extent; V/GDP represents traffic turnover per unit of GDP, defined as the transport intensity; and Y/P represents the per capita GDP, namely economic output. Thus, the change in carbon emissions is decomposed into the following factors: carbon emissions efficiency, energy structure, energy intensity, transport efficiency, transport intensity, economic output and population.

3.2 Generalized Fisher index (GFI) decomposition

Ang and Liu extended the traditional two-factor Fisher index method to multi-factor analysis, proposed the generalized Fisher index method (Generalized Fisher Index, GFI). The specific steps are as follows:

V is the total index is composed of n elements, so

$$V = \sum_i X_1 X_2 \cdots X_n \qquad (3\text{-}3)$$

Define the set N={1,2,⋯,n} where the cardinality of N is n. S is a subset of N, for which the cardinality is s'. Define a function V（S）=$\sum(\prod_{l\in S} X_l^T \prod_{m\in N\backslash S} X_m^0)$ and V（Φ）=$\sum(\prod_{m\in N} X_m^0)$ where Φ is a null set and superscripts denote the current year T and the base year 0. According to the “geometric average” principle, V^T/V^0 is divided into n parts, and the decomposition results of factor Xj (j=1, 2,⋯, n) are given by:

$$D_{X_j} = \prod_{\substack{S\subset N\\ j\in S}} \left[\frac{V(S)}{V(S\backslash\{j\})}\right]^{\frac{1}{n}\cdot\frac{1}{\binom{n-1}{s'-1}}} = \prod_{\substack{S\subset N\\ j\in S}} \left[\frac{V(S)}{V(S\backslash\{j\})}\right]^{\frac{(s'-1)!(n-s')!}{n!}} \qquad (3\text{-}4)$$

D_{X_j}（j=1，2，⋯，n）is the decomposition factor of the generalized Fisher index method.

According to the above method, formula (3-3) is defined as follows: the energy-related carbon emissions coefficient $X_{1i}=C_i/E_i$, energy structure $X_{2i}=E_i/E$, energy intensity $X_3=E/GDP_{tr}$, transport efficiency$X_4=GDP_{tr}/V$, transport intensity$X_5=V/GDP$, economic development $X_6=GDP/P$, and population size $X_7=P$. Thus, the carbon emissions formula can be written as:

$$C = \sum_i C_i = \sum_i \frac{C_i}{E_i}\frac{E_i}{E}\frac{E}{GDP_{tr}}\frac{GDP_{tr}}{V}\frac{V}{GDP}\frac{GDP}{P}P = \sum_i X_{1i}X_{2i}X_3X_4X_5X_6X_7 \qquad (3\text{-}5)$$

Generally speaking, the carbon emissions coefficients of all types of fossil fuels X_{1i} are fixed; therefore, the factors impacting traffic carbon emissions in Beijing are mainly energy structure, energy intensity, transport efficiency, transport intensity, economic development and population size. Its change can be decomposed into:

$$C^T/C^0=D_{X_1}D_{X_2}D_{X_3}D_{X_4}D_{X_5}D_{X_6} \qquad (3\text{-}6)$$

In equation (11), C^T is the carbon emissions in year T; C^0 is the carbon emissions in the base year; $D_{X_1}$is energy structure, X_1 is the product of the energy consumptions structure (E_i/E) and corresponding carbon emissions coefficients (C_i/E_i), D_{X_2} is energy intensity，D_{X_3} is transport efficiency, D_{X_4} is transport intensity, D_{X_5} is economic development, and D_{X_6} is population size. Among them：

$$D_{X_1}=\left[\frac{\sum_i X_{1i}^T X_2^0 X_3^0 X_4^0 X_5^0 X_6^0}{\sum_i X_{1i}^0 X_2^0 X_3^0 X_4^0 X_5^0 X_6^0}\right]^{\frac{1}{6}}\left[\begin{array}{l}\frac{\sum_i X_{1i}^T X_2^T X_3^0 X_4^0 X_5^0 X_6^0}{\sum_i X_{1i}^0 X_2^T X_3^0 X_4^0 X_5^0 X_6^0}\cdot\frac{\sum_i X_{1i}^T X_2^0 X_3^T X_4^0 X_5^0 X_6^0}{\sum_i X_{1i}^0 X_2^0 X_3^T X_4^0 X_5^0 X_6^0}\\ \cdot\frac{\sum_i X_{1i}^T X_2^0 X_3^0 X_4^T X_5^0 X_6^0}{\sum_i X_{1i}^0 X_2^0 X_3^0 X_4^T X_5^0 X_6^0}\cdot\frac{\sum_i X_{1i}^T X_2^0 X_3^0 X_4^0 X_5^T X_6^0}{\sum_i X_{1i}^0 X_2^0 X_3^0 X_4^0 X_5^T X_6^0}\\ \cdot\frac{\sum_i X_{1i}^T X_2^0 X_3^0 X_4^0 X_5^0 X_6^T}{\sum_i X_{1i}^0 X_2^0 X_3^0 X_4^0 X_5^0 X_6^T}\end{array}\right]^{\frac{1}{30}}$$

$$\cdot\left[\begin{array}{l}\frac{\sum_i X_{1i}^T X_2^T X_3^T X_4^0 X_5^0 X_6^0}{\sum_i X_{1i}^0 X_2^T X_3^T X_4^0 X_5^0 X_6^0}\cdot\frac{\sum_i X_{1i}^T X_2^T X_3^0 X_4^T X_5^0 X_6^0}{\sum_i X_{1i}^0 X_2^T X_3^0 X_4^T X_5^0 X_6^0}\cdot\frac{\sum_i X_{1i}^T X_2^T X_3^0 X_4^0 X_5^T X_6^0}{\sum_i X_{1i}^0 X_2^T X_3^0 X_4^0 X_5^T X_6^0}\\ \cdot\frac{\sum_i X_{1i}^T X_2^T X_3^0 X_4^0 X_5^0 X_6^T}{\sum_i X_{1i}^0 X_2^T X_3^0 X_4^0 X_5^0 X_6^T}\cdot\frac{\sum_i X_{1i}^T X_2^0 X_3^T X_4^T X_5^0 X_6^0}{\sum_i X_{1i}^0 X_2^0 X_3^T X_4^T X_5^0 X_6^0}\cdot\frac{\sum_i X_{1i}^T X_2^0 X_3^T X_4^0 X_5^T X_6^0}{\sum_i X_{1i}^0 X_2^0 X_3^T X_4^0 X_5^T X_6^0}\\ \cdot\frac{\sum_i X_{1i}^T X_2^0 X_3^T X_4^0 X_5^0 X_6^T}{\sum_i X_{1i}^0 X_2^0 X_3^T X_4^0 X_5^0 X_6^T}\cdot\frac{\sum_i X_{1i}^T X_2^0 X_3^0 X_4^T X_5^T X_6^0}{\sum_i X_{1i}^0 X_2^0 X_3^0 X_4^T X_5^T X_6^0}\cdot\frac{\sum_i X_{1i}^T X_2^0 X_3^0 X_4^T X_5^0 X_6^T}{\sum_i X_{1i}^0 X_2^0 X_3^0 X_4^T X_5^0 X_6^T}\\ \cdot\frac{\sum_i X_{1i}^T X_2^0 X_3^0 X_4^0 X_5^T X_6^T}{\sum_i X_{1i}^0 X_2^0 X_3^0 X_4^0 X_5^T X_6^T}\end{array}\right]^{\frac{1}{60}}$$

$$\cdot\left[\begin{array}{l}\frac{\sum_i X_{1i}^T X_2^T X_3^T X_4^T X_5^0 X_6^0}{\sum_i X_{1i}^0 X_2^T X_3^T X_4^T X_5^0 X_6^0}\cdot\frac{\sum_i X_{1i}^T X_2^T X_3^T X_4^0 X_5^T X_6^0}{\sum_i X_{1i}^0 X_2^T X_3^T X_4^0 X_5^T X_6^0}\cdot\frac{\sum_i X_{1i}^T X_2^T X_3^T X_4^0 X_5^0 X_6^T}{\sum_i X_{1i}^0 X_2^T X_3^T X_4^0 X_5^0 X_6^T}\\ \cdot\frac{\sum_i X_{1i}^T X_2^T X_3^0 X_4^T X_5^T X_6^0}{\sum_i X_{1i}^0 X_2^T X_3^0 X_4^T X_5^T X_6^0}\cdot\frac{\sum_i X_{1i}^T X_2^T X_3^0 X_4^T X_5^0 X_6^T}{\sum_i X_{1i}^0 X_2^T X_3^0 X_4^T X_5^0 X_6^T}\cdot\frac{\sum_i X_{1i}^T X_2^T X_3^0 X_4^0 X_5^T X_6^T}{\sum_i X_{1i}^0 X_2^T X_3^0 X_4^0 X_5^T X_6^T}\end{array}\right]^{\frac{1}{60}}$$

$$\cdot\left[\frac{\sum_i X_{1i}^T X_2^T X_3^T X_4^T X_5^T X_6^0}{\sum_i X_{1i}^0 X_2^T X_3^T X_4^T X_5^T X_6^0}\cdot\frac{\sum_i X_{1i}^T X_2^T X_3^T X_4^T X_5^0 X_6^T}{\sum_i X_{1i}^0 X_2^T X_3^T X_4^T X_5^0 X_6^T}\cdot\frac{\sum_i X_{1i}^T X_2^T X_3^T X_4^0 X_5^T X_6^T}{\sum_i X_{1i}^0 X_2^T X_3^T X_4^0 X_5^T X_6^T}\right]^{\frac{1}{30}}$$

$$\cdot\left[\frac{\sum_i X_{1i}^T X_2^T X_3^T X_4^T X_5^T X_6^T}{\sum_i X_{1i}^0 X_2^T X_3^T X_4^T X_5^T X_6^T}\right]^{\frac{1}{6}} \qquad (3\text{-}7)$$

And so on, D_{X_2}、D_{X_3}、D_{X_4}、D_{X_5}、D_{X_6} can be obtained by formula (3-4) .

4.Data

4.1 Carbon emission calculation

According to the IPCC Guidelines for National Greenhouse Gas Inventories of 2006, carbon emissions from energy consumption follow the following calculation:

$$C_t=\sum_{i=1}^{9} E_{it} B_i F_i \qquad (4\text{-}1)$$

In equation (4-1), C_t is the carbon emissions caused by energy consumption in year t, E_{it} is the ith fuel type in year t, B_i is the coefficients of the ith fuel type converted to standard coal, and F_i represents the carbon emission coefficient of the ith fuel type derived from the default value from the IPCC carbon emissions calculation guidelines. The original data used J as a unit, but for consistency with the statistical data, we converted energy into standard coal, where the specific transformation coefficient is 1kg standard coal equal to 2.93 x 10^4 kJ.

In the above parameters, B_i is derived from the appendix 4 of the 2013 China Energy Statistical Yearbook. The selection of fuel types references energy consumption data in transport industry from Beijing's energy balance tables, including coal, gasoline, kerosene, diesel, fuel oil, liquefied petroleum gas, natural gas, heat and electricity. Consistent with most scholars (Yang, 2014), we believe that heat and electricity do not directly generate carbon emissions.

4.2 Data resources

Various energy consumption data in the model were collected from previous China Energy Statistical Yearbooks, economic data from past Beijing Statistical Yearbooks. The sample data span the period from 1995 to 2012, and the statistical data are given at current prices. To eliminate the impact of price fluctuations, the GDP was converted into the 1995 price according to the corresponding price.

5.Results and discussion

From the factors influencing carbon emissions in above formulas, we draw the decomposition results of changes in carbon emissions as shown in Table 5.1 and in Figure 1.

Tabel 5.1 Decomposition effect of carbon emissions from the transport sector in Beijing

Year	D_{X_1}	D_{X_2}	D_{X_3}	D_{X_4}	D_{X_5}	D_{X_6}	V
1995-1996	0.995	0.998	1.220	0.894	1.031	1.007	1.124
1996-1997	1.000	0.922	1.128	0.908	1.106	0.985	1.028
1997-1998	1.021	0.981	1.187	0.847	1.101	1.005	1.112
1998-1999	0.994	1.104	1.060	0.927	1.101	1.009	1.197
1999-2000	0.993	0.993	1.040	0.954	1.068	1.084	1.133
2000-2001	1.007	1.163	0.970	0.958	1.065	1.016	1.178
2001-2002	1.001	1.042	0.979	0.954	1.091	1.028	1.091
2002-2003	0.985	1.021	0.999	0.937	1.083	1.023	1.044
2003-2004	1.000	1.187	0.929	1.026	1.114	1.025	1.291
2004-2005	1.002	0.987	0.896	1.054	1.091	1.030	1.051
2005-2006	0.982	1.190	1.081	0.881	1.091	1.041	1.263
2006-2007	0.979	1.103	1.109	0.851	1.097	1.047	1.170
2007-2008	0.977	1.122	1.001	0.953	1.037	1.057	1.146
2008-2009	1.012	0.996	1.038	0.900	1.046	1.050	1.035
2009-2010	1.001	0.961	0.956	1.060	1.048	1.055	1.077
2010-2011	0.990	1.008	0.909	1.080	1.038	1.029	1.047
2011-2012	0.990	0.965	1.028	0.966	1.049	1.025	1.020
1995-2012	0.930	1.967	1.582	0.400	3.345	1.654	6.402

Note: V represents "Total Effect of traffic carbon emissions"

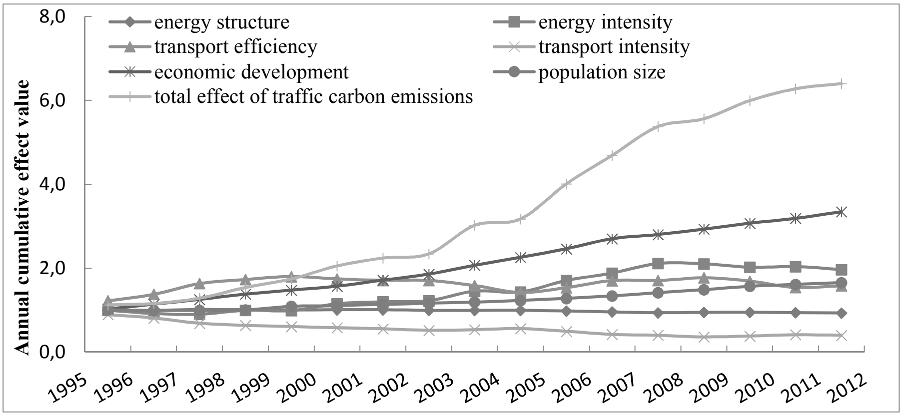

Fig 1 Influencing factors of traffic carbon emissions in Beijng from 1995 to 2012

From Table 2 and Figure 1, the total traffic carbon emissions in Beijing are growing. From 1995 to 2003, the total change in emissions was relatively stable, with an average annual growth rate of 11.79%. After 2003, with the accelerated process of city and the expansion of city scale, urban traffic carbon emissions of Beijing gradually increase, with an average annual growth rate of 17.73%. After 2008, along with the gradual implementation of energy-saving and emissions reduction, the growth rate of traffic carbon emissions tended to be stable again. The factors that played positive roles on traffic carbon emissions were economic development, energy intensity, population and transport efficiency, the cumulative contribution were 334.55%, 196.7%, 165.4% and 158.2%. The contribution of economic development to carbon emissions is far greater than that of other factors. It is the dominant factor in the growth of carbon emissions over the period 1995-2012. Energy intensity and population size basically play positive impact on traffic carbon emissions, but the degree of influence is weaker than economic growth. The contribution of transport efficiency on carbon emissions appears as flat “M”, Its influence on traffic carbon emissions is from positive to negative in 2000-2005 and 2009-2011. Transport intensity and energy structure play inhibitory effect on carbon emissions. The decreased of transport intensity has greater contribution to traffic carbon emissions. The contribution rate decreased from 0.894 in 1995 to 0.400 in 2012, this inhibition is further strengthening. Energy structure plays a negative effect on the whole, but the contribution is relatively small. This shows that the structure of energy consumption dominated by gasoline, diesel and other oil-based energy in transport sector has not changed but that natural gas, electricity and clean energy consumption are growing towards a benign direction. Between 1995 and 2003, the gap between the pulling factors and inhibition factors was smallest, and the total change in carbon emissions was stable. After 2003, the gap between the contribution rate of inhibition factors and pulling factors expanded. The contribution of the inhibiting factors was less than the pulling effects of economic development and other factors, which increased the total carbon emissions.

6.Suggestions

According to the above analysis, combined with the actual situation of Beijing’s transportation industry, we put forward the major policies of energy-saving and emissions reduction in Beijing’s transport sector:

(1) Deepen the tax reform, optimize energy consumption structure. Positively constructing a diverse, safe, clean, and efficient energy supply and consumption system, promoting the application and popularization of no- or low-carbon energy such as solar, wind, nuclear and tidal, and achieving the substitution of traditional fossil energy, will further ease

Beijing's traffic carbon emissions. At the same time, deepening the reform of resource tax, fuel tax and other tax system, increasing the subsidies of low-carbon technologies, promoting the development of natural gas and clean energy, will play a positive role on traffic carb carbon emissions reduction.

(2) Innovate management system, reduce energy intensity.In the future, Beijing should continue to reduce energy consumption per unit of GDP, establish a target responsibility system, and take a variety of approaches to accelerate the development of a low-carbon economy.Otherwise,constantly improve the management system, strengthen the traffic demand management by macroeconomic regulation and market economic means, realize the effective allocation of transport resources, will slow down the traffic emissions to a certain extent.

(3) Reduce transport intensity and improve transport efficiency.On one hand, pay attention to traffic infrastructure investment, balance traffic investment structure among different regions, improve transport efficiency. On the other hand, accelerate industrial upgrading and structural optimization, increase the added value of transport goods, effectively inhibit the growth of carbon emissions from transportation.

(4) Transform economic development mode, focus on environmental protection. we can adjust economic structure and transform economic development mode, making it to the direction of energy saving. Beijing should divert attention from a one-sided pursuit of economic growth to the pursuit of quality economic growth and environmental protection. gradually realize the industrial characteristic of high added value, low energy consumption and low carbon emissions, finally realize the harmonious development of economy, society and environment.

(5)Improve the quality of population, develop public transportation.The government should pay attention to optimizing the structure and the quality of population, and control the population to a scale in harmony with environmental capacity. At the same time, vigorously promote the concept of low-carbon transportation, optimizing the layout of urban traffic network, advocating residents to use public transport to control urban transport carbon emissions.

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Analysis of the influence of the implementation of electric vehicle in the environmental and acoustic pollution and in the electric demand of the city of Zaragoza

Angel A. Bayod-Rújula*, Eduardo García-Paricio

University of Zaragoza,Spain

Corresponding Author e-mail: aabayod@unizar.es

Abstract

The advantages of electric vehicles as a means of private transport make it an alternative to replace the internal combustion vehicle in the city. It's easy to find vehicle data about their noise and environmental pollution or energy consumption, but the effect in an urban environment requires a more complex study.

This paper analyzes the impact of the introduction of electric vehicles on noise and air pollution in the city as well as the influence on electrical load curves, focusing on the case of the city of Zaragoza, Spain. New software has been developed, which facilitates the estimation of environmental pollution before and after the replacement of vehicles for any Spanish city needing only readily available data.

Beginning from the different indicators of environmental pollution, noise and the current state and evolution of the electrical system; the variation of sound inmission is calculated from traffic data and measurements made on vehicles to estimate the noise impact of electric vehicles. The alteration of the electricity network due to vehicle recharges is evaluated by various hypotheses of charging methods. Emissions from internal combustion vehicles are estimated by the CORINAIR methodology so knowing pollutants from other urban activities; it is possible to know the effect of the substitution.

The PV power generation that it is necessary to install on the roofs of existing buildings in the area to reduce the emission of certain pollutants related to the electricity required for the vehicle recharging is also calculated.

With the simulation software the level of reduction of most environmental emissions, noise emission in the streets and alteration to the electrical grid of the highly probable introduction of electric traction vehicle in our towns is estimated in a quick and simple way.

On the road:
non-fossil fuel deployment for the public bus fleet of Sweden

Maria Xylia[1] & Semida Silveira[1]

[1] KTH Royal Institute of Technology, Stockholm, Sweden (Energy and Climate Studies Unit, Department of Energy Technology, School of Industrial Engineering and Management)

Corresponding Author e-mail: maria.xylia@energy.kth.se

Abstract

The public transport sector in Sweden has set a target to run 90% of its total vehicle-kilometers on renewable fuels by 2020, and double its market share in the long term. The focus of this paper is the adoption of renewable fuels in public bus fleets. Data for all 21 Swedish counties were gathered and analyzed, mapping the bus fleets' condition in relation to renewable fuel deployment, CO_2 emissions and energy efficiency. The main factors affecting fuel choices in the bus fleets were investigated through a survey among environmental managers and transport planners at regional public transport authorities. The analysis highlights the challenges implied in the rapid shift that regional bus fleets are undergoing to adopt renewable fuels and reduce emissions. Political will and procurement have been strong success factors in facing these challenges. The survey indicates the stakeholders' interest to switch to electricity for city routes, while biodiesel and HVO are preferred for longer routes. When it comes to how fuel choices are made, environmental factors seem to be prioritized, while the barriers identified are mainly economic and political.

1. Introduction

Sweden has set an ambitious goal to have a fossil-free vehicle fleet in 2030, in line with the CO_2-emissions neutral target by 2050 (Regeringskansliet, 2013). The public transport sector aims to run 90% of its total vehicle-kilometers on renewable fuels by 2020 (SKL, 2014). Biodiesel, biogas, ethanol and electricity from renewable sources are accounted as renewable fuels. Furthermore, the public transport sector aims to double its market share in the long term, and the volume of travel on public transport by 2020. While significant actions are needed to reach these targets, this is also a great opportunity to rethink public transport solutions and to improve both energy and service efficiency. However, there is currently lack of systematic policy analyses for the Swedish public transport sector that needs to be addressed (Nilsson et al., 2013).

The focus here is on the adoption of renewable fuels in public buses. Bus is the most common means of public transport in Sweden (52% of the total passenger boardings in 2013), and it is offered by all regions (Trafikanalys, 2014). The status of the Swedish public bus fleet in relation to the aforementioned 90% target for renewable fuels varies regionally, with the national average reaching 58% in 2014 (Svensk Kollektivtrafik, 2015). Thus there is still a long way to go before Sweden reaches carbon neutrality in the public bus fleet. *How do present policy initiatives affect renewable fuel deployment? Which are the main factors affecting fuel choices?*

In this paper, data on public bus fleets are gathered for all 21 Swedish counties. These data were analyzed in order to map the bus fleets' condition in relation to renewable fuels deployment, CO_2 emissions and energy efficiency, and to better understand the reasons behind broad regional variations. The main factors affecting fuel choices in bus fleets were investigated through a survey aimed at environmental managers and transport planners at public transport authorities, as well as transport service companies. Through the analysis, we identify best practices and lessons for developing successful strategies for renewable fuel deployment in public bus fleets.

2. The organization of Swedish public transport

Under the new Public Transport Act (Lag (2010:1065) om kollektivtrafik) that was enacted on January 1st 2012, new regional public transport authorities (PTAs thereof) were formed. The PTAs are responsible for the development of public transport systems in their respective region. The PTA is organized either as a federation or a committee of local authorities together with the County Council, for better co-ordination with other aspects of social planning.

The PTAs issue regional transport provision programs, which set the basis for issuing public service obligations for all regions, even where public transport services are not of commercial interest (Svensk Kollektivtrafik, 2014). The public transport services provision is up to 95% subject to procurement. The Swedish Public Transport Association (Svensk Kollektivtrafik – SK thereof) has issued a common sector standard for procurement of public bus services, named “Bus 2014-common sector functional requirements for buses”[i]. The standard includes requirements for safety, passenger comfort, information, communication etc. The environmental requirements are set in more detail in a separate sector standard, titled “Environmental requirements in connection with transport procurement”[ii]. Representatives from PTAs, transport operator companies, bus manufacturers and other stakeholders are involved in the development of these standards, which are issued by SK.

3. Regional mapping of non-fossil fuel deployment in public bus fleets

Information regarding environmental performance and other bus fleet characteristics is found in the FRIDA database (FRIDA miljö- och fordonsdatabas[iii]), which gathers official statistics for public buses in all 21 counties of Sweden. The web-based database was developed by Nordic Port in cooperation with SK and the transport service operators report the information to the PTAs who are responsible for curating FRIDA. The increase of vehicle kilometers run on renewable fuels has been impressive in the past few years, rising from a total share of 8% in 2007 to 58% in 2014. Biodiesel is currently leading among renewable fuels (33.7%), followed by biogas (17.2%) and ethanol (7.2%). Electricity has currently a very small share (0.3%), since electric buses are only in demo stage (only 7 reported). A significant increase trend for renewable fuels can be observed starting around 2010, which was the year when the first common sector standard was introduced. The even higher growth rates after 2012 could be credited to the boost given to procurement with the creation of PTAs in 2012, as well as the dissemination of new bus technologies.

Data on regional fuel mixes for buses are shown in Figure 1. Generally, higher renewable fuel shares are noticed in the South. Biogas is dominating in specific regions (e.g. Skåne, Västmanland) where investments on gas infrastructure and local production of biogas have been promoted. It can be observed that achievements vary across the country, and not only densely populated regions with large bus transport volume perform well in terms of renewable fuel deployment. In Figure 2, only 4 regions surpassed 50% renewable fuels in 2012, while in 2014 the number increased to 9, showing the rapid growth of renewable fuel use in bus fleets.

Thus, although there is an indication of a north-to-south axis for renewable fuel deployment trends in bus fleets, there is no strong correlation of population density or bus transport volume to the share of renewable fuels in the fleet. This places political will and strategic planning in public transport as very important factors affecting renewable fuel deployment, provided that limitations due to, for example, climatic conditions are overcome through alternative fuel choices and improved technologies.

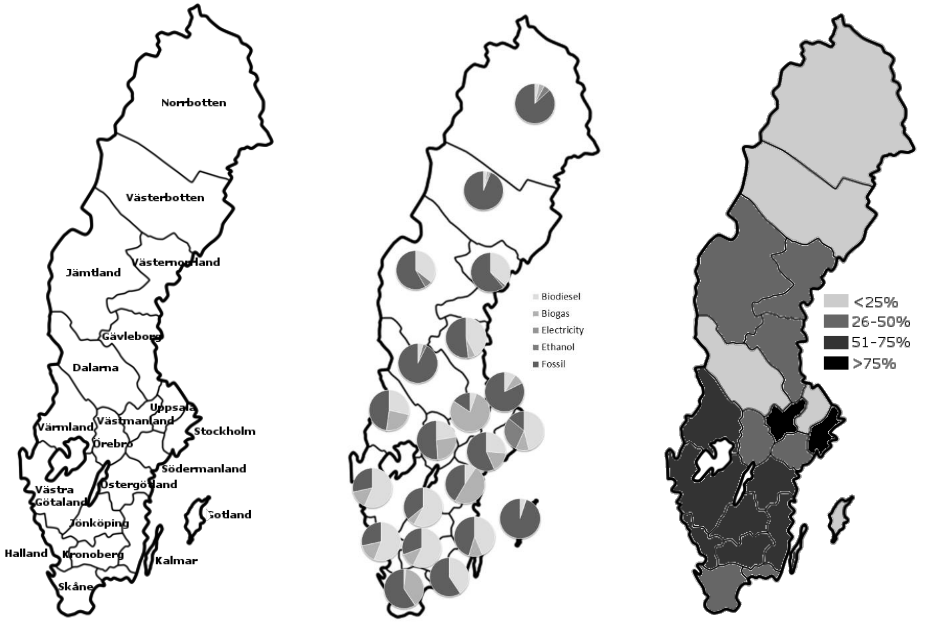


Figure 1: Map of (i) the 21 Swedish regions, (ii) fuel mix per region, and (iii) share of vehicle kilometers run on renewable fuels - public bus fleets in 2014 (Svensk Kollektivtrafik, 2015)

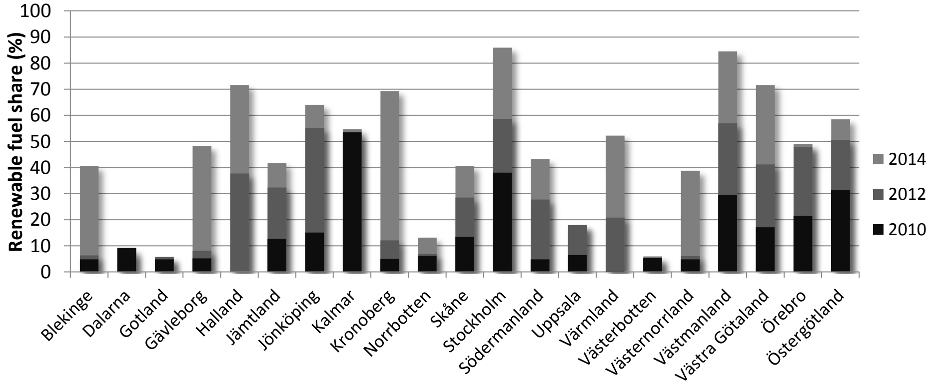


Figure 2: Renewable fuels share (%) on vehicle kilometers run by Swedish public bus fleets per region for the years 2010, 2012 and 2014 (Stockholm Läns Landsting, 2011; Svensk Kollektivtrafik, 2015)

Analyzing the environmental data on bus fleets, a steady decrease on CO_2 emissions per vehicle kilometer is observed at national level from 2007 to 2013 (see Figure 3). However, this is not the case for energy use, as energy efficiency values have remained relatively stable. Moreover, when counting CO_2 emissions and energy use per passenger kilometer, emission levels are stable and energy use seems to be increasing (see Figure 3). The statistics per passenger kilometer are directly connected to occupancy rates and average trip lengths. These numbers are only estimations made by the PTAs, so they should be considered with caution (Tom Petersen, personal communication, 12 January 2015). However, both figures imply the need for higher occupancy rates and more efficient vehicles in order to reduce energy use, especially in future scenarios with higher transport volume.

The statistics on emissions and energy use vary significantly among regions. In the Västra Götaland region, gas buses consume 36% more fuel than diesel buses (Hanna Björk, personal communication, 20 January 2015). So in regions with a larger share of biogas-driven busses, there is higher energy use, though also lower CO_2 emissions since the global Warming Potential (GWP) is lower for biogas than biodiesel (Hallberg et al., 2013). Energy use is also affected by the balance between city and regional traffic. From data provided for the region of Gävleborg (93% of buses are diesel), fuel efficiency for city routes was 14% lower than for regional routes (Claes Forsberg, personal communication, 17 February 2015).

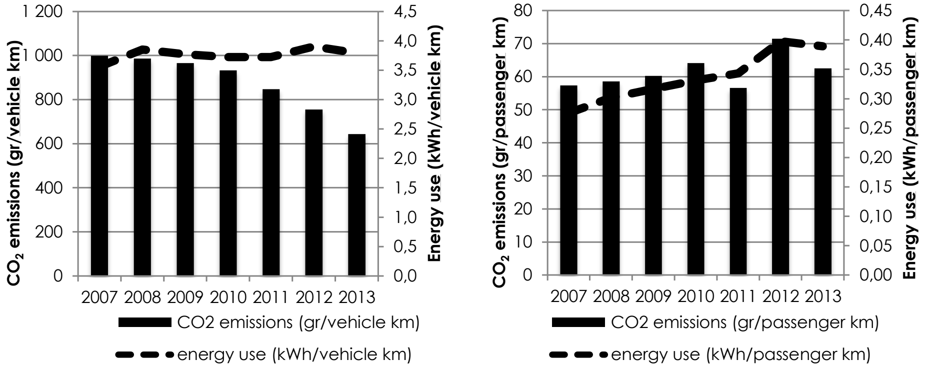


Figure 3: CO_2 emissions and energy use per vehicle kilometer and per passenger kilometer (national level, from 2007 to 2013) (Svensk Kollektivtrafik, 2014a; Trafikanalys,2015-personal communication)

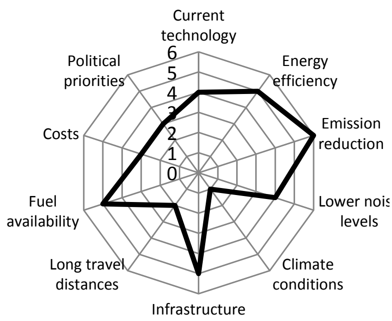
4. Fuel options for Swedish bus fleets: survey results and best practices

Input from stakeholders of the public transport sector was sought in order to understand the reasons why specific fuel choices are being made, as well as barriers and drivers to increasing renewable fuel deployment. Survey research methods, as in Sapsford (2007) were used, with an anonymous electronic questionnaire and personal interviews with straightforward note-taking. The sampling pool was environmental managers or persons working with strategy and planning at each one of the regional PTAs. Furthermore, the questionnaire was sent to the environmental managers of large transport service companies and representatives of the Swedish Bus and Coach Federation (Sveriges Bussföretag). The questionnaire was sent to 35 persons. In total, 19 persons responded the survey, thus the response rate was 55%.

The results from the survey and the personal interviews conducted show that public transport stakeholders are strongly interested in electricity as a fuel option for buses. The survey respondents mentioned a variety of demonstration projects for electric buses happening in several regions, e.g. Stockholm, Västra Götaland, Skåne. When asked about the most attractive fuel alternative in the foreseeable future, the respondents placed electricity first (6 responses). Biodiesel from rapeseed oil (RME), which is the most common type of biodiesel currently used in Sweden, was second, together with biogas (5 responses). Finally, 4 replied that HVO (Hydrogenated Vegetable Oil) is the most attractive fuel option. HVO's performance is similar to conventional biodiesel, but has significantly lower lifecycle GWP (Arvidsson et al., 2011).

The survey also shows the importance of biodiesel, especially in scarcely populated regions, where infrastructure for electricity or biogas may not be profitable. Biodiesel is quite a flexible fuel, which is used in ordinary diesel motors without modifications. It must be noted that, at the moment, electricity can only be seen as an alternative for city traffic while the natural choice for regional routes has usually been biodiesel. Currently transport service operators tend to choose biodiesel, unless another fuel is specifically procured by the PTAs. For regions that have already invested in a specific fuel, either biodiesel or biogas, the survey shows that the majority of PTAs wish to continue investing in the same fuel, in addition to the introduction of electricity as the main choice for city routes. In some cases, although biogas is currently the main fuel used, electricity or biodiesel are identified as more attractive in the future. The reason for this is the lower fuel efficiency of gas-driven vehicles compared to diesel, and the difficulties of securing the biogas supply.

Figure 4.a shows the responses indicating the main factors that affect fuel choices for bus fleets, as seen by the PTAs. Environmental aspects, such as emission reduction potential and energy efficiency, are a priority, as well as infrastructure needs and fuel availability. Lower noise was also a factor, as well as investments needed for specific vehicle technologies, as the latter make fuel switch more difficult. Political priorities are seen as a barrier in a context that requires long-term strategic commitment from the PTAs. Finally, climate conditions affect fuel choices, especially in the colder Northern parts of Sweden, where some fuels are not an option due to freezing points.



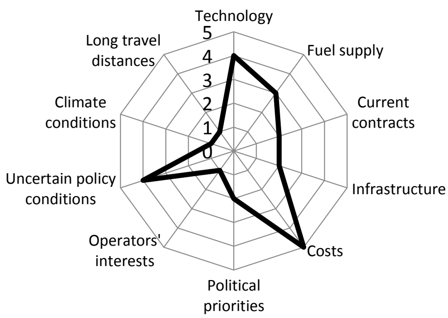


Figure 4.a: Survey results on factors that affect fuel choices for Swedish public buses
Figure 4.b: Survey results on barriers to higher renewable fuel deployment for Swedish public buses

Costs are what most of the respondents classify as the biggest barrier to increasing renewable fuel deployment in public bus fleets (see Figure 4.b). Uncertain policy conditions are also high in the response list, because the policy background on renewable fuel taxation and incentives is unclear at the moment, which hinders or delays new investments. Costs, infrastructure and current contracts with transport operators tie PTAs to specific fuels. Low population density leading to longer average trip lengths is also a barrier to increased renewable fuel use in buses.

Most of the respondents indicated that the common sector standards for procurement are followed by the PTAs of their region (59%). However, in the most populous regions of Sweden, e.g. Stockholm or Västra Götaland, the PTAs set even higher requirements than the common sector standards. SK's standard already has different levels of ambition for the requirements on procured bus services, thus giving flexibility to each PTA to design strategies that are realistic in specific regional conditions. For example, the high requirements on emissions reduction and energy efficiency set by Västra Götaland, will lead transport operators to opt for hybrid buses to improve the fleet's environmental performance (Hanna Björk, personal communication, 20 January 2015). Municipalities are also important, as they can develop more ambitious strategies and invest in new technologies independently. For example, the Skellefteå and Umeå municipalities in the Västerbotten region invest in biogas and electricity respectively, and have achieved much higher renewable fuel deployment than the aggregate for the region of Västerbotten, which only has 6% renewables in total (Bianca Byring, personal communication, 24 February 2015). Similarly, the municipality of Eskilstuna has set a requirement on biogas in procurement for city traffic since 2002 (Peter Dädeby, personal communication, 4February 2015).

The respondents agree on the success of transport service procurement as the most important instrument to promote renewable fuel deployment in bus fleets. Strategic decisions for local biogas production and promotion of biogas in the bus fleets through procurement (especially in Southern Sweden) has also been a strong driver, even if usually local biogas supply is not sufficient to cover all the fleet needs. This is especially observed during winter when natural gas is used as a complement. Knowledge transfer and effects of economies of scale in introducing renewable fuels and new bus technologies can help curb barriers, as has been observed in the case of Stockholm (Johan Böhlin, personal communication, 4 February 2015).

5. Conclusions

The analysis highlights the challenges implied in the rapid shift that regional bus fleets are undergoing to adopt renewable fuels and reduce emissions in Sweden. Political will to pursue the decarbonization of public transport has pushed the goals higher in a successful combination with fuel tax exemptions that made deployment feasible. Procurement requirements for public transport services are adjusted regionally, and thus the PTAs have freedom to cooperate with transport operators in designing strategies and adapting to regional preferences and conditions.

Environmental factors seem to be prioritized when fuel choices are made. There is a strong indication of switching to electricity for city routes, due to low emissions, higher energy efficiency and low noise that would improve urban environments. The future challenge for PTAs and municipalities will be to secure increased supply of electricity from renewable sources for their buses. For regional routes where longer fuel range is needed, biodiesel and HVO are preferred. The barriers to increasing renewable fuel penetration are mainly economic and political. A combination of ambitious procurement requirements with economic instruments can help alleviate these barriers. Long-term tax exemption policies are needed, especially in the case of HVO. The introduction of environmental bus premiums could also have significant effects, especially for fully electric and hybrid buses.

Acknowledgements

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[iii] http://frida.port.se/hemsidan/default.cfm

A Comparative Emergy Analysis of Municipal Solid Waste Collection and Treatment Modelling Variable Source-Separated Collection and Transportation Rates

Gengyuan Liu[1,*], Zhifeng Yang[1], Sergio Ulgiati[1,2]

[1] State Key Joint Laboratory of Environment Simulation and Pollution Control; Key Laboratory of Water and Sediment Sciences, Ministry of Education; School of Environment, Beijing Normal University, Beijing 100875, China

[2] Department of Sciences and Technologies, Parthenope University of Naples, Centro Direzionale – Isola C4, 80143 Naples, Italy

Corresponding Author e-mail: liugengyuan@bnu.edu.cn

Abstract

Waste management is a specific practice aimed at reducing its effects on health and the environment and increasing energy and material recovery. The Beijing Municipal Solid Waste Collection and Treatment System has been slow to adopt new technologies, to enable better treatment results. The aim of a thorough ecological- economic evaluation of different treatment technologies is to achieve the maximum practical benefits from investments and to ensure the minimum environmental impacts of wastes based on variable source-separated collection and transportation rates. This paper compares four garbage treatment systems, including separate collection and transportation, sanitary landfills systems, fluidized bed incineration system, and the composting system in Beijing. The emergy based method considers the economic and environmental impacts of waste treatment and disposal, impact of emissions, and contribution of wastes input. Results show that as far as the Source separation rate (SSR) grows, the yield of recycled materials and separated wastes also rises. Meanwhile, high SSR and STR could make recycling more beneficial, but the environmental impact (ecological and economic losses) and emergy yield will raise accordingly since the source-separation alters the output to the incineration and composting process. The emergy-based accounting method can be used to analyze the economic benefit, environmental pressure, and sustainability of different MSW treatment systems for decision-making and the whole process optimization.

1. Introduction

Municipal Solid Waste management is a complex task requiring the simultaneous modeling of collection, transportation, disposal and recycling. The United Nations Environmental Program endeavor to align with the prioritization of activities presented in waste hierarchy. Source Reduction is the first tier of the solid waste management hierarchy. The separation of materials at the point of collection results in a more homogenous and higher quality waste stream. Source separated material streams are less contaminated by other materials, and are easier and less costly for recyclers to recover. Therefore, source separated materials represent a higher value to recycling markets and may improve the environmental performance and economic efficiencies of waste treatment options. However, just like other megacities (Agostinho *et al.*, 2013), almost 90% of MSW collected in Beijing is disposed in sanitary landfills, 2% is incinerated and less than 8% is composted. Meanwhile, the municipal solid waste collection and treatment System in Beijing is characterized by a garbage disposal mode overlooking the front-end section and emphasizing the back-end. Specifically, garbage collection is conducted by sanitation workers instead of being sorted by residents at home and therefore it is collected and transported to landfill sites for disposal as a mixed material, which causes a huge waste of resources. By the way, the majority of domestic garbage in Beijing is food waste, which may be converted to valuable products like compost and mulch. However, since Beijing has not implemented source sparation of garbage, and the present separation and transportation recycling system achieves an insufficient sorting of the collected garbage, the quality of produced compost cannot be guaranteed.

In addition, the garbage transportation is an essential link within the garbage separation collection system. If garbage is sorted when discarded, but mixed when transported, it is far from allowing reuse of garbage based on classification. Therefore, in order to improve the quality of materials collected for recovery, the sorted garbage should be transported separately and reduce the volume of residual waste landfilled. According to investigations in Beijing, almost every organizer of garbage separation and collection considers hard to find a factory that is ready to receive separated garbage and reuse it. If the residents who have spent time and efforts to separate garbage at home know that the garbage they have bagged separately has been mixed with other waste and transported to the garbage sites, they will lose the motivation to separate garbage. At present, the main way of the city's garbage recycling system is mixed collecting. The primary reason for this is that there's no separation at the frontend, as well as a lack of corresponding facilities for garbage separation, collection and transportation. This short-sighted practice is likely to lead to exhaustion of the landfill areas in a couple of years and therefore is not sustainable. The aim of this paper is to compare the economic and environmental effects between different variable source-separated collection and transportation rates, highlighting potential improvements of the current MSW system.

2. Materials and Methods

2.1 Municipal solid waste management system

The life cycle flow-chart of MSW is depicted in Figure 1. The system boundary is the interface between the waste management system and the environment or other product systems. The life cycle starts once a material or product becomes waste, i.e. its owner discards it in the waste collection bins. MSW is collected either via sanitation workers or via scavengers. Each collection method requires its own infrastructure, i.e. dedicated bins and collection vehicles, followed by transportation to landfill of treatment plants. In the MSW management system, the separate waste can either go to the landfill or the waste-to-energy facility. The source-separated waste, if it is a dry stream (aluminum, glass, paper and cardboard, etc.), can go to the material reclamation facility; if it is a wet stream (kitchen leftovers, etc.) can go to the composting plant.

The municipal solid waste can be broadly divided into three phases: separated collection, separated transformation, and separated treatment and recycling. Usually, the household urban waste is packed in plastic bags and left in waste containers, from which the waste is taken by a collection team (official manual collection and special trucks for compaction, as well as unofficial scavengers collecting recyclable materials. The phase of separated collection and transportation plays an important role in increasing recovery rates. Householders or sanitation companies that separate waste before disposal help reduce the volume of residual waste to landfill and offer better opportunities for recycling. Some researchers have pointed out that the informal recycling of waste by scavengers not only constrains profits of the formal system, but also pollutes the environment if toxic substances leak when waste is not properly disposed of (Besiou, et al., 2011). After collection, the Beijing municipal waste can be handled in conventional ways in sanitary landfills, incineration or composed.

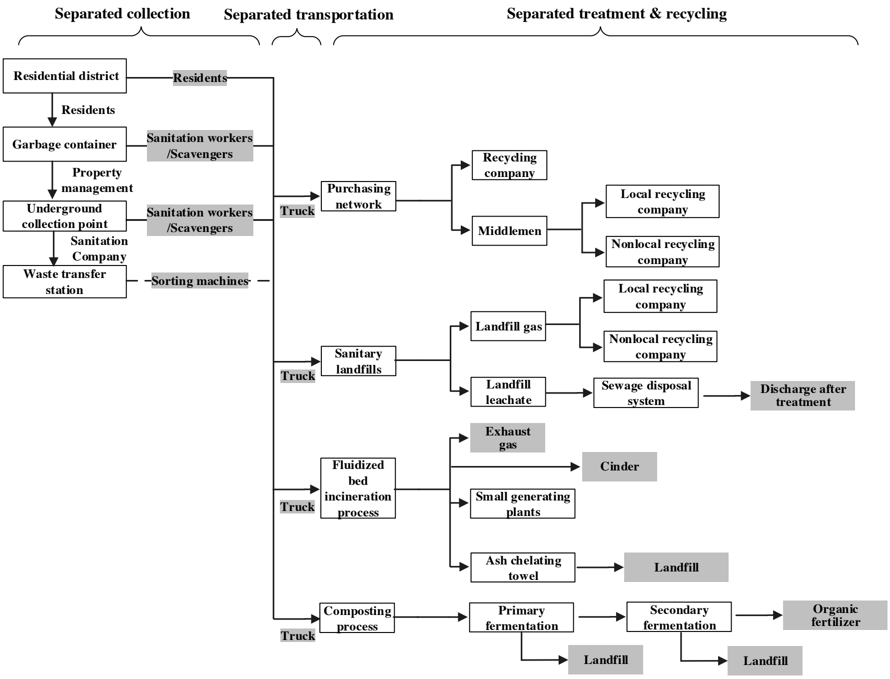

Figure 1 Flowchart of urban solid waste destinations in Beijing.

All material and energy resource inputs and outputs (emissions and products) must be preliminarily identified and quantified (inventory) to be converted to emergy flows and then emergy-based indicators.

2.2 Evaluating the Impacts of Emissions by integrating Emergy and LCA

The impact of emissions on human health can be viewed as an additional indirect demand for resource investment (Liu et al., 2013). Human resources (considering all their complexity: life quality, education, know-how, culture, social values and structures, hierarchical roles, *etc.*) can be considered as a local slowly renewable storage that is irreversibly lost due to the polluting production and use processes. Societies support the wealth and relations of their components in order to provide shared benefits. When such wealth and relations are lost, the investment is lost and such a loss must be charged to the process calling for changes and innovation. The emergy loss can be calculated as:

$$L_{w,1}{}^{*} = \sum m_i^{*} \times \mathrm{DALY}_i \times \tau_H \quad (1)$$

Here, $L_{w,1}{}^{*}$ is the emergy loss in support of the human resource affected, i refers to the i-th pollutant, m^* is the mass of chemicals released, DALY is its E.I. 99 impact factor and τ_H is the unit emergy allocated to the human resource per year, calculated as τ_H = total annual emergy/population. The rationale here is that it takes resources to develop the given expertise or work ability and societal organization. When it is lost, new resources must be invested for replacement (not to talk of the value of the individual in itself, which is not quantifiable in physical terms and remains outside of the present study).

PDF is the acronym for Potentially Disappeared Fraction of Species (Eco-Indicator 99 (Goedkoop and Spriensma, 2000)). Such effects can be quantified as the emergy of the loss of local ecological resources, under the same rationale discussed above for the human resource:

$$L_{w,2}{}^{*} = \sum m_i^{*} \times \mathrm{PDF}(\%)_i \times E_{Bio} \quad (2)$$

Here $L_{w,2}{}^{*}$ is the emergy equivalent of impact of a given emission on urban natural resource, while PDF(%) is the fraction potentially affected, measured as PDF × m^2 × yr × kg^{-1}. A damage of one in E.I. 99 means all species disappear from one m^2 during one year, or 10% of all species disappear from 10 m^2 during one year, *etc.* E_{Bio} is the unit emergy stored in the biological resource (seJ × m^{-1} × yr^{-1}), which is presented as the emergy of local wilderness, farming, forestry, animal husbandry or fishery production.

2.3 Evaluating the Impacts of Emissions by integrating Emergy and LCA

Two main aspects can be identified to characterize the efficiency and effectiveness of urban waste management, namely the Source Separation Rate (SSR) and the Source-separated Transportation Rate (STR). Source separation refers to the separation of MSW into several categories at the generation source according to the different characteristics of each material before further treatment. The MSW source separation rate indicates the percentage of the amount of pre-separated waste versus the total amount of waste generation. It represents the effectiveness of MSW source-separated collection in the city. STR was determined from the mass of waste transport-separated divided by the total mass of MSW. If all waste was transported separately, STR was 100%. The actually treated amount was calculated based to the proportions of both SRT and SSR (see Table 1). Here, x_1, x_2, and x_3 mean the kitchen garbage, recyclable waste and mixed waste respectively after the collection process. x_1', x_2' and x_3' mean the kitchen garbage, recyclable waste and mixed waste respectively which need to be transported. The theoretical demand number of garbage trucks could be calculated based on Table 1. The effective load values between ordinary truck (3.5 t/round trip), kitchen waste truck (6 t/round trip) and recyclable waste truck (1.5 t/round trip) could be found in refs.

Table 1. MSW amounts at different source separation rates (SSR) and source-separated transportation rates (STR)

STR (%) / SSR(%)	0	20	50	80	100
0	$x_1'=0$ $x_2'=0$ $x_3'= x_3$	$x_1'=0$ $x_2'=0$ $x_3'= x_3$	$x_1'=0$ $x_2'=0$ $x_3'= x_3$	$x_1'=0$ $x_2'=0$ $x_3'= x_3$	$x_1'=0$ $x_2'=0$ $x_3'= x_3$
20	$x_1'= 0$ $x_2'= 0$ $x_3'= x_1+x_2+ x_3$	$x_1'= x_1$*20% $x_2'= x_2$*20% $x_3'= x_3+(x_1+x_2)$*80%	$x_1'= x_1$*50% $x_2'= x_2$*50% $x_3'= x_3+(x_1+x_2)$* 50%	$x_1'= x_1$*80% $x_2'= x_2$*80% $x_3'= x_3+(x_1+x_2)$* 20%	$x_1'= x_1$ $x_2'= x_2$ $x_3'= x_3$
50	$x_1'= 0$ $x_2'= 0$ $x_3'= x_1+x_2+ x_3$	$x_1'= x_1$*20% $x_2'= x_2$*20% $x_3'= x_3+(x_1+x_2)$*80%	$x_1'= x_1$*50% $x_2'= x_2$*50% $x_3'= x_3+(x_1+x_2)$* 50%	$x_1'= x_1$*80% $x_2'= x_2$*80% $x_3'= x_3+(x_1+x_2)$* 20%	$x_1'= x_1$ $x_2'= x_2$ $x_3'= x_3$
80	$x_1'= 0$ $x_2'= 0$ $x_3'= x_1+x_2+ x_3$	$x_1'= x_1$*20% $x_2'= x_2$*20% $x_3'= x_3+(x_1+x_2)$*80%	$x_1'= x_1$*50% $x_2'= x_2$*50% $x_3'= x_3+(x_1+x_2)$* 50%	$x_1'= x_1$*80% $x_2'= x_2$*80% $x_3'= x_3+(x_1+x_2)$* 20%	$x_1'= x_1$ $x_2'= x_2$ $x_3'= x_3$
100	$x_1'= 0$ $x_2'= 0$ $x_3'= x_1+x_2$	$x_1'= x_1$*20% $x_2'= x_2$*20% $x_3'= (x_1+x_2)$*80%	$x_1'= x_1$*50% $x_2'= x_2$*50% $x_3'= (x_1+x_2)$*50%	$x_1'= x_1$*80% $x_2'= x_2$*80% $x_3'= (x_1+x_2)$*20%	$x_1'= x_1$ $x_2'= x_2$ $x_3'=0$

3. Results

In this study, we choose 15.2 × 10^{24} seJ/yr as the annual emergy global baseline, based on Brown and Ulgiati (2010). Unit Emergy Values (UEVs) calculated according to Odum (2000) baseline can be left unchanged, because the difference falls within the uncertainty claimed by these Authors; UEVs calculated before the year of 2000 (9.44E+24 seJ/yr baseline; Odum, 1996) should be multiplied by 1.61.

Emergy flow analysis of four urban domestic waste treatment methods is calculated. For the collection and transportation in Beijing, it was found that about 71.34% of emergy input came from diesel input (for solid waste transport). The maintenance cost and labor cost in this stage cover 17.13% (5.20 × 10^{12} seJ/t-waste). NO_x, CO_2 and SO_2 are the main gaseous emissions from fuel combustion in trucks.

The emergy-based treatment costs are significantly different. Landfills without leachate disposal system is the least expensive (1.02 × 10^{13} seJ/t-waste), the sanitary landfills system with leachate disposal system needs 1.35 × 10^{13} seJ per t-waste. The incineration system requires more emergy inputs. For fluidized bed incineration process, 4.27 × 10^{13} seJ are used for treating 1t waste. It is much lower in composting process (3.19 × 10^{13} seJ/t-waste). Therefore, if ecological service and emission's impacts are not considered, the sanitary landfill system shows promise for urban solid disposal based on the evolution of thermoeconomics.

We accounted the emergy costs of the phases under different source separated collection and transportation rates to obtain the total costs of the MSW collection and treatment system. The estimation was done for the whole SSR commingled with STR. The non-separated material was included in the mixed waste and will be treated by the landfill. The total emergy investments include the emergy input and environmental impact (ecological and economic losses). In general, Table 9 shows that, when STR is fixed, the emergy investment in collection phase increase as the SSR grows, while it's inverse for the transportation phase. The emergy investment of waste treatment processes (landfill, incineration, and composting) are considered to be a counter-balance relationship. When source separation rate equals to 0, all the wastes are considered as the mixed waste and transported to the landfills. And there's also no recycling materials collection and only a little electricity yield created by LFG. Along with the SSR grows, the yield of recycling materials and separated wastes will rise. High calorific value waste will be transported to fluidized bed incineration plant and food waste will be composed. Meanwhile, high SSR and STR could make recycling more beneficial, but the environmental impact (ecological and economic losses) and emergy yield will raise accordingly since the source-separation alters the output to the incineration and composting process.

It is clear that a source separated collection or transportation rate of 100% is theoretical only, but efficiency could be increased by targeted initiatives such as better guidance and education as well as providing a better infrastructure for citizens. As an example, the deposit-return system of beverage cans and bottles reaches a sorting efficiency near 100%. Such an efficiency, however, is not realistic to expect from the recovery of the food waste. Nevertheless, a future target of 50% reuse or recycling can be set and be expected to be realizable. This will depend on the development in waste composition, amount of waste as well as recycling technology. Therefore, development in waste amounts and efficiency of collection scenarios should be carefully monitored in the future.

4. Conclusion

If the decision makers conclude that the alternative collection systems are all acceptable with regard to environmental impact and costs, they would have the opportunity of putting weight on other aspects such as improvement of source-separated collection and transportation efficiency. The emergy-based accounting method can be used to analyze the economic benefit, environmental pressure, and sustainability of different MSW treatment systems for decision-making and the whole process optimization.

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Participatory Integrated Assessment of Urban Waste Management Systems

Rosaria Chifari[1]*, Mario Giampietro[1,2]

[1] Institute of Environmental Science and Technology (ICTA), Universitat Autònoma de Barcelona, 08193 Bellaterra, Spain

[2] Institució Catalana de Recerca i Estudis Avançats (ICREA), 08010 Barcelona, Spain

*Corresponding Author e-mail: rosaria.chifari@uab.cat

Abstract

An Urban Waste Management System (UWMS) modulates the interaction between the metabolic processes of a city, which generate a given mix of wastes, and the metabolic processes of its embedding ecosystems, which determine a given sink capacity. Framing the analysis of UWMS within this rationale of the metabolism of a 'socio-ecological system' allows us to study three criteria of performance: (i) feasibility in relation to external constraints (environmental impact at the local and global scale) and the prevailing law and regulations; (ii) viability in relation to internal constraints (economic costs and technical coefficients); (iii) desirability in relation to expectations and normative values of the social actors involved. A proper characterization of the performance of a UWMS in relation to these criteria requires us to define and assess four aspects: (i) the input from the society (city), that is, the quantity and quality of the flows of waste for processing; (ii) the characteristics of the embedding ecosystems that provide sink capacity; (iii) the mix of inputs required for the operation of the different stages of the process, such as technology, labour, energy, water and materials flows; (iv) the level of openness of the system, that is, the inflows and outflows of urban wastes for processing in the different stages of its operation and the final output to be disposed of into the environment. In this paper we illustrate a conceptual framework to integrate this quantitative information characterizing the performance of an UWMS based on MuSIASEM (Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism), an accounting method based on the flow-fund model developed by Georgescu-Roegen in the field of bioeconomics.

1. Introduction

We present here a general conceptual framework (grammar) for the analysis of the performance of Urban Waste Management Systems (UWMS), based on the Multi-scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM). Like any meta-model, it can be tailored to specific cases and situations as need arises. The construction of the conceptual framework involves two steps: (i) selection of a set of relevant semantic categories and definition of expected relations among these categories; and (ii) formalization of the semantic framework into a quantitative characterization.

2. Defining a conceptual semantic framework for the analysis of UWMS

MuSIASEM integrates two non-equivalent views of the system under analysis, in this case the urban waste management system, the outside view and the inside view (Giampietro et al 2012; 2013; 2014):

(A) The outside view focuses on the interaction of the UWMS (seen as a black box) with its context. In this view we consider: (i) the source of waste flow to be processed; (ii) the sink capacity of ecological funds; and (iii) the inflows/outflows of waste during the various steps of the waste management process that determine the final quantity and quality of wastes, particles and pollutants released into the local environment or exported elsewhere. The outside view provides relevant information on the environmental impact of the UWMS and the consequences for human health.

(B) The inside view focuses on the functions and the structures of the parts that make up the UWMS, such as processes and technologies used for collecting, processing and disposing waste, and that together determine the 'capacity of managing waste' of the system as a whole. This view provides relevant information on the performance of the UWMS in relation to criteria such as economic costs, employment, and local development. For the internal view we thus need a functional definition of the UWMS (what functions are expressed) and a structural definition (what technologies are used; how are the functions carried out). An overview of the generic semantic framework, including the external and internal view of the UWMS, is shown in Fig. 1.

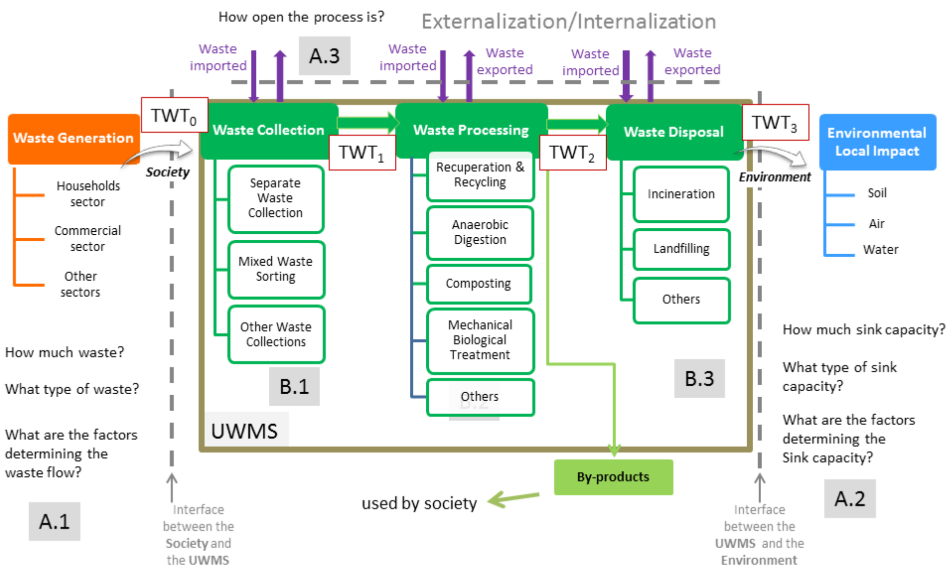


Fig. 1 *Conceptual semantic framework to characterize UWSM metabolism (UWSM = urban waste management system; A = outside view; B= inside view; TWT = total waste throughput)*

This pre-analytical, conceptual framing facilitates the definition of the technological option space of the UWMS (that is, the set of functions or tasks to be realised by the set of technologies) and also makes it easier, later on, to develop a multi-criteria assessment of alternatives and scenarios. Ideally, the semantic representation given in Fig. 1 should match with the perceptions of the social actors of what a UWSM is and what it does. Given the semantic skeleton of Figure 1, we thus need to operationalize and quantify the following concepts in our analysis:

A. In the outside view:
A.1 Waste generation by society (the input to the UWMS in terms of quantity and quality);
A.2 Environmental impact matrix (contextualization of the impact of the outputs of the UWMS in relation to relevant ecological funds);
A.3 Level of openness of the system as determined by the inflows and outflows of wastes and by-products from the various internal components of the system, including the final effluents (solid, liquid and gaseous) resulting from the overall function of waste disposal (all flows that are crossing the boundary of the UWMS);

B. In the inside view:
B.1 Waste collection (determining the interface: context/UWMS);
B.2 Waste processing (the network of processes taking place inside the black box);
B.3 Waste disposal (determining the interface: UWMS/environment);

This conceptual semantic framework can be further refined with additional, case-specific information about the different functional tasks within the UWMS and the technologies used to perform these tasks (inside view), as well as with context-specific aspects. For example, when focusing on solid urban waste management we may add the following processes to the conceptual semantic framework (see Fig. 1):

B.1 Waste Collection – Solid urban waste may be collected in different ways (as door-to-door, street containers, underground containers) separately, sorted afterwards, and/or other specific dedicated waste collection centres may be in place. The characterization of this step can be obtained by identifying: (i) the set of processes; and (ii) their relative importance.

B.2 Waste Processing – Also here, a mix of diverse technologies is usually in place. For example, separate waste collection of recyclables and biowaste, collection of mixed waste, complemented by waste collection centres. Selected solid municipal waste may be sent to recuperation and recycling material centres where different inorganic fractions of the separated municipal waste are extracted. Organic waste may be sent for anaerobic digestion or composting. As mixed municipal solid waste is concerned, it may be sent to mechanical and biological treatment plants or directly to landfills. The solutions adopted in this phase are affected by those adopted in the previous one (waste collection) and will affect those of the next phase (by influencing the level of reduction of the volume in quantity and quality). In the waste-processing phase it is essential to identify the fraction of waste that has been recycled or transformed in mechanical biological plants.

B.3 Waste Disposal – Any waste management system has a specific percentage of waste going to landfill/incineration. However, other solutions such as material or temporary storage may be employed. The percentage of TWT

(Total Waste Throughput) disposed of into the environment is key to defining typologies of UWMS.

The advantages of constructing a semantic framework for the UWMS are manyfold and include:

(1) Facilitation of participatory problem structuring – A semantic definition of the UWMS is helpful to identify and compare the different perceptions and narratives of social actors involved;
(2) Awareness of potential environmental problems – The semantic framework elucidates key aspects of the interaction of the USWM with its context, such as: (i) quantity and quality of waste to process (in terms of pace per hour and density per hectare); (ii) the characteristics of the ecological context (in terms of critical thresholds of environmental loading); (iii) the level of openness of the system (in terms of externalization/internalization of waste flows during the various operations of the waste management system);
(3) Insight into the functioning of the UWMS – The semantic framework establishes a relation between the overall performance of the UWMS and the technical characteristics of the specific processes taking place within the system. The hierarchical organization of the different processes and corresponding functional compartments, that together express the overall function of the UWMS, can be tracked in quantitative terms by adopting an appropriate set of accounting categories.

3. Formalization of the semantic framework into a quantitative characterization

The second step involves a translation of the semantic definition into a set of formal categories associated with quantitative variables. In relation to the external view we have:

A.1 Waste generation by society. Depending on the society under analysis, waste generated by the household-, commercial-, industrial, or other sectors may have different properties (e.g. impurities, contamination). Hence, first of all, we must define a set of relevant attributes and corresponding values to identify flows of municipal waste. We focus here on municipal solid waste and use three indicators to quantify its generation (D'Alisa et al. 2010): (1) the Solid Waste Metabolic Rate per person (SWMR), an intensive variable measuring the amount of solid waste (in kg) generated per person per day; (2) the Total Solid Waste Throughput per year (TSWT), an extensive variable measuring the total amount of solid waste (in kg) generated in a year in a given community (over its total population); and (3) the Solid Waste Metabolic Density (SWMD) the flow of solid waste (in kg) generated by a given socio-ecological system per unit of area. These three indicators are crucial to compare the flow of solid waste produced and to be handled (characteristics of the society) to the sink capacity of the context (characteristics of the embedding environment). Indeed, TSWT and SWMD are indicators of 'environmental loading' and are related to SWMR as follows: TSWT = SWMR x population x 365; SWMD = SWMR x population density x 365.

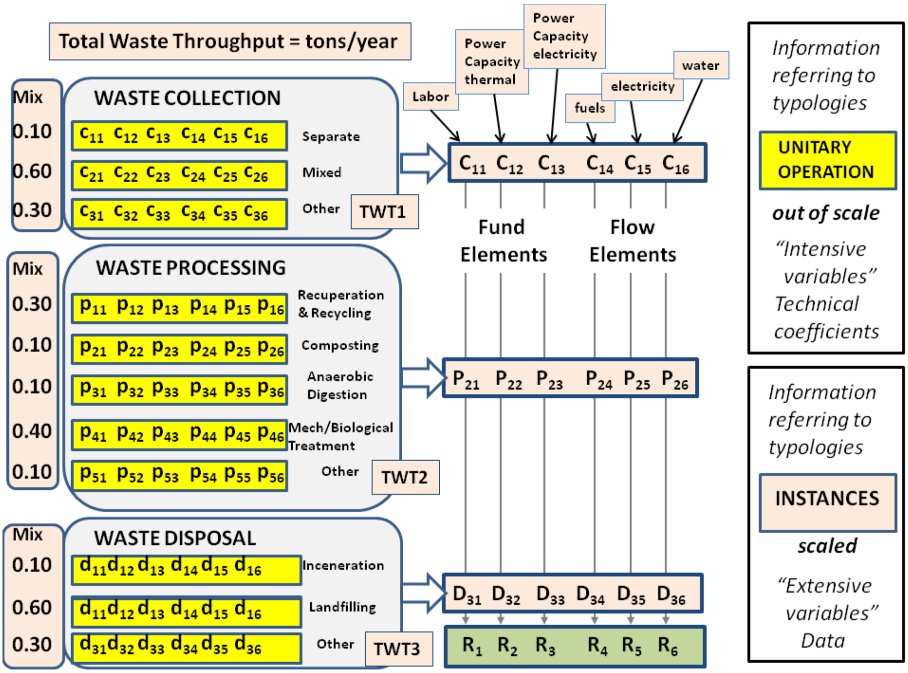
A.2 Environmental Impact Matrix. This matrix relates the effluents generated by the UWMS to the ecological funds in its surrounding areas. It is generated by considering the ecological processes that provide sink capacity (the capacity of absorbing wastes without the insurgence of environmental problems) and/or ecological funds vulnerable to damage by the final effluents. The conceptual framework should be helpful to individuate, for each of the three types of effluents (gaseous/particles, liquid and solid) produced, the ecological funds that are (i) required to absorb effluents or provide inputs (e.g. water) to the UWMS; and/or (ii) jeopardized by the effluents. This type of analysis, when dealing with local impacts, can only be carried out in spatial terms and requires the use of GIS and interdisciplinary expertise (e.g., geology, ecology, hydrology, soil science).

A.3 Inflows and outflows of wastes, by-products, and final effluents for the various internal compartments of the UWMS. This is the most delicate aspect of the analysis. Indeed, due to lack of transparency, it is often difficult to describe the degree of openness of an UWMS. At times unwanted or unplanned flows of waste are (illegally) appearing or disappearing from a given process. In other cases, problematic fractions are exported to other UWMS, thus boosting the efficiency of the given system through 'externalization' of the problem. It is important to have an idea of the extent to which a given UWMS depends on other UWMS for complementing its functions and tasks. The degree of externalization (or internalization) can be detected by carefully looking at the mix of flows (inputs and outputs) passing the 'borders' of the different functional compartments. For example, in Fig. 1 the value of TWT_0 may be different from TWT_1 (when assessing the weight of solid wastes on dry basis, not considering changes in water content), and that of TWT_1 may be different from TWT_2, etc. Only after having identified the actual functions carried out in the various internal processes of an UWMS and after having assessed the degree of externalization or internalization of the flow to be processed to/from other plants, can we generate relevant comparisons among UWMS.

As regards the internal view, the semantic definitions have to be translated into a quantitative representation that can track the characteristics of elements across hierarchical levels: (i) the characteristics of the individual technical processes (local scale); and (ii) the relative importance of the different technical processes within each functional compartment (meso scale); and (iii) the relative importance of the different functional compartments within the UWMS (scale of the whole system). The MuSIASEM accounting scheme allows us to characterize technical processes in terms of a vector of 'end uses'. Indeed, any technical process requires *a set of inputs* including: (i) human labour, technology, infrastructures, and land (fund elements); and (ii) electricity, fuels, water, and other material inputs that appear or disappear over the duration of the analysis (flow elements). See Georgescu-Roegen (1971) for the distinction between funds and flows. In this way, the expected metabolic characteristics of a given activity (technical process) can be described by a specific profile of fund and flow elements –the vector of end uses– required to express the given task. The concept of 'end uses' was originally developed in the field of energy analysis (Giampietro et al. 2013; 2014) and goes beyond the conventional idea of efficiency or productivity focused on one input and one output at the time (e.g., labour productivity, energy efficiency). The idea of the vector of end uses flags the obvious fact that in order to express a given function we do not simply need an input of energy or water or an amount of hours of labour but the right combination of these inputs in the right quantity at the right time. Thus, we map the characteristics of a technological process ***j*** (TPj) onto a vector of end uses describing the quantities of fund and flow elements required per unit of output:

$TP_j = x_1, x_2, \ldots, x_i, \ldots x_n$

An overview of this approach is illustrated in Fig. 2.



the different functional compartments of the UWMS (as illustrated in Fig. 1). For example, for "separate waste collection" (a specific process taking place within a specific compartment) we define an end-use vector made up of 6 (intensive) variables: three fund elements (x_1 - hours of labour per ton/year; x_2 - kW of power capacity (size) of machines using fuels per ton/year; x_3 - kW of power capacity (size) of machines using electricity per ton/year) and three flow elements (x_4 - MJ of fuels per ton; x_5 - kWh of electricity per ton; x_6 - m^3 of water per ton of TWT processed).

Obviously, the selection of relevant variables for inclusion in the analysis depends on the nature and the goal of the study. However, in general, the formalization of the semantic representation is based on an integration of different types of data (extensive variables and intensive variables):

(1) Fund elements that give information about the size of the system. These elements are supposed to remain "the same" over the duration of the representation of the whole process. They represent the set of attributes used

by the analyst to define *what the system is made of*. In general, the fund elements considered include:

- The hours of human work required in the process (linked to the presence of workers);
- The kW of power capacity of the machinery (either using electricity or fuels) required in the process;
- The infrastructure in the area required by the process (not shown in Fig. 2).

(2) Flow/fund ratios that give information on the characteristics of the processes performing specific tasks. Flow elements are both inputs and outputs that appear or disappear through the duration of the representation of the whole process. Flow/fund ratios are expected relations between fund and flow elements in relation to the throughput processes, that is, technical coefficient calculated on unitary operations. The profile of flow/fund ratios indicates *how the system does what it does*.

In relation to this point it is important to make a distinction between:

(1) technical coefficients (output/input ratios, flow/flow ratios) characterizing the technical performance of a process in relation to specific inputs. For example:

- kWh of electricity required in the process → kWh/ton of waste processed;
- MJ of fuels required in the process → MJ/ton of waste processed;
- m^3 of water required in the process → m^3/ton of waste processed;
- tonnes of technical inputs required in the process (not shown in Fig. 2). → ton of input/ton of waste processed

(2) flow/fund ratio defining the relation between the size (quantity of a given fund element) and the pace of a flow (quantity of the flow element per unit of fund). For example:

* Hours of labor → hours/ton of waste processed
* kW of power capacity electric → $kW_{electric}$/ton of waste processed
* kW of power capacity thermal → $kW_{thermal}$/ton of waste processed

Whereas the technical coefficients (flow/flow ratios) are essential to study the characteristics of technological processes in terms of unitary operations (out of scale), the information about flow/fund ratios, makes it possible to scale-up the information about the performance of technical processes, moving to the meso-scale. Therefore, the set of relations illustrated in Fig. 2 makes it possible to integrate two types of information referring to:
(i) structural types (technologies assessed in terms of unitary operations) – i.e. intensive variables describing technical coefficients (technological performance described using flow/flow ratios) and flow/fund ratios – the vector of "end uses";
(ii) instances of functional compartments – i.e. the characteristics of a specific functional compartment defined by extensive variables describing the overall use of fund and flow elements in the functional unit described in the grammar. The characteristics of a functional compartment do not depend only on the technical characteristics of the technologies used there, but also on the mix of technologies and the relative importance of the utilization of the different

technologies included in the mix. Therefore, when using extensive variables to describe the size of fund and flow elements at the level of functional compartments we are describing “special instances”, in the sense that the values of these numbers depend on the special combination of: (a) the mix of technical processes carried out within each one of the functional compartments; (b) the relative importance of these processes; and (c) the technical coefficients reflecting the characteristics of the technologies used in these processes (the characteristics of the types of technology assessed on unitary operations by the vector of “end-uses”).
The combination of technical coefficients (flow/flow ratios) and flow/fund ratios provided in the vector of “end-uses” makes it possible to interface these two non-equivalent forms of information.

Wrapping up, the organization of accounting categories illustrated in Fig. 2 includes three sets of accounting categories on the left side:
(i) a set of extensive variable referring to the size of the flow of waste to be processed – the assessment is expressed in tons/year of TWT. As illustrated in Fig. 1, depending on the level of openness of the UWMS the quantity of TWT_i can change when moving though the different functional compartments;
(ii) a set of intensive variables defining horizontal vectors of “end uses” (with 6 elements) describing both flow/fund ratios and technical coefficients (flow/flow ratios) of the different technologies used in the functional compartments to carry out specific Technical Processes, for example:
$TP_{jcollection} = c_{j1}, c_{j2}, c_{j3}, c_{j4}, c_{j5}, c_{j6}$; $TP_{jprocessing} = p_{j1}, p_{j2}, p_{j3}, p_{j4}, p_{j5}, p_{j6}$;
(iii) a set of fractions defining vertical vectors $[y_i]$ describing the profile of allocation of the throughput (TWT_i) over the mix of different processes included in the same functional compartment. In the example given in Fig. 2 there are three vertical vectors (one made of 5 elements – describing the profile of fractions of TWT handled by the mix of technologies adopted in waste processing – two vertical vectors made of 3 elements – describing the fractions of TWT handled by the mix of technologies adopted in the other two functional compartments). In each one of the three vertical vectors the fractions have to get closure on TWT: $\Sigma y_i = 1$
The two sets of accounting categories on the right side are:
(i) a set of six extensive variables defining three horizontal vectors describing the amounts of fund and flow elements used in each one of the three functional compartments FC_j:

$FC_{1(collection)} = C_{11},C_{12},C_{13},C_{14},C_{15},C_{16}$; $FC_{3(disposal)} = D_{31},D_{32},D_{33},D_{34},D_{35},D_{36}$;

(ii) a set of six extensive variables defining a horizontal vector describing the total requirement of fund and flow elements to operate the whole UWMS:

$UWMS = R_1, R_2, R_3, R_4, R_5, R_6$;

The organization of the categories of accounting illustrated in the scheme of Fig. 2 establishes a set of relations in the dataset making possible to combine: (i) information referring to technical coefficients (structural types described by intensive variables – flow/fund ratios and flow/flow ratios - describing the performance of unitary operations); and (ii) information referring to the specific circumstances of operation of the functional compartments: mix of technical processes and the relative quantity of TWT processed in each one of the processes included in the mix. For example, when considering the first of the three vectors on the right, the vector of "end uses" of collection determining the value of six cells:

$FC_{collection} = C_{11}, C_{12}, C_{13}, C_{14}, C_{15}, C_{16}$.

Each one of the six elements of this vector can be calculated combining the information provided by the categories of accounting illustrated on the left side of the figure. That is, information referring to: (1) types (c_{ij}); (2) fractions (y_i); and (3) extensive variable defining how much waste is processed (TWT_i) in each compartment. Then the element C_{1i} of this vector can be calculated as follows:

$C_{11} = (y_1 * c_{11} * TWT_1) + (y_2 * c_{21} * TWT_1) + (y_3 * c_{31} * TWT_1)$

. . .

$C_{1i} = (y_1 * c_{1i} * TWT_1) + (y_2 * c_{2i} * TWT_1) + (y_3 * c_{3i} * TWT_1)$

. . .

$C_{16} = (y_1 * c_{16} * TWT_1) + (y_2 * c_{26} * TWT_1) + (y_3 * c_{36} * TWT_1)$

This operation can be repeated for each one of the three horizontal vectors:

$FC_{processing} = P_{21}, P_{22}, P_{23}, P_{24}, P_{25}, P_{26}$

$FC_{disposal} = D_{31}, D_{32}, D_{33}, W_{34}, D_{35}, D_{36}$.

Finally, we can combine the three vectors describing the "end uses" of fund and flow elements in each one of the three functional compartments (collection, processing and disposal) to form an "end uses matrix" referring to a higher hierarchical level of organization: the requirement of funds and flow elements described at the level of the whole "Urban Solid Waste Management System".

Collection	C_{11},	C_{12},	C_{13},	C_{14},	C_{15},	C_{16}
Processing	P_{21},	P_{22},	P_{23},	P_{24},	P_{25},	P_{26}
Disposal	D_{31},	D_{32},	D_{33},	D_{34},	D_{35},	D_{36}
UWMS	R_1,	R_2,	R_3,	R_4,	R_5,	R_6

Having generated this end use matrix, by summing the values included in each of the columns we can generate a vector describing the overall requirement of each one of the fund and flow elements considered in the accounting for the entire UWMS.

In this way, the accounting scheme illustrated in Fig. 2 makes it possible to bridge information referring to different levels of analysis (local and meso scale) and different external referents – typologies of technologies and specific instances of functional compartments, when adopting the internal view. Then this information can be integrated with data referring to the outside view: (i) the input of waste produced by society; (ii) the sink capacity required from the environment; and (iii) the level of openness of the UWMS; with data referring to the inside view: (iv) the matrices and vectors of extensive and intensive variables describing the functioning of the functional compartments of the UWMS; and (v) the vector of extensive variables describing the requirement of inputs of the UWMS as a whole.

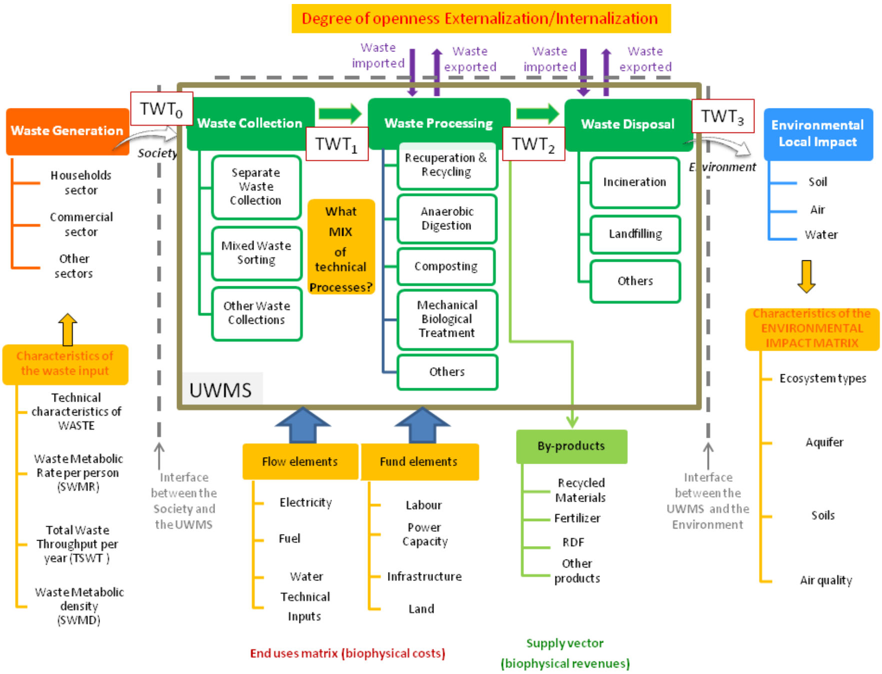


Fig. 3 – *Formal categories associated to the grammar needed to characterize the performance of UWMS metabolism – adopting both the outside and inside view - defining an integrated set of indicators.*

4. Conclusion

The scheme of multi-scale integrated accounting illustrated in this paper, based on the flow-fund model of metabolic analysis proposed by Goergescu-Roegen, can be used to combine different typologies of information: (i) internal and external view, as illustrated in Fig. 1, and (ii) information about "types" - bottom-up data referring to technical coefficients – and "special instances" – top-down data referring to statistical data, as illustrated in Fig 2.

The integration of the different data is illustrated in Fig. 3:

In relation to the outside view it identifies: (i) the characteristics defining the waste input coming from the society (on the left side); (ii) the characteristics defining the Environmental Impact Matrix used to check the sink capacity of the ecosystems embedding the UWMS (on the right side); (iii) the characteristics defining the degree of openness of the UWMS determining changes in the volume of TWT_i going through the different functional compartments (on the top).

In relation to the inside view (in the middle of the figure) we can identify the requirement of investments of fund and flow elements inside the UWMS determining the biophysical and economic costs (please note that in this figure we are listing among the production factors more than 6 typologies among the required fund and flow elements) and the overall supply of economic valuable by-products determining the revenues.

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Renewable Refined Biomass Fuel from Municipal Solid Waste. A Life Cycle Assessment.

Maddalena Ripa[1], Gabriella Fiorentino[1*], Luigi Sergio[1], Viviana Cigolotti[3], Sergio Ulgiati[1, 2]

[1] Department of Science and Technology, Parthenope University of Napoli, Napoli, 80143, Italy

[2] School of Environment - Beijing Normal University - China

[3] ENEA - Portici Research Center, Napoli, 80055, Italy

Corresponding Author e-mail: gabriella.fiorentino@uniparthenope.it

Abstract

Waste disposal has recently become a controversial issue in many European countries: concerns about potential health effects and land value loss as well as the fulfillment of the European Landfill Directive and Waste Framework Directive have significantly changed the way waste should be managed. An efficient management of municipal solid waste (MSW) allows a significant enhancement of efficiency in resources use, by recovering both energy and materials from wastes, otherwise landfilled, thus replacing fossil fuels and virgin materials with renewable sources. Significant efforts are required to devise alternative waste management strategies, merging together the development of new advanced technologies and a totally new approach to the concept of waste. One of the main focus of treating MSW is energy recovery, as waste is known to contain a considerable amount of bio-waste and therefore can generate renewable energy. This paper presents a comprehensive system study of a recently developed technology proposed to meet up, in the next future, the power supply for city dwellers and to reduce space needed for new landfills. As part of a wider Life Plus Project entitled MARSS (Material Advanced Recovery Sustainable Systems), funded by European Community in 2012, an environmental assessment of an innovative pilot plant located in Mertersdorf (Germany) was performed by means of SimaPro 8.0 software, utilizing ReCiPe (H) Midpoint method for the impact assessment. The plant under study has the aim to concentrate the biodegradable part of MSW in the <40 mm fraction, through a series of cleaning and recovery steps, to remove contaminants and obtain a suitable biomass fuel with a final marketable quality for biomass power plants for the urban decentralised production of heat and power (CHP). This study aims at understanding to what extent the MARSS plant is environmentally sound, by pointing out the environmental advantages of replacing fossil fuels with local MSW for renewable energy production, and if there are steps and/or components that can be further improved. Our findings provide a quantitative understanding of the MARSS technology, showing that proper operation of the plant can lead to substantial reduction of environmental impacts and savings of resources and energy, offering a technical solution to those cities/countries without access to other Waste-to-Energy treatment facilities.

1. Introduction

The effort of European member states to comply with the EU Landfill Directive (EU Directive 1999/31/EC), according to which only a limited amount of biodegradable Municipal Solid Waste (MSW) can be landfilled, has translated in the last decades in the proliferation of Mechanical-Biological Treatment (MBT) plants all over Europe and not only (Gunawardana et al., 2009; Mollare and Le Bozec, 2009; Velis et al., 2009; Montejo et al., 2010; Tintner et al., 2010; Pires et al., 2011). MBT, followed by energy recovery and direct disposal through landfilling, represents a valid alternative to thermal Waste to Energy (WtE): processing of MSW in MBT plants is intended to reduce the biodegradable fraction of waste to which the main polluting emissions (gas, leachate) are associated. As a consequence, the long term pollution potential of landfills is decreased, in the overall purpose of protecting environment and human health (Heyer et al., 2013; Siddiqui et al., 2013).

MBT plants integrate mechanical processing with a bioconversion step (Bilitewski et al., 2011). Generally, the mechanical phase consists of a combination of sorting, separation, shredding and screening, to maximize the recovery of recyclables from mixed waste streams and prepare the remaining waste for subsequent biological processing. The biological treatment consists of composting or anaerobic digestion (or both), to reduce the biodegradability of the residual material which is then usually burned as Refuse Derived Fuel (RDF) or landfilled. The removal of certain waste fractions during mechanical processing and the partial degradation during the biological step ensure a lower polluting load of MBT waste in landfills than that of unprocessed MSW.

Therefore, on the one hand, MBT technologies allow the recovery of additional resources and broaden the range of possible energy recovery applications, including high efficiency industrial processes (Cimpan and Wenzel, 2013). In particular, energy recovery from MSW, in the form of electricity and/or heat production, is a valuable option, due to the biogenic origin of most of the carbon contained in MSW that allows to classify MSW as an at least partially renewable energy source (Fellner et al., 2007; Gohlke, 2009; Palstra and Meijer, 2010). In so doing, the EU's Renewable Energy Directive, that sets a binding target of 20% final energy consumption from renewable sources by 2020 (EU Directive 2009/28/EC), is addressed as well.

On the other hand, MBT technologies increase system complexity, by adding inherent system losses and requiring additional energy consumption. Many studies have been carried out to assess the environmental performance of MBT technologies, especially versus WtE, but still consistent research efforts have to be made to demonstrate their environmental, resource and socio-economic relevance (Velis and Cooper, 2013).

In this paper, the Life Cycle Assessment (LCA) methodology was adopted to evaluate the environmental performance of an innovative MBT plant, proposed in the framework of the EU Life Plus Project MARSS (Material Advanced Recovery Sustainable Systems) (www.marss.rwth-aaachen.de) and currently operating in Mertesdorf (Germany) at pilot plant scale. The technology of the MARSS plant aims at concentrating the biodegradable part of MSW in the <40 mm fraction, through a series of cleaning and recovery steps, to remove contaminants and obtain a suitable biomass fuel with a final marketable quality for biomass power plants for the urban decentralised production of heat and power (CHP). By comparing environmental benefits and drawbacks deriving from its implementation, a contribution to the correct development of waste management strategies is provided as the main goal of this study.

2. Description of the MARSS plant

The MARSS demo plant is developed in the framework of MARSS “Material Advanced Recovery Sustainable Systems”, a Life+ Project founded by EU in 2012.

After being collected and transported, mixed municipal solid waste (hereinafter indicated as MMSW) is treated via Mechanical Biological Treatment (MBT): waste is dried (with an efficiency of 35% water losses) and then sorted to recover ferrous and non-ferrous metals (with a recovery rate of 1.3% and 0.4%, respectively, of the total waste input), translating into the production of a dry fraction (which is traditionally sent to WtE plant). The MBT plant investigated in this study is located in the municipality of Mertesdorf in the region of Trier, Germany. The owner and the operator of the MBT plant is RegEnt (a consortium responsible of waste collection and treatment in the region) and the MBT plant is designed to treat 120,000 tons per year. In the innovative system (MARSS), consisting of additional refining steps downstream of the traditional MBT plant, the dry fraction undergoes size reduction and the materials with organic content are sorted. Processing lines include a combination of processes including magnets, blowers, windshifters, eddy currents etc. Results of preliminary laboratory tests show that the organic material can be concentrated in the MMSW fraction with size ≤ 40 mm and selected, through a series of cleaning and recovery steps, at a recovery rate of at least 30%, corresponding to more than 45% of the dried MMSW (Clausen et al., 2013). The selected fraction, with a Lower Heating Value of 12 MJ/kg, meets requirements for being used as Renewable Refine Biomass Fuel (RRBF) in biomass power plants. The advantage would be that the RRBF from the MARSS process can be accepted for combustion in CHP biomass-based plants, the performances of which – regulated by the European law – are claimed to be more environmental friendly under correct management. The fraction of the MARSS plant output, containing more than 95% of biogenic materials, is directly combusted in fluidized bed reactors for Combined Heat and Power production (CHP). In addition to the main plant, pollution control units are operating: a wastewater treatment plant, where leachate produced in various compartment are treated, biofilters, scrubber and regenerative thermal oxidation (RTO) unit for dust removal.

3. Method: Life Cycle Assessment

Life Cycle Assessment is a methodological framework to assess the potential environmental impacts and resources used throughout a product's lifecycle, from raw material acquisition, via production and use phases, to waste management. All activities and processes result in environmental impacts due to consumption of resources, emissions of substances into the natural environment, and other environmental exchanges. In other words, LCA looks at the process relation with the environment as a source and as a sink, and provides indicators related to many different environmental impact categories, such as climate change, stratospheric ozone depletion, depletion of resources, toxicological effects, among others (Pennington et al., 2004). In the evaluation of a process, identifying "hot spots" facilitates prioritization of activities to improve its environmental performance. LCA allows technology comparisons in terms of environmental burden, providing valuable insights about the environmental performances of different technologies across categories (Sathaye et al, 2011). Although developments of the tool continue to be achieved, International Standards of the ISO 14000 series provide a consensus framework for standardized LCAs (ISO 2006 a,b). The ILCD Handbook, stemming from the ISO 14040-44 standards, confirms the importance and the role of LCA as a decision-supporting tool in contexts ranging from product development to policy making. The Handbook provides clear and goal-specific methodological recommendations, specific terminology and nomenclature, an accurate verification and review frame other supporting documents and tools. According to the ILCD handbook, an LCA consists of four phases. The main aspects of the analysis are summarized in the following points.

3.1 Goal of the study, Functional Unit and System Boundary

The aim of this LCA study is to calculate the amounts of material and energy resources required, the emissions generated, and the contribution to environmental impact categories of the MARSS plant from an output-oriented perspective. Furthermore, the exergy balance, meaning the ratio between the exergy gained from plants outputs and the exergy invested for the plant construction and operation is also explored in order to evaluate the energetic feasibility of the MARSS plant.

The functional unit, that is a quantitative identification of the function/product of the studied system providing a reference to which the inputs and outputs can be related, is a key element of LCA that has to be clearly specified, so that all input and output flow can make reference to it (Laurent et al., 2014 a,b).

Although several studies claim that for waste management the functional unit must be defined in terms of system's input (e.g. Cherubini et al., 2009; Clearly et al., 2009), in this study the environmental impacts are analyzed with reference to one kWh of exergy (1 kWhex) delivered, i.e. gained from plant outputs, as alternative to a unit of waste input. The following equation was applied to the output power, in order to convert energy flows to exergy:

$$\text{Exergy delivered } (kWh_{ex}) = \text{Electricity delivered } (kWh_{el}) + \varsigma_{th} * \text{ Heat delivered } (kWh_{th}) \quad \text{Eq (1)}$$

where $\varsigma_{th}=1-(T_a/T_d)$ is the Carnot factor. T_a is the ambient temperature and T_d the temperature of heat delivered (assumed to be 293 K and 473 K, respectively). In so doing, process performances related to both a service perspective (waste disposal) and a product perspective (energy and material recovery) were taken into account.

The LCA system boundary is the interface between the waste management system and the environment or other product systems. Typically, the life cycle starts once a material or product becomes waste (McDougall et al., 2001). Upstream burdens for the production and use of the materials that end up in waste are not considered based on the ‘‘zero burden’’ assumption used in LCA of waste management systems (Ekvall et al., 2007). In our case, the start of the life cycle of the waste is the gate of the plant.
During the treatment process, recovered and utilized materials and energy are generated, and accounted for as functional outputs from the system. In the consequential perspective (Laurent et al., 2014b), these outputs (electricity, heat and metals) are modelled to include the markets in which they are sold and in which they replace alternative supplies of the same functional outputs. The scope of the modelled system is, then, expanded to include these replaced alternative flows, also called avoided flows. The waste treatment system is, thus, credited with substituting a similar amount of materials or energy produced from primary sources.

3.2 Life Cycle Inventory and main assumptions

During the inventory phase, local data were collected for construction and operative phases: all different materials (e.g. concrete, steel, glass), machinery, as well as the energy consumption and local direct emissions for construction and plant operation. The data used for this study refer to the year 2013. Construction inputs have been amortized over plant life time (20 years). Background data referring to the supply chain of energy and materials were derived from the Ecoinvent library (Ecoinvent, 2014). According to the in progress experimentation, only the 50% of the dried waste exiting the MBT step forms the RRBF going to CHP. The remaining 50% (dry fraction without organic fraction) is disposed of in a landfill (not considered in the current study). Electrical and thermal efficiencies of average European CHP plants were used for calculations, respectively as 14.2% and 45.9% (Reimann, 2009; Lombardi et al., 2014). The primary data regarding the MARSS plant were collected within the framework of the MARSS Project, whilst operative data and emissions of an appropriate CHP for dry biomass combustion were taken from Ecoinvent database. Wastewater treatment, airborne and waterborne emissions were also accounted for. Since the MARSS RRBF combustion tests are still under experimentation and monitoring, airborne emissions from combustion were assumed to be the same as those resulting from wood combustion in a biomass power plant, considering that the final goal of the MARSS project is exactly the extraction of a refined organic fuel from waste that can be authorized as biomass fuel.

3.3 Life Cycle Impacts Assessment

Direct and indirect environmental impacts of the construction and operation of the plant are accounted for, taking into account the life time and needed maintenance of each component. LCIA was performed by means of the LCA software SimaPro 8.0.3.14. Among the impact assessment methods, the ReCiPe Midpoint (H) v.1.10 (http://www.lcia-recipe.net/) was chosen, considering that it includes both upstream and downstream impact categories, among which fossil depletion (Frischknecht et al, 2007). Moreover, the ReCiPe Midpoint (H) method allowed to assess the environmental impacts in different impact categories of interest in waste management (e.g. global warming, abiotic depletion, acidification, eutrophication). The ReCiPe method provides characterization factors to quantify the contribution of processes to each impact category and normalization factors to allow a comparison across categories (Europe ReCiPe Midpoint (H), 2000, revised 2010) (Wegener Sleeswijk et al., 2008). Normalization is a life cycle impact assessment tool used to express impact indicator (characterized) data in a way that can be compared among impact categories. This procedure normalizes the indicator results by dividing characterized values by a selected reference value. There are numerous methods of selecting a reference value, including, for example, the total emissions or resource use for a given area that may be global, regional or local. In this study, the following categories were explored: Global Warming Potential (GWP, in kg CO_2 eq), Terrestrial Acidification Potential (TAP, in kg SO_2 eq), Human Toxicity Potential (HTP, in kg 1,4-DB eq), Photochemical Oxidant Formation Potential (POFP, in kg NMVOC), Terrestrial Ecotoxicity Potential (TEP, kg 1,4-DB eq), Water Depletion (WD, in m^3), Metal Depletion (MD, in kg Fe eq), Fossil Depletion (FD, in kg oil eq).

In order to evaluate the energetic feasibility of the plant for urban energy applications, an exergy ratio was calculated as follows:

Exergy Ratio = Exergy delivered (kWh_{ex}) / Exergy invested (kWh_{ex}) Eq (2)

where Exergy delivered is the total exergy gained from the outputs (electricity, heat and metals) and Exergy invested accounts for all cumulated exergy along the whole chain of operations of the system. The value of FD (kg oil eq.) was converted into exergy (kWh_{ex}) by means of chemical exergy content of oil components (Szargut et al., 1988), thus providing the total exergy invested into the system.

4. Results

The MBT plant under investigation was firstly assessed using an attributional approach, in order to identify physical flows, resources consumption and emissions to the environment, with reference to one ton of waste processed in the plant and one kWh of exergy delivered to the final user, as input and output functional units. The avoided costs, deriving from the production of electricity and heat and the recovery of ferrous and non-ferrous metals were then considered in a consequential perspective (Ekvall and Andrae, 2006; Sanden and Karlstrom, 2007) In both analyses, impacts deriving from the construction phase of the MBT plant were distinguished from the impacts related to its operative phase.

In Table 4.1 the characterized results of the attributional approach are listed, with reference to the functional unit of 1 kWh of exergy delivered. Metal Depletion is the only category where the highest contribution, corresponding to about 60% of the total impact, arises from the construction phase, likely due to the high supply of metals needed for the implementation of the plant and the production of machineries, mostly consisting of steel. Concerning all the other categories, the operative phase of the MBT plant is heavily more impacting than the construction, with contributions that in most cases account for over the 90% of the total impacts.

Special attention was focused on the FD impact category, that indicates the requirements of fossil resources for implementing the MARSS plant. If the total impact of 13.72 kg oil eq is translated in terms of exergy invested in the construction and operation of the plant, according to the description given in Section 3.3, the entailed exergy input for the production of 1 kWh_{ex} amounts to 0.18 kWh_{ex}, thus allowing an exergy ratio of 5.60. This means that the construction and operation of the MARSS plant is feasible from an exergetic standpoint, offering the double advantage of treating waste and recovering exergy.

Table 4.1: Characterized impacts calculated for construction and operative phases of the MARSS plant (attributional approach, referred to a functional unit of 1 kWh of exergy delivered).

Impact category	Unit	Total impact	Construction phase	Operative phase
GWP	kg CO_2 eq	46.16	4.11	42.05
TAP	kg SO_2 eq	1.53	0.04	1.49
HTP	kg 1,4-DB eq	34.32	3.31	31.01
POFP	kg NMVOC	0.07	0.02	0.05
TEP	kg 1,4-DB eq	0.01	0.00	0.01
WD	m^3	130.48	12.26	118.21
MD	kg Fe eq	2.66	1.57	1.09
FD	kg oil eq	13.72	1.04	12.68

If impacts are normalized according to Europe ReCiPe Midpoint (H) method normalization factors, a comparison among impact categories becomes possible (Figure 4.1): HTP and TAP result the most affected categories, with calculated total impacts of 5.46E-02 and 4.45E-02, respectively. Also in this case, the contribution deriving from the operative phase is predominant in all the impact categories, except from MD. WD is not detectable at all, due to the normalization factor equal to zero, and therefore it is not shown in the Figure.

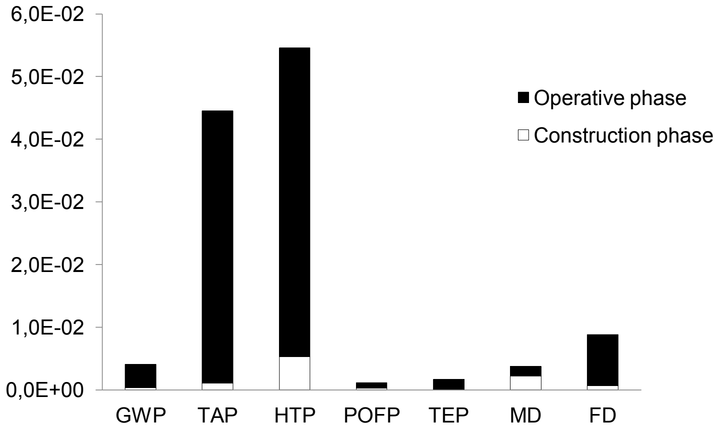

Figure 4.1 Normalized impacts calculated for construction and operative phases of the MARSS plant (attributional approach, referred to a functional unit of 1 kWh of exergy delivered).

A further analysis of the operative phase was carried out (data not shown), in order to identify the hotspots of the system in deeper details: as far as HTP is concerned, 50% of the total impact is caused by the dedusting process and by the cooling circuit, due to very high electrical consumption. In the case of TAP, 96% of the total impact derives from the Regenerative Thermal Oxidation (RTO) unit for purification of waste air.

When a consequential approach is adopted, the system boundaries are typically re-defined to include the activities that might benefit from using recovered resources in order to generate different environmental consequences as a follow up of changes of resources used (e.g., use of recovered resources *versus* virgin resources). In the present study, environmental costs of goods and energy (i.e. electricity, heat and metals, both ferrous and non-ferrous) produced by the system under investigation are detracted from the accounting of the system's impacts, considering that their production by conventional routes is avoided.

Table 4.1: Total characterized and normalized impacts calculated for the MARSS plant (consequential approach, referred to a functional unit of 1 kWh of exergy delivered).

Impact category	Total characterized impacts	Total normalized impacts
GWP	-1.53E+02 kg CO_2 eq	-1.36E-02
TAP	1.31E+00 kg SO_2 eq	3.82E-02
HTP	-6.56E+02 kg 1,4-DB eq	-1.04E+00
POFP	2.92E-02 kg NMVOC	5.14E-04
TEP	-1.55E-02 kg 1,4-DB eq	-1.88E-03
WD	-5.46E+02 m^3	0
MD	-2.24E+02 kg Fe eq	-3.14E-01
FD	-3.24E+01 kg oil eq	-2.08E-02

If the characterized and normalized results of the consequential approach are taken into account (Table 4.2), the negative values indicate that the recovery of ferrous and non-ferrous metals as well as the production of electricity and heat from MMSW allow savings in the production of virgin metals, electricity and heat by conventional routes so that impacts become negative and an environmental benefit is attained. Positive values of consequential impacts are calculated only for TAP and POFP categories, but these values are in any case minor than the corresponding attributional impacts. The most advantaged category is HTP, followed by WD and MD. Analogous trends are observed for both characterized and normalized impacts.

5. Conclusion

When we talk about residual waste we usually mean waste that is a mixture of different things. In future we are aiming to prevent, reuse and recycle more of our waste, so the amount of residual waste should go down. Residual waste is mixed waste that cannot be usefully reused or recycled. It may contain materials that could theoretically be recycled, if they were perfectly separated and clean, but these materials are currently too contaminated for recycling to be economically or practically feasible. It is important that the presence of energy recovery as an option does not diminish efforts to overcome the range of barriers to capturing and recycling these. However, it is equally important that while those barriers do exist, energy from waste is used effectively to ensure those materials do not go to a worse environmental fate in landfill. Of course, this implies a change of perspective that is not necessarily justified by the specific local needs (waste disposal *versus* energy recovery) because the two perspectives are not opposite to each other and may instead offer synergic information for management.

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Energy efficiency and recycle patterns scenarios for urban wastewater and sewage sludge treatment.

Elvira Buonocore[1] *, Salvatore Mellino[1], Gengyuan Liu[2], Giuseppe De Angelis[2], Linyu Xu[2], Antonio Puca[2], Gaetano Protano[1], Sergio Ulgiati[1,2].

[1] Department of Science and Technology, Parthenope University of Naples, Centro Direzionale-Isola C4, 80143 Napoli, Italy

[2] State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Beijing Normal University, Beijing 100875, China

*Corresponding Author e-mail: elvira.buonocore@uniparthenope.it

Abstract

Growing concerns about environmental impacts associated with the use of fossil fuels, national energy security, global warming and sustainability issues lead cities to pay more attention on energy efficiency and the environmental impacts of their production activities and services. Energy consumption in wastewater treatment (WWT) plants and the related (GHG) emissions are steadily increasing due to strict treatment requirements. Life cycle assessment (LCA) can be used as a valuable tool to evaluate the environmental impacts associated to WWT plants. In this study LCA is applied to compare the environmental performance of five scenarios for wastewater and sludge disposal in a WWT plant located in southern Italy. The first business-as-usual scenario is based on the present sludge management performed within the case-study plant: after mechanical treatment, dewatered sludge is transported by truck to a landfill for final disposal. The second scenario assumes a circular pattern, with anaerobic fermentation of sludge to biogas, and biogas use for electricity and heat cogeneration: electricity is feedback to WWT, while heat is used for digestate drying, in addition to thermal energy from previously recovered waste cooking oil (WCO). The third scenario suggests an improved circular pattern where the dried sludge is further gasified for syngas production and syngas is added to biogas for heat and electricity production. The fourth scenario builds on the third scenario in that the volume of treated wastewater is not discharged into local rivers but is used for fertirrigating *Brassica Carinata* fields close to the WWT plant, thus providing biomass for bioenergy purposes. The last scenario assumes that the electricity used is totally produced from renewable sources. Results suggest that increased circularity through recycling would be capable of reducing the process contribution to several environmental impact categories. The use of a green electric mix (geo + hydro + wind + photovoltaic electricity) would further improve the environmental performance.

1. Introduction

Growing concerns about environmental impacts associated with the use of fossil fuels, national energy security, global warming and sustainability issues lead cities to pay more attention on energy efficiency and the environmental impacts of their production activities and services (IEA, 2014; Moriartya and Wang, 2014). Urban wastewaters are not easy to deal with and require large energy, economic and technological investments for their treatment. Energy consumption in wastewater treatment (WWT) plants and the related greenhouse gas (GHG) emissions are steadily increasing due to strict treatment requirements. Life cycle assessment (LCA) is a valuable tool that can be used to evaluate the environmental impacts associated to WWT plants (Guest et al., 2009).

Many LCA studies dealing with WWT plants have been published in international peer-reviewed journals examining the energy consumption, GHG emissions of existing plants as well as the potential energy and GHG emission benefits that can be achieved by introducing new alternative technologies (Hospido et al., 2005; Corominas et al., 2013; Cao and Pawłowski, 2013).
In this paper LCA is used to compare the environmental performance of different scenarios for sludge management in a WWT plant located in the municipality of Nocera Superiore, in the province of Salerno, southern Italy. The different scenarios aim at decreasing the amount of sludge disposed of in landfill as well as at increasing the energy efficiency of the different process steps via increased recycling of still usable waste resources.
One of the options assumes the use of biogas from anaerobic digestion of sludge together with recovered waste cooking oil (WCO) for sludge drying. The reuse of WCO within the WWT plant is a valuable alternative since uncontrolled disposal of WCO may cause severe environmental problems (Ripa et al., 2014).
Sewage sludge gasification for syngas production and the cogeneration of heat and electricity from syngas combustion are also considered within a circular pattern designed to save on the transport and land-filling of sludge, on the thermal energy required for sludge drying and on the electricity consumption within the wastewater treatment plant.
Another scenario assumes the reuse of treated wastewater for fertirrigating *Brassica Carinata* fields (Fiorentino et al., 2014). The use of wastewater for irrigation and fertilization of substrates that can also be used for energy purpose reduces water pollution in the form of eutrophication, allows non-negligible energy savings and contributes to renewable energy generation (Buonocore et al., 2012).
Finally, a green electricity mix is supposed to be used within the WWT plant. Conventional electricity generation is a significant source of greenhouse gas emissions. The emissions from conventional electricity generation contribute to a number of serious environmental problems, including acid rain, fine particulate pollution, and climate change (EPA, 2010). Green power generates less pollution than conventional power and produces no net increase in greenhouse gas emissions, helping protect human health and the environment.

2. Methods

The methodological framework used in this paper is the LCA as defined by ISO and ILCD standards (International Standard Organization, ISO 14040/2006, ISO 14044/2006, ILCD, 2010 a,b).
A typical LCA study consists of the following stages:

- Goal and scope definition phase, where the final goal of the LCA is stated and the central assumptions and choices in the assessment are identified.
- Life Cycle Inventory (LCI) phase, where input and output flows of matter and energy are quantified for the investigated process. For an LCA study, two types of data are usually required: specific inventory data about the foreground system, and average or generic data about the background system.
- Life Cycle Impact Assessment (LCIA) phase, where the collected input and output flow data are translated into indicators that reflect the pressure on environment and human health as well as the potential or actual resource scarcity.

- Interpretation phase, where the results of the life cycle assessment are interpreted according to the goal of the study to answer questions posed in the goal definition. In this phase the significant issues are identified and evaluated and conclusions and recommendations are developed.

In this study the treatment of 1000 m^3 of wastewater was chosen as functional unit. All materials, emissions, cost, energy consumption, and recovery levels are referred to this amount of water to be treated.
Among the impact assessment methods, the ReCiPe midpoint[1] was chosen. The ReCiPe midpoint method allowed to assess the environmental impacts in different impact categories (e.g. global warming, abiotic depletion, acidification, eutrophication). The method provides characterization factors to quantify the contribution to impact categories and normalization factors to allow a comparison across categories.

3. Scenarios description

Five scenarios for wastewater and sewage sludge treatment are considered in this study.

The first scenario (Scenario A, BAU, business-as-usual) is based on the wastewater treatment process actually performed in the WWT plant located in the municipality of Nocera Superiore, southern Italy. The sludge line includes dynamic thickening and belt press dewatering while anaerobic digestion with biogas recovery and heat drying are not in operation for technical and administrative reasons. Disposal of wet sludge is forbidden in Campania region, due to environmental concerns. For this reason, the wet sludge is transported to Puglia Region for disposal in a controlled landfill (the average transportation distance is 200 km).

The second scenario (Scenario B) assumes the anaerobic digestion of sewage sludge with biogas recovery within the WWT plant (already existing machinery in the WWT site) and its use for cogeneration of heat and electricity. Electricity is fedback to the WWT process, in order to lower the huge demand for grid power. Heat is used for downstream thermal drying of digestate, in order to lower its mass and make transportation less energy expensive. Moreover, while wet sludge cannot be disposed of in Campania region, dry sludge disposal in local landfills is allowed. As a consequence, transport distance decreases to 30% of the distance in scenario BAU. Thermal drying of digestate also benefits from the use of heat from WCO collected from restaurants, hotels and agro-food industry in Campania Region (Ripa et al., 2014).

The third scenario (Scenario C) suggests a furtherly circular pattern: the sludge is dried by utilizing biogas and oil and the residual mass is gasified for syngas production. Syngas is added to previously produced biogas for power cogeneration. Then, the heat and electricity generated are fedback to the WWT plant as in scenario B. The feedback of electricity further lowers the demand for grid power of BAU scenario.

The fourth scenario (Scenario D) is based on the same assumptions of Scenario C except for the final disposal of wastewater. This Scenario assumes that the volume of treated wastewater is not discharged into surface waters but it is used for irrigating

[1] http://www.lcia-recipe.net/

2000 ha of *Brassica Carinata* fields in the same area where the WWT plant is located. Fertirrigation decreases the eutrophication impact of the nitrogen still contained in treated wastewater. The irrigation with nutrient-rich water would promote plant growth, thus resulting in high biomass yield that could be used for further bioenergy purposes.

The last scenario (Scenario E) assumes that the electricity used in the BAU scenario is totally produced from renewable sources. The “ Enel Green Power ” mix adopted includes 57.3% of wind, 29.2% of hydroelectric, 9.0% of geothermal, 3.4% of solar and 1.1% of biomass.

The Ecoinvent 2.2 database is used for relevant background data of anaerobic digestion, syngas production, oil combustion, power cogeneration and irrigation processes.

4. Results and discussion

The total contribution per 1000 m^3 of wastewater (functional unit) of the investigated scenarios to selected impact categories is displayed in Table 1. The characterized impacts of the five scenarios are shown as percentages in Figure 1. The potential improvements that could be achieved in scenarios B, C, D and E are compared to the results of scenario A (put conventionally at 100%).
Results show that the contributions to the chosen impact categories decrease in Scenarios B, C, D and E confirming the important role played by a better management of wastewater and of the sewage sludge conversion and use of its residual energy content.
The best performance in most of the impact categories is achieved in Scenario C that represents a circular pattern where sludge is not disposed in landfill but further processed to generate syngas. As a result of this “towards zero-emission” oriented production pattern, where waste generated by a process can be used and upgraded as input to support another process, the overall generation of waste and emissions decreases significantly. Such a perspective should represent a valuable option for a sustainable management of wastewater and sewage sludge. However among the impact categories, the freshwater eutrophication (FEP) results to be lower in scenario D (almost 90% lower than the other scenarios). The abatement of the eutrophication impacts in scenario D is due to the utilization of wastewater for growing energy crops that avoids the discharge of nutrients rich water in surface waters.

Another interesting finding is the decrease of all the impact categories in scenario E compared to scenario A. The fossil depletion and climate change categories decrease by 70% and 40%, respectively. The same improvements would be obtained if the green mix was assumed in all the other scenarios. These results confirm the importance of substituting conventional power generation with green power.

Figure 2 shows the normalized impacts of the five scenarios to impact categories. Normalization is an optional step in LCA that allows comparison across categories. The most impacted category results to be the eutrophication potential in all the scenarios except for Scenario D. This finding is due to the high content in nitrogen and phosphorus in wastewater mainly deriving from human waste, detergents and fertilizers. Wastewater discharges are understood to make a significant contribution to the problems of eutrophication and Scenario D seems to be a valuable option for reducing the nutrient pollution of surface waters. Still the irrigation process is energy intensive and for this reason the contributions of Scenario D to all the other impact categories result higher than Scenario C. The second most impacted category is human toxicity. The high contribution to human toxicity is associated to the massive use of stainless steel for the construction of the WWT plant. The production processes of the stainless steel releases chromium compounds that are toxic for human health. Such an impact, occurring out of the plant boundary, could be reduced by replacing stainless steel with lower impact materials.

It is clear that all potential improvement strategies for wastewater and sludge management need to be carefully evaluated and LCA proves to be a most suitable tool to such purpose.

Table 1. Total contribution of the five scenarios to impact categories. Values are referred to 1000 m^3 of waste water treated (functional unit).

Impact category	**Scenario A**	**Scenario B**	**Scenario C**	**Scenario D**	**Scenario E**
Climate change-GWP (kg CO_2-Eq)	657.05	646.69	373.79	423.47	395.98
Fossil depletion-FDP (kg oil-Eq)	129.01	105.09	67.14	89.14	37.29
Freshwater eutrophication-FEP (kg P-Eq)	0.83	0.82	0.80	0.08	0.78
Human toxicity-HTTP (kg 1,4-DCB-Eq)	184.29	169.28	92.45	108.91	156.25
Particulate matter formation-PMFP (kg PM10-Eq)	0.59	0.49	0.36	0.46	0.32
Photochemical oxidant formation-POFP (kg NMVOC)	1.40	1.10	0.74	0.95	0.68
Terrestrial acidification-TAP (kg SO_2-Eq)	1.65	1.41	0.96	1.15	0.99

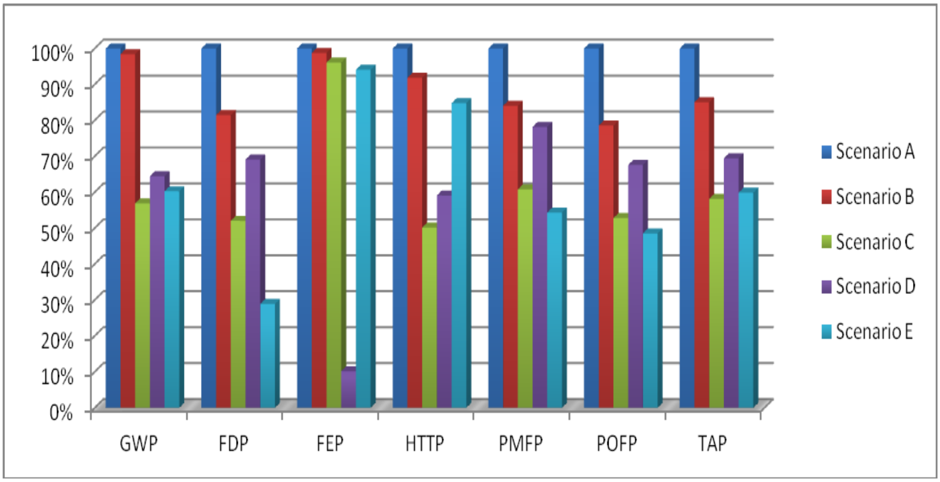

Fig. 1: Characterized impacts of the five scenarios (percentage values; data from Table 1).

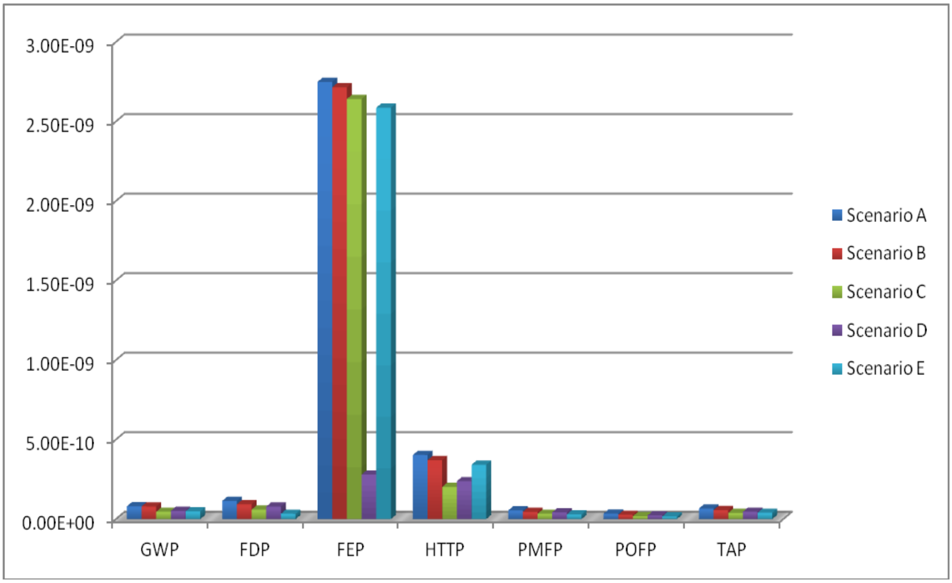

Fig. 2: Normalized impacts of the five scenarios to impact categories.

Conclusions

Life cycle assessment allowed to compare the environmental performance of different scenarios for wastewater and sludge management. Results showed that the most desirable option would be a circular pattern where sludge is not disposed in landfill but processed to generate biogas and syngas to be further combusted for the generation of electricity and heat, for internal use in the WWT plant. Still, this scenario highly impacts the eutrophication potential category because of the discharge of nutrient rich wastewater in surface waters. This problem could be solved by utilizing wastewater for the irrrigation of energy crops (Scenario D). On the other hand, the irrigation process is energy intensive, thus causing higher impacts to other impact categories while improving FED. It is evident from the investigated case study that new and improved processes and technologies enable significant opportunities for reducing the environmental impacts of WWT plants, but each option needs to be carefully evaluated over the entire life cycle, according to the particular context in which the WWT plant is located.

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Systemic behavior of a Brazilian municipality whose economy is based on agricultural commodities

Luz Selene Buller*[1], Enrique Ortega[2], Marilia Ribeiro Zanetti[3], Ivan Bergier[4]
[1,2,3] Ecological Engineering Laboratory, State University of Campinas, Campinas-SP, Brazil
[4] Biomass Conversion Laboratory, Brazilian Agricultural Research Corporation, Corumbá-MS, Brazil

Abstract

The municipality evaluated is São Gabriel do Oeste, located in the state of Mato Grosso do Sul, Brazil. In the 1960's the region was occupied by migrants from southern Brazil who have converted native vegetation (savanna) into extensive cattle and monocrops (coffee, cotton, soybeans and corn, successively), and more recently intensive swine was introduced. The following emergy indicators were calculated for the current municipal situation: Renewability (%R): 8%; Emergy yield ratio (EYR): 14; Emergy investment ratio (EIR): 0.08; Environmental loading ratio (ELR): 11; Emergy exchange ratio (EER): 13 and Transformity of the commodities: $8x10^5 seJ.J^{-1}$. The very low %R and high environmental pressure (ELR) signalize that the municipality's economy is highly dependent on external inputs. Above all, there is a high loss of system internal stocks (soil) and the high EYR obtained is directly related to this predatory land use. The emergy value of the soil loss is 83% of the total emergy, which is an environmental imbalanced situation. The main land use in São Gabriel do Oeste, accounting for 39% of the territory, is extensive cattle farming that demands few agricultural inputs, what explains the very low EIR. The EER shows that the rural area is subsidizing urban economies that import products from the study area. The real value of the agricultural products should be 13 times the market value of such commodities to be considered as a fair trade. The inclusion of soil loss as a negative externality shows that (in economic terms) the amount of soil lost by erosion and leaching ($4,149x10^6$ $emUSD.year^{-1}$) corresponds to 46% of the total production monetary value ($9,018x10^6$ $emUSD.year^{-1}$). The emergy diagnosis shows that the business model established for commodities producers is highly dependent on the external market, which does not remunerate the imported resources accordingly to its real value. To settle this situation, a dialogue between farmers, consumers and authorities should be established. The latter two should involve not only local representatives as well as players of the importing countries.

1. Introduction

Brazil is a leading global producer of agricultural commodities at the expense of vast areas of forests and savannas converted into farmland, a phenomena that was intensified during the 1990's when cropland area and cattle herd increase coincided with the greatest deforestation of Amazonia and Cerrado (Lapola et al., 2014). Although the agroindustry accounts for 25% of the country's gross domestic product (GDP) this commoditized economy generates environmental and social inequalities in terms of soil and water resources degradation (Bergier, 2013, D'Odorico et al., 2010), unfair income distribution and land concentration in the hands of a few large landowners (Abbey et al., 2006). Historically, Brazilian agricultural activities were concentrated in the South and Southeast regions. However, due to this economic concentration, uneven demographic densification and the need to increase productivity, the Brazilian government has promoted several programs of agricultural expansion in the country's Midwest region (WWF, 2000). In the last three decades, this expansion contributed to the depletion of local natural resources accelerating the degradation of the Cerrado (WWF and CI, 2009). Currently, 50% of this biome is occupied by agriculture and in the last two decades it has been observed a pronounced conversion of Cerrado to soybean monoculture (Lapola et al., 2014). From 2000 to 2014 soybean harvested area throughout Brazil expanded in 116%[1]. In addition, the Cerrado biome has inherent characteristics of rainfall, soil and relief that represent high potential for laminar erosion, and the areas covered by Lithosols and Quartz Sands offer higher sediment yield risks (Galdino et al., 2006). The land use for agriculture should be done in such a way to minimize erosion and this requires crops management (pastures, soybeans, etc.) to provide a good vegetation cover in the soil surface, especially in the rainy season associated with soil conservation practices to reduce runoff and to favor water infiltration. Crop-livestock-forest integration systems has

[1] AMIS Statistics- Agricultural Market Information System, www.statistics.amis-outlook.org/data/index.html

been implemented and researched in the region aiming to reincorporate tree-element in the agroecosystem, to recycle energy, to reduce soil losses and to mitigate other undesired agricultural side-effects in Cerrado (Buller et al., 2014).

The continuous change of Brazilian agricultural scenarios associated with the need for land use change and soil loss diagnoses for a variety of purposes such as monitoring, damage prevention and policy formulation, requires a new approach related to system internal stocks role for a sustainable agriculture. In this work, we propose the inclusion of soil loss as an additional system's externality in the Emergy methodology (which was applied for the entire municipality assessment) in order to understand and measure its magnitude in the Cerrado's agriculture.

2. Methodology

2.1 Study area description

The study area, São Gabriel do Oeste (SGO) municipality (Mato Grosso do Sul state, latitude 18º40'00 "S and 19º35'00"; longitude 54º10'00"W and 54º50'00"), is a typical case of the grain-cattle based economy in the Brazilian Cerrado that suffered massive deforestation (Figure 1). This location is a representative case of land use changes over the past decades. Initially, the municipality economy was based on extensive cattle ranching and subsistence farming. From the 1970's, coffee was introduced by São Paulo (Southeast) and North of Paraná (South) farmers. In the 1990's, a new migratory movement from Santa Catarina and Rio Grande do Sul (South), started with rice, beans, wheat, oats and later large-scale soybeans and corn monocrops, and, at last, intensive swine (Assis et al., 2003).

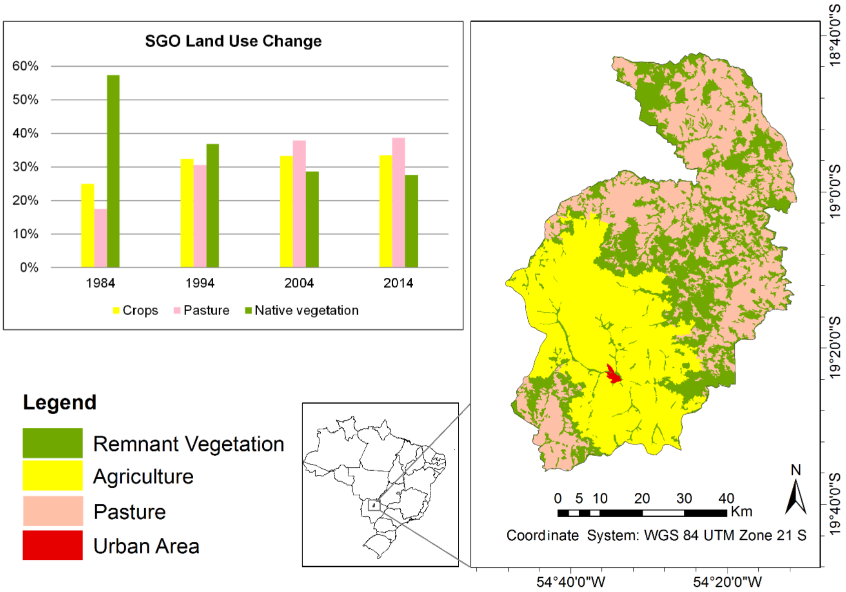

Fig. 1: SGO location map and land use change graph

2.2 Emergy assessment

The Emergy methodology converts all forms of energy, materials and human services into equivalents of solar emergy allowing the establishment of a common basis to compare nature work in natural or human-dominated processes (Odum, 1996). Emergy is an economic-environmental accounting method that considers the biophysical value of renewable and nonrenewable resources necessary for the operation of a system. In general, conventional economic assessments disregard the energy used for biosphere's resources formation and the costs of negative externalities associated to human interferences in the environment. In the present study, the emergy analysis accounts for those externalities as additional services (Ortega et al., 2005) and considers the soil loss flow among them (normally this flow is considered as a non-renewable one). SGO economy data (year 2012) were collected from the Mato Grosso do Sul State Agency of Environment, Cities, Planning, Science and Technology (SEMAC). SEMAC supplied a full report including SGO's production and GDP per economy segments namely: urban, agricultural, livestock, commerce and industry sectors. The report also included City Hall revenue and taxes and fees collection.

The area of native vegetation necessary to mitigate or absorb environmental impact (carbon sequestration) of agricultural occupation was calculated by means of the equation:

$A = F/(NPP*E_b*Tr_b)$, (AGOSTINHO et al., 2007). Where: *F* is the economy emergy flow, *NPP* (Net Primary Production) for the Brazilian Cerrado is 3,700 $kg.ha^{-1}.year^{-1}$ (Meirelles and Henriques, 1992), E_b is the biomass energy estimated as 16,736 $kJ.kg^{-1}$, and Tr_b is the transformity of a typical savanna considered as 4.55E+04 $seJ.J^{-1}$ (Prado-Jatar and Brown, 1997).

3. Results and discussion

Figure 2 shows the systems diagram for the current SGO municipality economy.

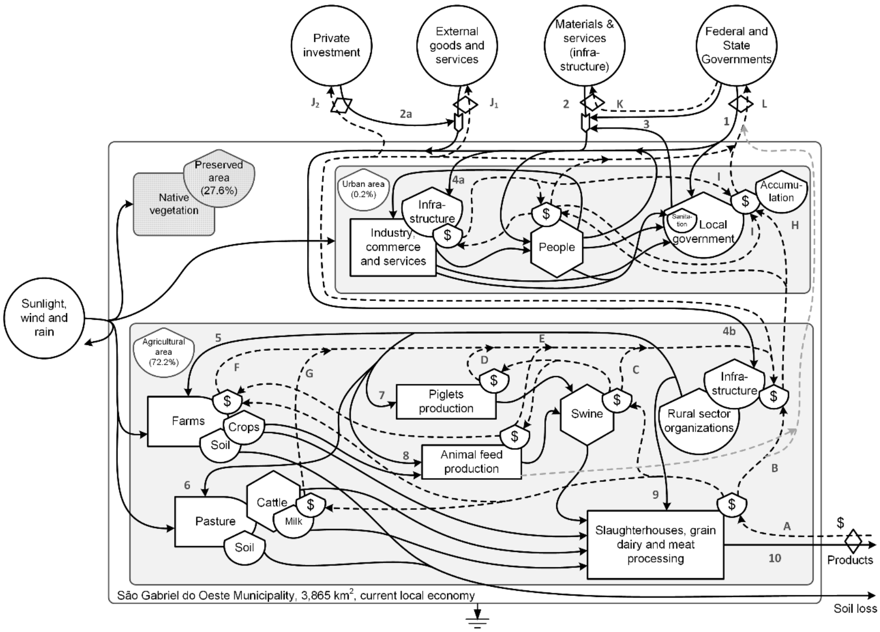

Fig. 2: SGO current economy systems diagram

Flows description is given below:

1- Federal/state governments are "sponsors" of the infrastructure to economic processes used by states and/or municipalities that, in turn, are home to agriculture, industry, trade and services.

2- The production of public infrastructure above mentioned requires materials and services that are distributed in accordance with the needs of each sector.

2.a- In addition, the operation of the several subsystems usually demands other materials and services from the external economy, such as steel and cement for construction, chemicals,

fertilizers, seeds, swine matrices, calves, machinery, electricity (not locally generated), fossil fuels etc. The purchase of these items often requires external economy investments.
3- The local government also contributes to the flow of materials for local infrastructure.
4.a/4.b- Materials and public services are used for the infrastructure for production, transformation and consumption in urban areas (industry, commerce and urban services).
5/6- In the countryside, rural organizations (cooperatives and associations) intermediate materials, goods and services with farmers through their structures or organizations.
7- Rural organizations also work with the piglets' production units interacting with pig farmers who fatten and mostly work in integrated systems (grain and pig farming).
8- Grains flows to market and to animal feed mill (also coordinated by rural organizations).
9- Local organizations also make the intermediation of the sales of agricultural commodities for processing industries (grains and meat processing, dairy, slaughterhouses).
10- The local agroindustry exports the most part of the processed products to regional, national and international markets.

Money circulation- the money from sales firstly goes to the agroindustry (A) who pay suppliers or intermediary organizations (B), local taxes (H) and state/federal taxes and fees (L). Rural organizations pay materials producers (C, D, E, F and G). Payments for the rural products flow to the population (I), both people working in the field and in the city. People consume local industrial goods, trade and services, also external resources and services (J_1 and J_2) and pay for them and for the local and federal governments' taxes and fees. Local governments receive taxes for the maintenance of the public infrastructure (L).

A simplified diagram of the emergy cash flow for economy sectors is presented in Figure 3.

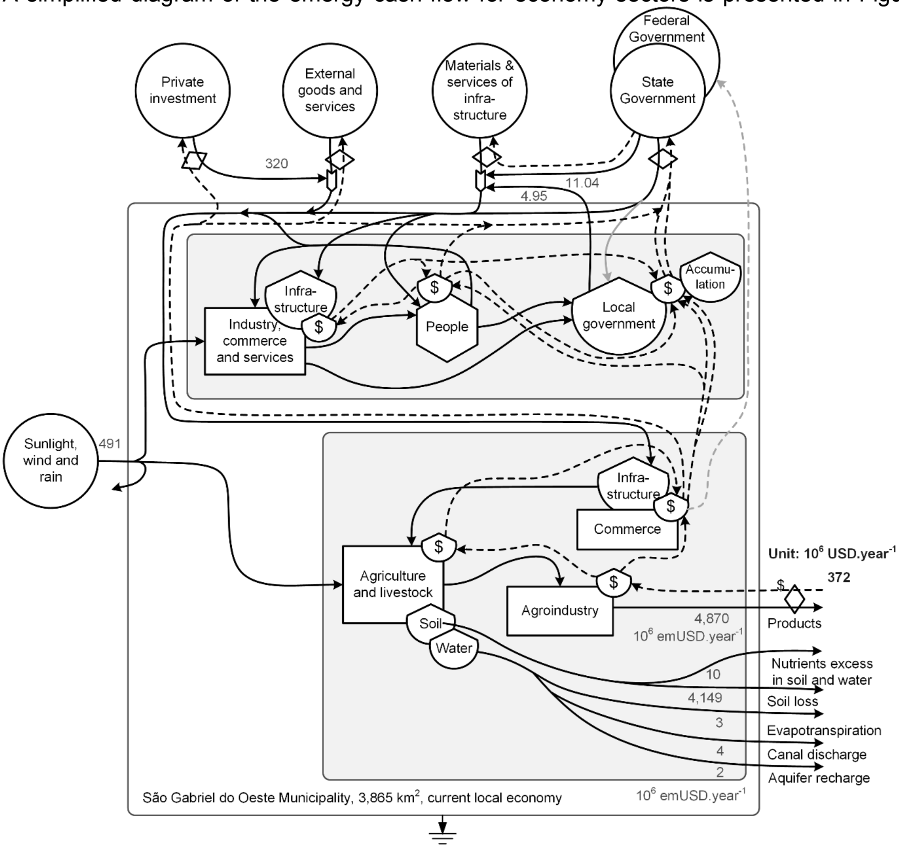

Fig. 3: SGO current economy cash flow systems diagram

The biophysical values of economy materials were replaced by their correspondent values in currency accordingly to the available data provided by SEMAC for this work. The biophysical values are desirable in the emergy method in order to place items in the energy hierarchy and properly consider its role in the system. Anyway, the material unit emergy value (UEV) should consider the economy's services to its production what it is already accounted for in the calculation done through the GDP net of taxes and fees and City hall revenues.

The emergy table (Table 3.1) shows values of renewable flows, materials, services and externalities. The externalities values were based on: a previous valuation of nutrients excess in soil and water for European agriculture (Pretty et al., 2000), evapotranspiration, canal discharge and aquifer recharge for the surrounding region (Watanabe and Ortega, 2014) and soil loss for the study region (Buller et al., 2014). The aggregated emergy indicators calculated (Table 3.2) for the current municipal situation signalize that SGO's economy is highly dependent on external inputs.

Table 3.1: SGO current economy emergy table (baseline: 15.83E+24 seJ.US$$^{-1}$ (Odum et al., 2000))

Item	Description	Flow	Unit	UEV (seJ.unit^{-1})	Ref	Emergy (seJ.year^{-1})	Cash flow (EM$.year^{-1})
Natural resources						8.49E+20	4.91E+08
R_1	Sunlight	2.24E+19	J.year^{-1}	1	a	2.24E+19	9.93E+06
R_2	Wind	9.33E+16	J.year^{-1}	2.51E+03	a	2.34E+20	1.04E+08
R_3	Rain	2.77E+16	J.year^{-1}	3.06E+04	a	8.49E+20	3.77E+08
N	Soil loss	2.89E+16	J.year^{-1}	3.23E+05	c	9.33E+21	4.15E+09
Imports (inputs from the system´s outside)							
Materials and Services from Economy (M)						7.19E+20	3.20E+08
M_1	For the urban sector	3.08E+07	US$.year^{-1}	2.25E+12	b	6.93E+19	3.08E+07
M_2	For agricultural (crops) sector	6.50E+07	US$.year^{-1}	2.25E+12	b	1.46E+20	6.50E+07
M_3	For livestock sector	1.29E+07	US$.year^{-2}	2.25E+12	b	2.89E+19	1.29E+07
M_4	For commerce sector	1.33E+08	US$.year^{-3}	2.25E+12	b	3.00E+20	1.33E+08
M_5	For industry sector	7.76E+07	US$.year^{-4}	2.25E+12	b	1.75E+20	7.76E+07
Services (S)						3.60E+19	1.60E+07
S_1	City Hall services	4.95E+06	US$.year^{-1}	2.25E+12	b	1.11E+19	4.95E+06
S_2	State Government services	1.10E+07	US$.year^{-1}	2.25E+12	b	2.48E+19	1.10E+07
Additional services - Negative Externalities (S_A)						9.35E+21	4.16E+09
S_{A1}	Nutrients excess in soil and water	9.98E+06	US$.year^{-1}	2.25E+12	b	2.25E+19	9.98E+06
S_{A2}	Evapotranspiration loss	2.73E+06	EM$.year^{-1}	2.25E+12	b	6.14E+18	2.73E+06
S_{A3}	Rivers discharge loss	4.04E+06	EM$.year^{-1}	2.25E+12	b	9.09E+18	4.04E+06
S_{A4}	Aquifer recharge loss	1.55E+06	EM$.year^{-1}	2.25E+12	b	3.48E+18	1.55E+06
	TOTAL EMERGY (U)					1.10E+22	4.98E+09
Exports to outside the system (O)		1.39E+16				1.10E+22	4.87E+09
O_1	Soybean	5.91E+15	J.year^{-1}	7.86E+05		4.64E+21	2.06E+09
O_2	Corn	7.22E+15	J.year^{-1}	7.86E+05		5.67E+21	2.52E+09
O_3	Processed meat	7.46E+14	J.year^{-1}	7.86E+05		5.86E+20	2.60E+08
O_4	Milk	7.18E+13	J.year^{-1}	7.86E+05		5.64E+19	2.51E+07
	Total sales	3.72E+08	US$.year^{-1}	2.25E+12		8.36E+20	3.72E+08

[a] (Odum, 1996)
[b] (Pereira, 2012)
[c] (Cohen et al., 2006)

Table 3.2: SGO's economy emergy aggregated flows and indicators

Renewable flow	$R=\Sigma R_i$	8.49E+20	seJ.year^{-1}	
Non-renewable flow	N	9.33E+21	seJ.year^{-1}	
Flow from economy	$F=\Sigma M_i+\Sigma S_i$	7.55E+20	seJ.year^{-1}	
Negative externalities	$S_A=\Sigma SA_i$	4.12E+19	seJ.year^{-1}	
Emergy Used	$U=R+N+F+S_A$	1.10E+22	seJ.year^{-1}	
System's Transformity	U/(Product energy)	7.87E+05	seJ.J^{-1}	*In the expected range*
Emergy Intensity	U/Area	2.85E+18	seJ.year^{-1}.ha^{-1}	*Very high*
Renewability (%R)	R/U	7.73%		*Very low*
Emergy Yield Ratio (EYR)	$U/(M+S+S_A)$	13.79	dimensionless	*Very high (soil erosion)*
Emergy Investment Ratio (EIR)	F/I	0.08	dimensionless	*Very low (pasture)*
Environmental Loading Ratio (ELR)	$(M+S+S_A)/R$	11.04	dimensionless	*High*
Emergy Exchange Ratio (EER)	U/[(USD*(seJ.USD^{-1})]	13.13	dimensionless	*Very high*
Lost soil Transformity	U/(Soil loss energy)	3.79E+05	seJ.J^{-1}	*Close to Cohen et al., 2006*
Area for carbon sequestration	A	2,680	km^2	*70% of the total area*

SGO agriculture is mainly based on grains what corresponds to 94% of the total energy output (Table 3.1). The system's Transformity (Tr) is around the expected value, a grains production system presents Tr of $2.77x10^5$ $seJ.J^{-1}$ while for swine system Tr is $2.09x10^6$ $seJ.J^{-1}$ (Cavalett et al., 2006) and for cattle only it is $1.85x10^5$ $seJ.J^{-1}$ (Teixeira, 2012). Because of the high soil loss the Emergy Intensity is 13 times higher than another tropical agricultural system (Cohen et al., 2006). The very high soil loss and EYR values are directly related to intense and destructive land use in the Brazilian Cerrado. The soil loss emergy value (N) represents 83% of the total emergy (U), a sign of the environmental imbalanced and predatory situation. The very low EIR is related to the main land use, extensive cattle farming that demands few external inputs and accounted for 39% of SGO's territory in 2014 (Figure 1). EER shows that the rural economy is subsidizing commodities for importing areas. The real value of agricultural commodities should be 13 times higher than the current market value to be a fair trade.

If soil loss is included as additional service, EYR is 1.08, i.e., there is low productivity for high soil loss and, EIR is 11.91. The latter means that the investment is very high or the cost of losing soil is elevated. Both have an opposite behavior compared to the first situation (Table 3.2), what would mean that the municipality presents a low regional development at the expense of high soil loss (if accounted as an externality). Soil loss in economic terms shows that the quantity of soil degraded by erosion and leaching ($4,149x10^6$ $emUSD.year^{-1}$) corresponds to 46% of the total SGO's production monetary value ($9,018x10^6$ $emUSD.year^{-1}$).

An important indicator is the native vegetation area to absorb environmental impacts of human activities, calculated as 2,680 km^2 or 70% of the total SGO area. For similar agricultural systems in Santa Catarina (South of Brazil) it was 65% of the total area (Teixeira, 2012). The necessary additional native vegetation area is 1615 km^2. Native forestry recovery could be achieved by means of strategies for land sharing[2] in a modified version of the integrated crop-livestock-eucalyptus systems previously evaluated for the region (Buller et al., 2014), substituting eucalyptus that causes hydric stress among other damages for native vegetation, or land sparing[2] for ecosystem services restoration and biodiversity conservation.

4. Conclusion

The large-scale expansion of soybean monocrops throughout the Brazilian Cerrado allowed local economies to prosper, as it is the case of SGO whose IDH is outstanding for Brazilian Midwest region pattern. SGO 2010 IDH was 0.73 and Brazilian IDH was 0.72 also the GDP growth was of 259% from 1999 to 2011(IBGE(a), IBGE(b)). Although the economic behavior, the future prosperity depends directly on public policies to eliminate current denying of environmental risks. As well as international beef and soybean players could reward positive incentives for producers that achieve rainforest deforestation low rates in developing countries, and some large companies has already established a zero tolerance for any level of deforestation[3]; soil loss, that directly affects the productivity and water and carbon balances, could be included in new policies for the agricultural expansion. All the agricultural involved stakeholders like international commodities buyers, local farmers, ecological groups and political leaders of developing and importing countries should align new agricultural systems for the south hemisphere countries to assure food security without environmental degradation aiming to remunerate the imported embodied natural resources of commodities products accordingly to its real value.

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UrbanFood – Urban-Industry related food production and supply

Björn Frostell[1*], Anders Kiessling[2], Anna Norström[3], Håkan Sandin[4], Gunnar Nordberg[5]

[1] KTH-Royal Institute of Technology, Stockholm, Sweden

[2] Swedish University of Agricultural Science, Uppsala Sweden

[3] Ecoloop AB, Stockholm Sweden

[4] Swedish University of Agricultural Science, Alnarp, Sweden

[5] Ramböll Sweden, Stockholm, Sweden

Corresponding author E-mail bjorn.frostell@abe.kth.se

Abstract

More than half of the global population now lives in cities and urban population grows rapidly. It is expected that in the next 30-40 years, this population will more than double. To feed them in an appropriate way is a very challenging task, considering (i) the availability of land, (ii) availability of water and fertilizer and (iii) availability of (sustainable) energy to power the food production system. At the same time, environmental impact of food production in many areas is becoming critical and it may be questioned whether food production might continue to grow by the same means as used today.

Sweden is one of the most urbanised countries, with more than 85 % of the population living in urban areas. In total, the fraction of the population involved in food production is approx. 2 % and this has resulted in a comparatively low degree of Swedish self-support in food production; more than 50 % of Swedish food is imported. At the same time, an increasing amount of Swedish consumers raise demands on better food quality control, higher ethical standards of food production, better environmental performance of food production and better traceability of food.

These new challenges of food production and supply have stimulated a group of food businesses, government bodies, public organisations and researchers to jointly develop a proposal for a national strategic innovation programme addressing urban food production and supply. The programme is named *UrbanFood – Urban-industry related food production and supply.*

The vision of this strategic innovation programme is a partial reorientation of current urban food supply, moving some parts of food production closer to consumers. In this way, future urban food supply will become a balance between globalized, large-scale food and food component production and food production in and in proximity to urban areas.

The strategic innovation programme comprises three different focus areas, (i) aquaculture in closed systems, (ii) horticultural production systems and (iii) feed from rest product streams. The basic idea of the programme is to create an integration of aquaculture, horticulture and use of rest product streams from urban areas. By using low-grade waste heat from industry, new innovative energy storage solutions and organic rest product streams from urban areas, several advantages may be achieved and a basis for circular production systems created. The paper will present and discuss the UrbanFood strategic agenda and innovation programme in more detail.

The assessment of the groundwater ecological value of Beijing based on South-to-North water diversion project

Ling Wang [a, b], *, Shanmei Li [a, b]
[a] School of Humanities and Economic Management, China University of Geosciences, Beijing, China
[b] Key Laboratory of Carrying Capacity Assessment for Resource and Environment, Ministry of Land and Resources, Beijing 100083, China

Abstract

Beijing is suffering a desperate shortage of water. From 1999 to 2011, it suffered a continuous drought. To ensure water supply, the average annual exploitation of groundwater in Beijing is over 5 hundred million cubic meters since 1999, which has caused a series of ecological environment problems. The South-to-North water diversion project will alleviate the pressure of water supply in Beijing, this project is also a favorable opportunity for groundwater recharging. The research on ecological value of groundwater is important for the government to strengthen the scientific decision-making of water resources comprehensive management. In this paper, the ecological value of groundwater will be divided into two categories: the Groundwater Resource Function Value(GRFV) and Groundwater Ecological Service Function Value(GESFV). The following data were based on the initial stages of South-to-North Water Diversion Project recharge of groundwater. The GRFV of that is 6155 million yuan by using the Energy theory. The Alternative Engineering Method(AEM) is adopted to calculate its GESFV, which is 4927.3 million yuan, of which the data contains the function of water conservation value (RMB 3055 million), water quality purification function value (RMB 10 million), air purification function value (RMB 0.3 million), the function of climate regulation value (RMB 1318 million), and the value of preventing the ground subsidence function (RMB 544 million).

1. Introduction

In the past thirty years, the serious shortage of water resources in Beijing has restricted the development of economy. The implementation of the South-to-North(S-to-N) Water Diversion Project recharges groundwater timely, realizes the joint regulation and storage of Yangtze River, the local surface water and groundwater, and improves the surface and the ecological environment of groundwater.

At present, study on the assessment of ecological value involves watershed, forest, grassland, wetland, and nature reserve. For study on ecological value, there are two classifications; the first one is shown in table 1.1.

Another classification is to divide the ecological value into tangible resource function value and intangible ecological service value. To comparison, the first classification has profound meaning, but the second one is more concise and easy to calculate, as shown in table 1.2

This study on eco-value of groundwater is based on the second classification, considering information of the first one, dividing the eco-value of groundwater into tangible resource function value and intangible ecological service value

Table 1.1: Classifications of Ecosystem Value

Total value of ecosystem	Use value	Direct use value	food, biomass, recreation, health
		Indirect use value	ecological function, biological control, storm protection
		Option value	biodiversity, protect habitats
	Non-use value	Bequest value	habitats, irreversible change
		Existing value	habitats, endangered species

Table 1.2: The compose of Groundwater Ecosystem Value

Item	Feature	Classification
Resource function value	Tangible, material, resource value, visible from the outside	The value of groundwater in agricultural irrigation, forestry, graziery, fishery, industry production and households
Ecological service value	Invisible, potential, service value of comfort, being ignored easily	water conservation, water purification, producing organic compounds by nourishing surface green vegetation, carbon fixation and oxygen release, conserve soil and water, sand fixation, biodiversity etc.

2. Theory and Method

2.1. Ecological economics emergy value theory

Ecological economics value---Emergy value theory is put forward by an American system ecologist Odum H.T. in 1980s. He established a new approach to study the ecological value of economic resources based on the past energy value theory. Its essence is transforming energy or substances of different categories or forms into unit of emergy solar value firstly, and then does comparative research. Odum and other researchers over the world (such as Brown MT, Ulgiati S. etc) calculated the transformity of the Emergy of the main energies and substances.

2.2. Replacement cost method(RCM)

RCM can be used to estimate the value of the ecosystem. The shadow engineering method is a special form of it. When the ecological resources function value is difficult to estimate, with the help of an artificial construction to replace the original environment function, it uses the costs of the artificial one to estimate the ecological resources value.

The RCM give an official method to assess the value of functional and biologically diverse landscapes, which are used to quantify the direct consumptive value of aquatic species and sites for indigenous subsistence in 3 Arustralian tropical river catchments where negligible data exists on indigenous water values and the extensive use of wild resource for food, art, craft and medicines.(Sue Jacksona,2014). And the RCM has been proved an efficient method to estimate the economic value of protective function for homogeneous zones by identifying the main forest attributes directly and indirectly involved in protection(Sandra Notaroa, 2012).

3. Study area description

The water system of Beijing is comprised of five rivers, which are all belong to Haihe River Watershed, respectively is: the Yongding river system, Daqinghe, north canal river system, the Chaobai River system and the thistle canal. The lithology of the top of alluvial and flood fan is sand gravel. Its strong permeability and water abundance provide advantage for recharging ground water.

According to the selection principles of recharging site, three factors should be considered: the capacity of underground reservoirs, the water conveyance route of the S-to-N water diversion project and the quality of groundwater. Based on the the three factors, the underground reservoir in Mi-Huai-Shun and Pinggu are considered as short-term recharge site. Xijiao underground reservoir (Nanhan River district) and Changping underground reservoir (Machikou district) work as long-term recharge site. Compared of considerable recharging ways, the main way of recharging groundwater based on the S-to-N water diversion project is confirmed: place the river natural recharge first, open well second. According to the principle that a new recharging water line must go along with the existing river or other water areas, two recharge plans are formed: Mi-Huai-Shun and Pinggu underground reservoir.

Mi-Huai-Shun underground reservoir: use Bai River and Chaobai River to recharge and recover ecological environment, the amount reaches 420 million m^3 per year. (See Fig 1)

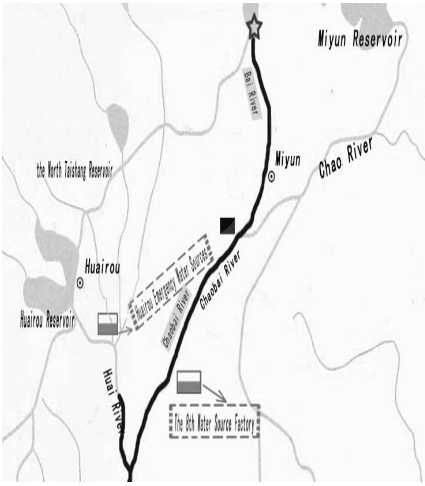

Figure 1: The recharge scheme of the groundwater reservoir in Mi-Huai-Shun

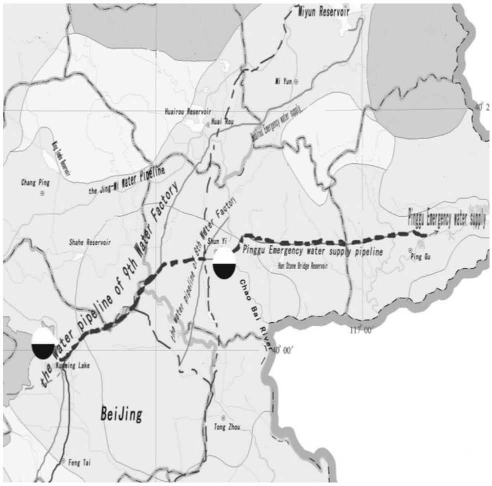

Figure 2: The recharge scheme of the groundwater reservoir in Pinggu

Pinggu underground reservoir: build a pipe from the regulating reservoir in Tuanjie Lake to the 8th Water Source Factory, and then use the emergency pipe in Pinggu to convey water reverse to the water source in Pinggu. Recharging the underground reservoir and lifting the groundwater level, the amount reaches 80 million m^3 per year. (See Fig 2)

4. The calculation of the ecological value of the ground water recharge in Beijing
   4.1 Function value of resources increased by the recharge of groundwater

In my essay 'Evaluation of Values of Groundwater Resources in Beijing-Based on Emergy Theory' (Advances in Materials Science and Engineering, vol.2015), emergy method was used to formulate water resources ecological economic system, industrial production subsystem, agricultural subsystem, subsystem of emergy network, based on the analyze of water circulation system of energy transfer and conversion process. Based on the development of the economic society, and water resources development and utilization status quo, the value of the groundwater in2008-2012 is calculated. (See Table4.1)

Table 4.1: Beijing groundwater integrated price calculation

Year	Agricultural Water		Industrial Water		Life Water		Total Water Use	
	Price, ￥/m^3	Vol. & Rto.	Price ￥/m^3	Vol. & Rto.	Price ￥/m^3	Vol. & Rto.	Vol. & Rto.	Price ￥/m^3
2008 Rto.	5.02	9.09 45.96%	30.97	2.42 12.23%	14.22	8.27 41.81%	19.78 1	12.04
2009 Rto.	4.82	8.78 43.66%	29.83	2.29 11.39%	14.19	9.04 44.95%	20.11 1	11.88
2010 Rto.	5.10	8.23 42.34%	34.14	2.11 10.85%	14.88	9.1 46.81%	19.44 1	12.83
2011 Rto.	5.19	7.93 41.45%	30.19	2.1 10.98%	14.61	9.1 47.57%	19.13 1	12.42
2012 Rto.	4.44	7.31 38.88%	28.19	2.13 11.33%	14.99	9.36 49.79%	18.8 1	12.38
AVG.	4.91		30.66		14.58			12.31

The function value of groundwater resources is calculated by using market value method:

$$V_1 = Q_1 \times P_1 \quad (1)$$

Annotation: V_1 refers to the function value of groundwater resources (billion yuan); Q_1 refers to the amount of the groundwater recharge (billion m^3); P_1 refers to the integrated water price.

The recharge project will increase the amount of the groundwater by 5 billion m^3 annually, the Beijing integrated water price calculated by using emergy method is 12.31 ￥/m3, the annual increment of the function value of groundwater resources is 61.55 billion yuan.

4.2 The function value of ecological services increased by the groundwater recharge

4.2.1The function value of groundwater conservation

Using the reflection engineering method, namely the shadow engineering method, people replace the function value of groundwater conservation with the cost of imaginary reservoirs. This method here is used to evaluate the ability of groundwater conservation.

$$V_2 = Q_2 \times C_r \quad (2)$$

Annotation: V_2 refers to the function value of the water conservation (billion yuan);Q_2 refers to the amount of groundwater recharge in this area(billion m^3);Cr refers to the cost of water storage, and it is the ratio of the cost of reflection engineering method applied in constructing reservoir and the storage capacity of projects.

The recharge project will increase the amount of groundwater by 5 billion m^3 annually. According to the standards of the forestry industry published by the China's Academy of Forestry, *The Evaluating Regulation of Forest Ecosystem Service Function*(LY/T1721-2008) indicates that the cost of standard reservoirs is 6.1107 yuan per storage capacity, and that the annual increment of the function value of groundwater conservation is 30.55 billion yuan.

4.2.2The function value of the groundwater purification

The function value of water purification is calculated by using reflection engineering method, and its formula is shown as follow: $V_3 = \sum_i^n P_{3i} \times Q_{3i}$ (3)

Annotation：V_3 refers to the function value of water purification (yuan); Q_{3i} refers to the pollution receiving capacity of the i-th substance(kg);P_{3i} refers to the cost of handling the i-th substance.

The recharge project will increase the amount of COD, total nitrogen and total phosphorus by 2600t, 255t and 51t. And this project will also enhance the increment of the function value of water purification by 0.1 billion per year.

4.2.3 The function value of groundwater air purification

(1)Increasing the negative ion

The increased function value of negative ions is calculated by using reflection engineering method, and its formula is shown as follow: $V_4 = Q_4 \times S \times L \times P_4/100$ (4)

Annotation：V_4 refers to the value of the increased negative ions (￥); Q_4 refers to the negative ion concentration (ind/cm^3); S refers to water area (hm^2); L refers to rivers effective height (cm); P_4 refers to the market price of negative ions (￥/10^{10}ind).

The negative ion concentration on the shore side of the Yongding River is 1315.6 ind/cm^3 after the water being drawn into the river. The recharge project increases the water area by 764 hm^2. Because of the recharge project, the negative ions content function value increased annually by 209100 yuan, which is calculated by the negative ions increment of the flowing river, which is calculated by the total amount of negative ions located at above the river and riverside zone 10cm area, and the market price of negative ions instead by the the negative ion generators' market price, which is 2.08yuan/10^{10}ind..

(2)The amount of absorption dust

The function value of increased absorption dust is calculated by using reflection engineering method, and its formula is shown as follow: $V_5 = Q_5 \times P_5$ (5)

Annotation：V_5 refers to the function value of absorption dust (yuan); Q_5 refers to the amount of absorption dust (m^3); P_5 refers to the treatment cost of industrial dust.

The average dust flux in Beijing water body is 7.23t/km^2 per month. The recharge project increases the water area by 764hm^2. The treatment cost of industrial dust is 0.15yuan/kg. The knowable amount of absorption dust caused by the recharge project is 662.85t. The function value of the amount of absorption dust is 99,400 yuan per year.

4.2.4 The function value of groundwater climate regulation

(1)Absorbing heat

The function value of absorbing heat is calculated by using reflection engineering method, and its formula is shown as follow: $V_6 = Q_6 \times P_6 \times 10^{-11}/3600\alpha$ (6)

Annotation：V_6 refers to the function value of absorbing heat (billion yuan); Q_6 refers to the heat absorbed by water surface evaporation (m^3); P_6 refers to the electricity price; α refers to energy consumption ratio

The annual average water surface evaporation in Beijing is 1100mm. The heat of vaporization of water is 2.26 x10^6 under 1000℃ 1 standard atmosphere. In the recharge project, the heat absorbed by water surface evaporation is 18.99 x 10^{15}J. The function value of absorbing heat increases by 8.06 billion yuan annually.

(2)Increasing air humidity

The function value of increasing air humidity is calculated by using reflection engineering method, and its formula is shown as follow: $V_7 = Q_7 \times P_6 \times \beta$ (7)

Annotation：V_7 refers to the function value of increasing air humidity (yuan); Q_7 refers to the water quantity of water surface evaporation (m^3); β refers to the electricity consumption that caused by the translation from 1 m^3 water to steam

The annual average of water surface evaporation in Beijing is 1100mm. Calculations indicate that the amount of the recharge project's water surface evaporation is 8,404,000 m^3, and the function value of the annual increased air humidity is 5.12 billion yuan.

4.2.5The function value of avoiding land subsidence of groundwater

According to the results of *Water Ecosystem Service Assessment and Valuation in Beijing*, the economical loss caused by land subsidence in Beijing is about 84.544 billion yuan, the groundwater multi-surface reserves and variables is 77.66 billion m^3, and the economical loss caused by the overdraft in unit volume groundwater is 1.09yuan/m^3. As a result, the reduced land subsidence economical loss that the recharge project causes is 5.44 billion yuan.

5. Conclusions

The total of the integrated resources function value, the ecological service function value and the ecological value increased by the S-to-N Project groundwater recharge in the initial stage is 110.825 billion yuan,as shown in table5.1.

Table5.1: The ecological value increment of groundwater recharge of the S-to-N Project

Function	Index System	Value (billion yuan)	Rto. (%)
Resources Function	Industrial, Agricultural and Domestic Water	61.55	55.54
Ecological Service Function	Water Conservation	30.55	44.46
	Water Purification	0.1	
	Air Purification	0.003	
	Climate Regulation	13.18	
	Preventing Land Subsidence	5.44	
	Subtotal	49.273	
Total		110.823	100

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Residential and non-residential hot water use models for urban and regional energy integration

Bertrand Alex [1,2]*, Aggoune Riad [1], Maréchal François [2]

[1] Luxembourg Institute of Science and Technology (LIST), Belvaux/Luxembourg, Grand-Duchy of Luxembourg

[2] Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland.

Corresponding Author e-mail: alexandre.bertrand@list.lu

Abstract

Various hot water end-use models in residential and non-residential buildings, as well as an approach to consider simultaneous use are presented in this paper. Using the detailed residential models to calculate the utility power shows that the hot water load is underestimated at least by a factor 6 when a constant and averaged hot water use is considered. Applied to urban and regional energy integration approaches, the detailed hot water models will therefore lead to improved investment cost calculations and to more appropriate solutions during the technology selection of the optimisation phase.

1. Introduction

Initially developed for process and industrial sites optimisation, energy integration (EI) methods have been applied in recent years to urban [Girardin et al. (2010)], [Fazlollahi (2014)] and regional [Perry et al. (2008)], [Cucek et al. (2013)] systems. The objectives of these approaches are mainly reducing economic and environmental impacts of buildings, by the optimal selection and sizing of heating and cooling utilities, energy storage systems and distribution networks. In EI approaches, space heating (EU 28 household final energy consumption: 199.04 Mtoe in 2012 [Enerdata (2015)]) has been modelled according to variable outdoor conditions, but hot water use (HW, 37.72 Mtoe) has so far been assumed as being constant [Girardin et al. (2010)]. Its consumption is averaged over one day, instead of being modelled as peak demand. Also, no differentiation as to the various end-uses is made, although these require different hot water temperature levels at tap level. Such assumptions imply that the thermal power of hot utilities are underestimated, which has an impact on investment costs calculations and therefore technology selection.

Residential as well as, most recently, non-residential water use models describing end-use types, volumetric flows, frequency and patterns of usage have already been proposed in the past years. More particularly, field measurements conducted in Germany and Switzerland [Jordan and Vajen (2001)], Sweden [Widen et al. (2009)] and the Netherlands [Blokker et al. (2010)] were used for the characterisation of household (Hh) water consumption. Non-residential water use, particularly offices [Blokker et al. (2011)], [Pieterse-Quirijns et al. (2013)] and hotels [Cobacho et al. (2005)], [Pieterse-Quirijns et al. (2010)], [Blokker et al. (2011)] were also assessed. However, while these publications provide relevant information and validated methods, the models cannot be transposed directly to an urban or regional EI (UREI) approach as described by [Fazlollahi (2014)]. This is mostly due to the already excessive computing requirements of UREI [Fazlollahi et al. (2014b)], which would further be increased by dynamic simulation approaches.

Therefore, this paper has as objective to characterise various hot water streams in residential and non-residential buildings, with the purpose to improve the outcomes of UREI approaches. Relevant parameters of typical HW streams in various buildings and the consideration of their simultaneous use in load calculations are described in section 2. The detailed household HW models are applied to the city of Esch-sur-Alzette (Grand-Duchy of Luxembourg), and their effect on hot water load calculations are compared to a constant load approach in section 3. Finally, in section 4, conclusions are drawn and next steps are proposed.

2. Model description

Energy integration as described by [Fazlollahi et al. (2014b)] requires the characterisation of the inlet and outlet temperatures T_{in} and T_{out}, the thermal power $\dot{Q}^{hw}$ and the minimum temperature difference at heat exchange dT_{min}. Typical hot water end-uses, described in table 2.1, can be combined to describe HW demand of certain categories of buildings (*households:* WC hand washing, washing and shaving, dishwashing, cleaning, showering or bathing; *hotels, hospitals, nursing homes:* WC hand washing, washing and shaving, short and long kitchen tap, cleaning, showering or bathing; *offices:* WC hand washing, short and long kitchen tap, cleaning, showering; *restaurants:* short and long kitchen tap; cleaning, *swimming pools:* showering, pool water renewal). Other building categories (schools, sport facilities) are currently not covered as some relevant data (e.g. typical appliance number) could not be gathered. The shower type described below does not include particular water-saving measure. The HW models and their aggregation for single buildings consider direct heat usage, excluding hot water storage tanks to reduce the peak load.

2.1 Temperature levels

The inlet temperature of fresh water T_{in}^{fresh} varies over the seasons between 5°C and 15°C, but is generally assumed to be at 10°C [Spur et al. (2006)], [Widen et al. (2009)]. As measured data on real outlet warm water temperature T_{out}^{ww} of various end-use types is scarce, typical values given in [Schramek (2007)] are used here (see table 2.1). A value of 5K for the difference of temperature dTmin is assumed [Fazlollahi et al. (2014a)].

2.2 Thermal power

The mixed water thermal power demand $\dot{Q}^{hw}$ [kW] is calculated by:

$$\dot{Q}^{hw} = \rho \cdot c_p \cdot (T_{out}^{ww} - T_{in}^{fresh}) \cdot \dot{V}^{hw} \quad (1)$$

with density ρ =1000 kg/m^3, specific heat capacity c_p =4187 J/kgK and mixed warm water volumetric flow $\dot{V}^{hw}$ [m^3/s]. Typical flows for various end-uses can be found in [Jordan and Vajen (2001)]), [Widen et al. (2009)] and [Blokker et al. (2010)]). Given the recent and detailed descriptions of the high number of different end-uses, data from [Blokker et al. (2010)] and [Blokker et al. (2011)] is used here, except for the cleaning flow, which is taken from [Pieterse-Quirijns et al. (2010)] as the initial value of 0.5 l/s appeared as too high, and the pool water renewal, used over a daily duration of 12 hours, taken from [Schramek (2007)].

2.3 Availability rate and number of appliances

The occurrence of certain hot water end-uses varies between households. While it can be considered that all households have bathroom taps (hand washing, washing and shaving), showers and kitchen taps (dish washing, cleaning) [Blokker et al. (2010)], some households are also equipped with a bath tub. As no statistics on bathtub availability in households are available at European level, the dissemination rate of 36% mentioned by [Blokker et al. (2010)] for households in the Netherlands can be used as reference. The attribution of this end-use at household level, should the georeferenced data not be available, can be done using a randomizing function.

Information on appliance numbers of non-residential buildings is scarce [Pieterse-Quirijns et al. (2010)]. For offices, appliance number is taken from [Pieterse-Quirijns et al. (2013)]. The cleaning is assumed to have at least a number of one, or is a function of the employee number e. Concerning hotels, the number of appliances of various end-uses in function of the room number r is taken from [Pieterse-Quirijns et al. (2010)]. Showers for personnel are not included, as their use compared to that of the hotel costumers is small ([Pieterse-Quirijns et al. (2010)]: two showers for a hundred rooms hotel). In order to consider hospitals and nursing homes in UREI approaches, the hotel appliance numbers, which are generally in a one-to-one relation with the room number in the building, are used for these building categories too. Concerning stand-alone restaurants, the same appliance number for kitchen taps as for hotels is used. For the cleaning, a minimum number of one end-use is assumed.

Table 2.1: Hot water end-use characterisation for UREI based on [Schramek (2007)], [Blokker et al. (2010)], [Pieterse-Quirijns et al. (2010)], [Blokker et al. (2011)], [Pieterse-Quirijns et al. (2013)]

Use	Temp. [°C]	Flow rate [l/s]	Power [kW]	Number of appliances [-]
WC hand washing	35	0.083	10.41	r^{ho} < 50: 0.042525 r + 6.39 r^{ho} > 50: 0.0447 r + 7.74 e^{of} < 300: 2 e / 12 e^{of} > 300: e / 18
Washing and shaving	40	0.042^{hh}, 0.083^{ho}	5.27^{hh}, 10.41^{ho}	r^{ho}
Dish washing	55	0.125	20.90	1^{hh}
Kitchen tap, short	55	0.167	20.94	$3^{ho, re}$; 0.0052 e +2.24^{of}
Kitchen tap, long	55	0.250	31.35	$3^{ho, re}$; 0.0052 e +2.24^{of}
Cleaning	55	0.125^{hh}, 0.250^{ho}	20.90^{hh} , $41.80^{ho, of}$	$1^{hh, re}$; 0.063 r+2.8^{ho} Min: 1, else 0.0265 e + 0.027^{of}
Showering	40	0.142	18.99	r^{ho}; $0.07/m^{2\ sp}$; 0.0132 e – 0.49^{of}
Bath filling (120 l)	40	0.200	29.26	r^{ho}
Pool renewal	28	50 l/m^2*d	0.09 kW/m^2	-

hh: households; ho: hotels; re: restaurant; sp: swimming pools, of: offices

2.4 Simultaneity factor

To calculate the power of the heating utility, it is not necessary to add up the thermal loads of the single end-uses, as neither all hot water demands occur nor is the maximum heating power required at the same time [Thorsen and Kristjansson (2006)], [Schramek (2007)]. An oversizing of the utility, and thus higher investment costs, can therefore be avoided. The corrected hot water load can be calculated using a simultaneity factor S(N), which is the sum of the actual power demand P of the utility i at the time where the total maximal load t_{max} is required divided by the sum of the nominal power of all hot water utilities of the units N [Winter et al. (2001)], [Thorsen and Kristjansson (2006)]:

$$S(N) = \frac{\sum_{i=1}^{n} P_i(t_{max})}{\sum_{i=1}^{n} P_{N,i}} \quad (2)$$

While heating utility dimensioning for single households is largely described in literature, standards and publications, methods to calculate the hot water load do vary. According to [Thorsen and Kristjansson (2006)], the Danish standard DS 439 sets the hot domestic water load to 32.2 kW (simultaneous use of kitchen sink and shower), independent of the existence of a bath tub (approach also used by [Dalla Rosa (2012)]. [Schramek (2007)] mentions that for single households, only the number of bathtubs or showers is relevant, taking the end-use with the largest load as reference. For that case, the simultaneity factor is set to 1.15. The Spanish standard UNE 149.201/07 includes all end-uses for the calculation of the hot water load [Iglesias and Palensky (2014)]. In the framework of an UREI approach, where detailed data on end-uses is most probably not available and computational efforts should be limited, it is proposed to use the approach of [Schramek (2007)], meaning that the hot water load of a single household corresponds to the one of the largest hot water utility (either cleaning or bathing), multiplied by a factor of 1.15 in order to consider a simultaneous use with another utility.

For buildings with several units, the simultaneity factor S(N) must be determined according to the number of units N in the building. Considering the similar use patterns, the simultaneity factor described below for residential buildings can also be applied to hotels, hospitals and nursing homes. N therefore represents the number of households in residential buildings, and the number of rooms in hotels, hospitals and nursing homes. S(N) values are based on empirical data, and several models have been proposed to describe its behaviour (see [Gaderer (2007)] and [Christiansen et al. (2012)] for a comparison of German and Danish S(N) models, respectively). The outcomes for S(N) using the equations provided by [Thorsen and Kristjansson (2006)] and [Gaderer (2007)] are represented in figure 2.1. Considering that the results of the former approach are still overestimated when compared to measured data [Thorsen and Kristjansson (2006)], [Christiansen et al. (2012)] and that the equation has been designed for Danish hot water utility design conditions (32.3 kW), the equation of the latter approach is selected for this work:

$$S(N) = 0.02 + 0.92\ N^{-0.58} \quad (3)$$

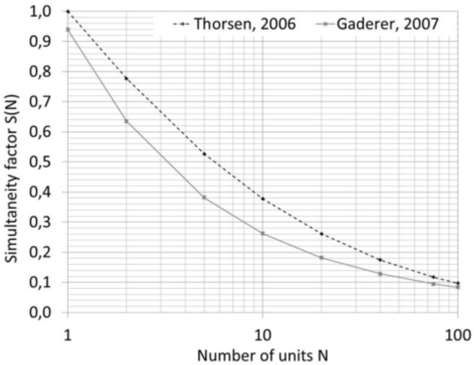

Fig. 2.1: S(N) values as proposed by [Thorsen and Kristjansson (2006)] and [Gaderer (2007)]

The hot water power demand P_{hw} in a building with lodgings is therefore obtained from the simultaneity factor S(N) multiplied by the sum of the single largest hot water end-use $P_{i,max}$ in each unit N:

$$P_{hw} = S(N) * \sum_{i=1}^{i=N} P_{i,max} \tag{4}$$

For swimming pools, as first approximation, the simultaneity factor is to be applied to the number of showers. The resulting heating load should then be added to the constant water renewal load. As for other categories of buildings, considering that the various end-uses are required by several types of employees with different schedules, it is assumed that no simultaneous use occurs. The hot water heating power should therefore be dimensioned according to the highest end-use load.

3. Illustrative example and discussion

The detailed hot water models are applied to the residential buildings of the city of Esch-sur-Alzette (population: 32’600). The calculation outcomes are compared to those of an constant, averaged hot water load model for residential buildings: 70 l/d per person at temperatures of 60/10°C [Girardin et al. (2010)] over an assumed duration of 16 hrs (use between 5 am to 11 pm, [Blokker et al. (2010)]), providing a hot water load of 0.25 kW per person. An average of 2.41 persons per household is assumed [Heinz et al. (2013)]. The impact on hot water load using the simplified and detailed models is depicted in figure 3.1.

In the case of single-family houses, the ratio of detailed model load to simple model load ranges from 6.0 to 134.6, while the multi-family buildings ratio ranges from 6.7 to 37.2. These ratios show thus that the constant, averaged model approach strongly underestimates the hot water load. This has an important effect on the investment costs of small (approximately < 200m2) or well-insulated (with a space heating demand < 50 W/m2) buildings, as the heating utility load is then dominated by hot water demand [Thorsen and Kristjansson (2006)], [Schramek (2007)], [Rosa et al. (2012)]. Although not covered in this example, it is relevant to note that commercial buildings are not affected much by the improved calculation, as this category of building has its hot utility load sized up according to space heating demand [Rosa et al. (2012)].

Fig. 3.1: Hot water loads with simplified (left) and detailed (right) model

In the example above, the heat load ratio displays a large range of values. This is due to the fact that the detailed approach considers end-use types with a specific load demand, independently of the number of inhabitants in the household. Therefore the hot water load of a single-person household can be identical to that of a 2.4 persons household, provided that the households are equipped with the same end-use types. With the simplified approach, the hot water load calculation depends only of the number of inhabitants. In the case of multi-family buildings, the use of the simultaneity factor can lead to an important decrease in load, e.g. for buildings with 50 inhabitants the hot water load is diminished by 83%, therefore limiting the heating utility investment costs of this category of building. Considering geographical clustering methods as developed by [Fazlollahi et al. (2014c)] for urban energy integration, the application of such a factor should therefore be considered when district heating systems are automatically designed in such approaches. Finally, the application of randomizing functions lead to a more realistic representation of the stochastic distribution of certain end-uses in households, which is not reflected in a constant, averaged hot water demand model.

4. Conclusions

Various hot water end-use models in residential and non-residential buildings, as well as an approach to consider simultaneous use are presented in this paper. Using the detailed residential models to calculate the utility power shows that the hot water load is underestimated at least by a factor 6 when a constant, averaged hot water use is considered. Applied to urban and regional energy integration approaches, the detailed hot water models will therefore lead to improved investment cost calculations and to more appropriate solutions during the technology selection of the optimisation phase. In order to make the link between heat load and energy requirements, the use patterns of the streams described above shall be detailed out in a future work. The calculation of the total heat load of buildings, considering building category, size and heating demand, will also be addressed.

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Wood-based bioenergy value chain in mountain urban districts: A case study in the Italian Alpine region

Nikodinoska Natasha [1,*], Paletto Alessandro [2], Pier Paolo Franzese [1]

[1] Laboratory of Ecodynamics and Sustainable Development, Department of Science and Technology, Parthenope University of Naples, Italy.

[2] Council for Agricultural Research and Economics, Forest Monitoring and Planning (MPF), Trento, Italy.

Corresponding Author e-mail: natasha.nikodinoska@uniparthenope.it

Abstract

Oscillations in the price of fossil fuels as well as political initiatives aimed at reducing the impact of fossil fuel consumption by promoting renewable energy options have led to an increasing demand for wood biomass as a renewable energy source. In the context of mountain urban settlements, the use of wood biomass for bioenergy production can represent a win-win stategy as it combines the energy provision to households with a sustainable management of local forests. The exploitation of locally available renewable resources like wood biomass and residues can significantly lower the impact of energy production while boosting rural development and stakeholders' cooperation in mountain areas. In this study, we investigate the environmental performance and sustainability of bioenergy production for heating in the Sarentino Valley (Northern Italy) focusing on three main sub-systems of the local bioenergy value chain: 1) forestry activities, 2) logistics and upgrade of wood material, and 3) conversion. A multi-method environmental accounting framework was used to assess material, energy and emergy demands as well as main environmental impacts generated at each of the three steps of the bioenergy chain. Alternative scenarios were drawn to explore possible higher rates of utilization of local wood biomass in relation to the ecological boundaries of the forest ecosystem. Finally, direct and indirect economic costs of the bioenergy production chain were also evaluated to provide an overall picture of its environmental and economic performance.

Keywords: bioenergy chain; environmental accounting; environmental footprints, Sarentino Valley.

Renewability and support area of electricity produced from different mixtures of biomass: a case study of Miajadas, Spain.

Fabiana Morandi, Andreas Kamp, Hanne Østergård*

Department of Chemical and Biochemical Engineering, Technical University of Denmark, DTU, 2800 Kgs. Lyngby, Denmark

* Corresponding author e-mail: haqs@kt.dtu.dk

Abstract

Electricity is one of the most important components in urban systems and, therefore, technologies for power production are constantly improved. Presently, much development is related to the use of biomass as feedstock to produce electricity, primarily to limit greenhouse gas emissions and reduce the risk of potential supply constraints. In several ways, biomass-based fuels may be a good fossil fuel alternative: biomass is potentially renewable, can be produced locally and is storable. However, for each specific context, the sustainability of the bioenergy production with respect to resource use and renewability has to be evaluated.

The Miajadas Biomass Power Plant produces electricity through biomass combustion. It supplies the Spanish national grid with 128 GWh/year by burning a mixture of herbaceous and woody biomasses. The question is, which biomass mixture can be considered the most sustainable with respect to resource use and renewability? A sustainability assessment of the electricity production is performed for three different compositions using emergy assessment (EmA). EmA is particularly suited to quantify the use of agricultural resources making it possible to estimate the percentage of renewability of a product or service. The investigated system consists of all power plant operations including the transport of biomass from fields to the plant. In this work, results of the emergy evaluation of the electricity production system in Miajadas are presented, considering different compositions of biomass mixtures used as feedstock in the plant. Unit emergy values (UEV) and renewability of the electricity provided for the city of Miajadas as well as the Emergy Footprint (EmF) for the electricity consumption are also estimated. The renewability fraction of the electricity produced in the most efficient scenario is 31% while the EmF is 1.1 ha/MWh. The EmF of electricity, food and transport fuel for the municipality is estimated to approximately 300,000 ha, equivalent to 26 times the municipality's geographical area.

1. Introduction

During the years, electricity has become one of the most important components in defining characteristics of modern life and it is difficult to imagine a world without it. Especially in urban systems, electricity represents one of the most important components because both economy and society are dependent on it. Together with the advantages, there are also some disadvantages that electricity carry on as for example that it is mainly produced by burning fossil fuels that are non-renewable resources. To avoid this, technologies for power production from renewable sources are being developed. Some of these are related to the use of biomass as feedstock to produce electricity. Biomass, in fact, may be a good fossil fuel alternative because it is potentially renewable, can be produced locally and is storable. Moreover, by using biomass as feedstock, greenhouse gas emissions are also reduced.

Miajadas Biomass Power plant (MBP) is the first Spanish power plant designed to use mixed biomass. It is located in the municipality of Miajadas (Extremadura) and it generates electricity through the combustion of herbaceous and woody biomasses and supplies it to the Spanish national grid. We have investigated which biomass mixture can be considered the most sustainable with respect to resource use efficiency and renewability. To do this, we evaluate the sustainability performance of the electricity production at MBP by considering three different scenarios. The scenarios refer to different compositions of the feedstock, calculated based on the calorific value of the biomasses. The evaluated system includes the power plant, including the transport of biomass. The sustainability evaluation is performed by using Emergy Assessment (EmA), a method particularly suited for studies of environmental costs and renewable resource use of processes. By using EmA, in fact, it is possible to quantify the use of resources and the percentage of renewability (%R) of the electricity provided by the plant. Moreover, the emergy footprint (EmF) for the electricity consumption is calculated. EmF estimates the system's required support area and will be related to the land area demands of other consumption goods to indicate the scale of support area of Miajadas municipality.

2. Material and methods

2.1 Miajadas Biomass Power Plant

Miajadas Biomass Power plant (MBP), owned by Acciona Energia, covers an area of 4.7 ha. It was designed for working 8000 hours/year with an estimated production of 128 GWh of electricity but in practice, the plant is operating 6500 hours/year with an average production of 97.5 GWh. This output is equivalent to the demand from approximately 17,600 persons, which is well above the local population so some production is exported through the electricity grid.

The average amount of biomass used at MBP in 2014 is around 110 kt/year and it is composed of 48% herbaceous biomasses (herbaceous energy crops and agricultural residues) and 52% woody biomasses (forestry energy crops and forestry residues) but, depending on different seasonal circumstances (e.g. crop production yields and market prices) the composition can change from year to year. In order to understand which biomass mixture can be considered the most sustainable with respect to resource use and renewability, we study three different scenarios S1, S2, and S3 (Table 2.1). For all scenarios the annual production of electricity is 97.5 GWh/yr, the functional unit in this study.

Table 2.1. Biomass mixture composition for three scenarios. Percentages are calculated based on the calorific values of the biomasses.

	herbaceous	woody
Scenario1 (S1)	75%	25%
Scenario2 (S2)	55%	45%
Scenario3 (S3)	40%	60%

Concerning biomass types, herbaceous biomasses are from herbaceous energy crops (e.g. triticale, oats, sorghum) and from agricultural residues (e.g. straw from wheat, oat, barley), while woody biomasses are from forestry energy crops (poplar SRC and other forest energy crops), forestry residues and woody agricultural residues (prunings). All biomasses used at the plant to produce electricity are from crops cultivated in the Extremadura region. Due to the lack of detailed data, we assume in our calculations that the herbaceous and the woody biomasses are, respectively, wheat straw and chips of poplar SRC. The average yield of SRC poplar is 47 t/ha (24 tdm/ha) with an average moisture content of 48%, while the average yield of wheat straw is 3.6 t/ha (3.1 tdm/ha), with an average moisture content of 13% (I. E. Goñi, pers. comm.). According to these data the total area required for producing biomass is between 3,000 and 5,000 ha for the three scenarios (Table 2.2).

Table 2.2. Total area required for providing biomass to the plant in the studied scenarios.

	Total area required (ha)		
	S1	S2	S3
Poplar SRC	1.98E+02	3.57E+02	4.76E+02
Straw	4.89E+03	3.58E+03	2.61E+03
Total	5.09E+03	3.94E+03	3.09E+03

The LHV of wheat straw and poplar are, respectively, 17.2 MJ/kgdm and 18.2 MJ/kgdm. Biomasses are transported from the fields to the plant by trucks. In particular, platform trucks are used to transport poplar chips and combined trucks are used for transporting bales of straw.

The registered inhabitants in Miajadas in 2014 are approximately 10,000 and the annual Spanish average electricity consumption is equal to 5.53 MWh per capita[1]. We therefore assume that the average electricity consumption in Miajadas is equal to 55.4 GWh/yr.

2.2 Emergy Assessment

Emergy assessment is a thermodynamics-based method, introduced by H.T. Odum in the 1980's, and it is used to estimate the environmental costs of products or services. Emergy is defined as the solar energy required, directly and indirectly, to make a product or service (Odum 1996). All forms of energy, materials and human labour that contribute, directly or indirectly, to the production process are taken into account and converted into the common unit of solar equivalent Joules (seJ). The conversion takes place by multiplying physical quantities with their respective Unit Emergy Values (UEV), where the UEV is the emergy used per unit, given in seJ/unit (e.g. seJ/J, seJ/g). The obtained values are summed by following the rules of emergy algebra (Brown and Herendeen 1996) and the result is the amount of resources required for the production process. This value is considered an estimate of the environmental cost, and the higher the value is, the larger is the associated environmental impact. Moreover, because the UEV of the output indicates resource use efficiency, it is possible to compare similar outputs and decide which is most efficiently produced, based on the value of the UEVs. A low value of UEV indicates a small environmental cost per unit of output, i.e. an efficient use of resources.

An important aspect of Emergy Assessment is that it allows for the categorisation of resource use related to the functioning of a production system, making it possible to indicate how renewable an output is. All inputs that contribute to the system under study are divided into three input categories: local renewable resources (R), local non-renewable resources (N) and feedbacks from society (F), i.e. external inputs. The renewability fraction %R (i.e. R/(R+N+F)) indicates the dependence on resources that are considered to be renewable (Odum 1996). The higher %R, the less dependent on non-renewable inputs is the system.

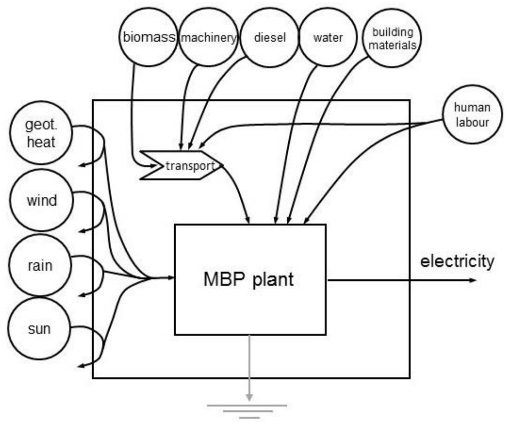
[1] www.data.worldbank.org/indicator/EG.USE.ELEC.KH.PC

The emergy footprint (EmF) indicates a system's required support area (Björklund and Johansson 2013, Agostinho and Pereira 2013, Wright and Østergård 2015). It is defined as the area, in hectares, required to supply the total emergy use if the system was supported only by renewable resources. In its simplest form, the EmF is calculated as the total annual emergy flow (in seJ) divided by the renewable empower density (in seJ/ha), i.e. the annual flow of local renewable emergy per hectare. Since part of the emergy flow is usually from non-local sources and thus related to non-local empower density, the EmF may be calculated as the sum of (local emergy flow / local renewable empower density) and (imported emergy flow / global renewable empower density).

3. Results and discussion

The emergy flow for electricity production is calculated for each of the 3 scenarios by using published or calculated UEVs for all inputs and considering the 15.83E+24 seJ/yr baseline (Odum et al. 2000). The system under study is represented in Fig. 1 by using symbols of the energy language (Odum 1996).

Fig. 1: Energy System Diagram of electricity production at MBP.



Emergy flows are reported in Table 3.1. Renewable inputs refer to the Miajadas area and when they were not available, they were taken from the NASA website[2] by considering the relevant geographic coordinates (39°9'N, 5°54'W). Due to similarities between case studies, all data referring to the buildings and machinery in the plant (items 10 to 14) are from Pang et al. (2013). All water necessary to the processes within the plant comes from a river and it is equal to 600,000 m^3 per year[3]. Quantities for items referring to renewable inputs (items 1 to 4) and to the plant (items 10 to 16) are the same for all scenarios. Differences between scenarios are in the biomass composition used as feedstock and in the transportation of biomass from the fields to the plants (items from 5 to 9). According to the rules of emergy algebra, the total emergy flow, for each scenario, has been calculated as the sum of all independent

[2] www.eosweb.larc.nasa.gov

[3] www.bioenergyinternational.es/noticias/News/show/primera-central-de-biomasa-mixta-de-europa-376

items, that is the sum of the emergy flow of rain and geothermal heat and the emergy flows of items from 5 to 16. Results show that S1 requires more emergy than S2 and S3 and that S3 has the lowest environmental cost.

Table 3.1. Emergy table for electricity production in 1 year at MBP for S1, S2 and S3 scenarios.

item		Quantity			UEV seJ/unit	Emergy flow seJ/yr			%R
plant		S1	S2	S3		S1	S2	S3	
1	solar rad. (J)		2.86E+14		1.00E+00		2.86E+14		100
2	rain (J)		2.33E+11		3.10E+04		7.21E+15		100
3	wind (J)		2.57E+12		2.45E+03		6.29E+15		100
4	geoth. heat (J)		1.27E+11		5.77E+04		7.32E+15		100
biomasses (fresh weight)									
5	straw (J)	2.53E+14	1.86E+14	1.35E+14	1.69E+05	4.28E+19	3.14E+19	2.28E+19	
6	poplar (g)	9.27E+09	1.67E+10	2.23E+10	5.92E+08	5.49E+18	9.88E+18	1.32E+19	
transport									
7	machinery (g)	8.55E+06	6.62E+06	5.18E+06	variable	1.37E+17	1.06E+17	8.29E+16	0
8	diesel (g)	4.02E+07	3.16E+07	2.51E+07	4.89E+09	1.97E+17	1.54E+17	1.23E+17	0
9	human labour (J)	1.68E+09	1.32E+09	1.05E+09	1.24E+07	2.08E+16	1.63E+16	1.30E+16	5
plant									
10	concrete (g)		2.73E+09		3.04E+09		8.30E+18		0
11	brick (g)		5.56E+07		3.68E+09		2.05E+17		0
12	steel (g)		2.77E+08		5.78E+09		1.60E+18		0
13	copper (g)		5.55E+05		8.60E+10		4.77E+16		0
14	cooling oil (g)		1.24E+07		4.51E+09		5.60E+16		0
15	water (g)		6.00E+11		2.34E+05		1.40E+17		100
16	human labour (J)		8.50E+10		1.24E+07		1.05E+18		5
total emergy use						**6.01E+19**	**5.30E+19**	**4.76E+19**	
output									
	electricity (MWh)	9.75E+04							
UEV (seJ/MWh)		**6.16E+14**	**5.43E+14**	**4.89E+14**					
UEV (seJ/J)		1.71E+05	1.51E+05	1.36E+05					
%R		**23%**	**27%**	**31%**					

References for UEV's values are: Odum 1996 (items 1 and 2), Campbell and Ohrt 2009 (item 3), Campbell et al. 2010 (items 4, 12 and 13), Coppola et al. 2009 (item 5), Bastianoni et al. 2009 (items 8 and 14), Odum 2000 (items 9 and 16), Pulselli et al. 2008 (item 10), Pulselli et al. 2007 (item 11), Pulselli et al. 2011 (item 15). UEV for poplar (item 6) has been calculated for this study while UEV for machinery (item 7), for each scenario, is the weighted average of the UEVs of the material components of the trucks.

The percentage of renewability (%R) is 23% for scenario S1, 27% for S2 and 31% for S3. This means that the fraction of the total emergy flow coming from local renewable sources varies between 23% and 31%. UEVs for the produced electricity have been calculated as the ratio between total emergy flow (in seJ) and output of electricity (in MWh or J) (Table 3.1). Obtained values are 6.16E+14 seJ/MWh for S1, 5.43E+14 seJ/MWh for S2 and 4.89E+14 seJ/MWh for S3. The most efficient process with respect to resource use measured in emergy terms is S3 because it has the lowest UEV. These values are comparable to values found in literature for electricity based on willow as feedstock: Kamp and Østergård (2013) obtained 2.31E+05 seJ/J and 17%R, Pang et al. (2013) 1.14E+05 seJ/J and 51%R and Buonocore et al. (2012) 1.2E+05 seJ/J and 31%R.

For the EmF calculation, we separate the emergy flow into local and non-local flows, and divide the flow by a local (1.45E+16 seJ/ha) and a global (3.10E+14 seJ/ha) renewable empower density, respectively. The two parts are then added to provide the emergy footprint for the system. For simplification, we assume that the local flow can be approximated by the flow of renewable emergy. The emergy footprint is calculated for S3 (the scenario with highest resource use efficiency and highest degree of renewability) as approximately 108,000 ha/97,500 MWh or 1.1 ha/MWh. Thus, the area of direct, indirect and imaginary substitution land needed for electricity supply to the population of Miajadas is 61,000 ha, using the biomass mixture in S3. This is equivalent to 5 times the area of Miajadas (12,100 ha) and 20 times the area required for growing of the biomass (3,000 ha). This EmF for electricity is compared to EmFs for food and transport fuel, two other primary consumption goods, to give an indication of the support area of Miajadas (Table 3.2). Food consumption is from the FAOSTAT website[4] and the food UEV is from Johansson et al. (2000). Transport energy consumption is from the Eurostat website[5] and the UEV from Bastianoni et al. (2009).

Table 3.2: Emergy footprints for selected consumption goods for Miajadas Municipality

Consumption	Amount	UEV (seJ/unit)	Emergy (seJ)	EmF (ha)
Electricity (S3) (MWh)	5.54E+04	4.89E+14	2.71E+19	61,100
Food (J)	4.87E+13	1.25E+06	6.10E+19	138,000
Transport fuel (J)	3.32E+14	1.13E+05	3.73E+19	120,000

Based on these results, which refer to only three consumption goods, we can conclude that the total support area of Miajadas vastly exceeds its geographical area.

Conclusion

The sustainability assessment of electricity production from biomass has been performed for three different scenarios that refer to three different compositions of the feedstock. The emergy assessment shows that the most sustainable feedstock mixture is the one with more woody content (scenario S3) because of the lowest UEV value and the highest percentage of renewability in the final product. Moreover, the emergy footprint shows that the support area for a number of important components of consumption each exceeds the actual area of Miajadas demonstrating large overshoot.

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[4] www.faostat.fao.org

[5] www.epp.eurostat.ec.europa.eu

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Agriculture as net energy provider for urban systems exemplified by a model of energy self-sufficient dairy farms

Hanne Østergård[1*], Mads V. Markussen[1]

[1] Department of Chemical and Biochemical Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark

Corresponding Author e-mail: haqs@kt.dtu.dk

Abstract

Bioenergy based on biomass from energy crops may in future be needed as an energy source for urban systems. However, for this to be efficient, agricultural systems need to be much less dependent on fossil fuels and as a goal even energy self-sufficient. In this study, we investigate whether organic agriculture is capable of providing both food and surplus energy to the society as evaluated from a model study of Danish dairy farms. We evaluate the integration of food and bioenergy production in present situation without energy crops and in three different energy crop scenarios: 1) 10% of crop land used for oilseed rape to produce vegetable oil, 2) 10% of crop land used for grass-clover lays to produce biogas in combination with cattle manure and 3) a combination of 1) and 2) demanding 20% of crop land for bioenergy. Only in scenario 3), the farming system is self-sufficient with respect to energy for crop management and bioenergy production, and even then, the urban population may be nourished but there will not be enough surplus energy for an urban system as today.

1. Background

Before the era of fossil fuels, agriculture was together with forestry the main source of net-energy in the society by providing food for human labor, fodder for draft animals and biomass for heating (Hall et al. 2009). During the 19th and 20th century, coal, oil and natural gas took over as society's main source of net-energy and agriculture was industrialized in the way that farms were supplied with oil and industrial based inputs. Altogether, the productivity per ha was boosted with the consequence that food supply systems now uses 4 to 10 times more fossil energy than the food energy they produce (Heller and Keoleian 2003; Markussen and Østergård, 2013), i.e. agriculture has become an energy sink. If agriculture should play a significant role in the future urban energy system, then the first milestone to be achieved would be to become self-sufficient with fuels.

Organic agriculture has taken the first step in reducing its dependence on fossil energy by using neither fossil based fertilizer nor pesticides. However, the energy input for organic agriculture is still large as organic production depends on fossil fuels for transportation and electricity (Halberg et al. 2008). The next step in making organic agriculture into a net-energy provider is to implement strategies that increase farm energy output. In this respect, it is important to pay attention to the various non-equivalent energy carriers, which are needed in agriculture (i.e. liquid fuels, electricity and heat) and in which way they can be provided by biomass.

2. Materials and methods

A model system consisting of a community of dairy farms of 1000 ha in total (approx. corresponding to 10 Danish organic farms) has been developed. Milk is transported to a shared dairy where it is converted to cheese and the whey is transported back to the farms and utilized as fodder for the livestock. The livestock diet consists of 78% whole crop (grass-clover, maize, barley and peas), 16% cereals and peas, and 6% whey from the cheese-production. The number of milk-producing cows is calculated as the maximum herd size possible based on the fodder produced on the farms including the whey from the cheese production (Table 2.1). The crops are fertilized from manure without any import of fertilizer.

Table 2.1. Mix of crops in percentage of total area in each scenario and the associated number of milk producing cows being fed based on these fodder crops.

Crops	Reference scenario	Scenario 1 (Vege.oil)	Scenario 2 (Biogas)	Scenario 3 (Vege.oil and biogas)
Cereals incl whole crop	37	33	33	30
Peas incl whole crop	3	3	3	3
Grass clover ley	47	42	42	38
Permanent grass	13	11	11	10
Oilseed rape (energy crop)	*0*	*10*	*0*	*10*
Grass clover ley (energy crop)	*0*	*0*	*10*	*10*
Milk producing cows	730	680	660	610

A reference system for the farm community with no energy crops, i.e., corresponding to the average mix of crops for Danish organic dairy farms on loamy soil according to StatBankDanmark (2007), and three scenarios, including growing and converting energy crops to bioenergy, were developed. The bioenergy scenarios have 10% - 20% energy crops but maintain the same relative mix of fodder crops as in the reference system. The three scenarios are (Table 2.1):

Scenario 1: Each farm uses 10% land to produce oilseed rape as energy crop. The seeds are used in a low-tech farm scale cold press system that produces vegetable oil to substitute diesel as well as oilcakes, which are used as fodder.

Scenario 2: The farm community shares a biogas facility. The biogas reactor is fed with a mixture of manure and grass and clover from 10 % of land. The biogas is on location applied to a CHP unit, which is assumed to convert the raw biogas to electricity and heat. Part of the electricity is used in the farming system, and the surplus is exported to an urban energy system. The biogas effluent is spread on the fields as fertilizer.

Scenario 3. This scenario uses 20% of the land for energy crops and the management and technologies are a combination of Scenario 1 and Scenario 2.

3. Results and discussion

The results show that using 10% of land for oilseed rape production (Scenario1) can make the system more than self-sufficient with liquid fuel and using 10% land for grass and clover as biogas feedstock (Scenario 2) can make the system more than self-sufficient with electricity and heat. Only Scenario 3 achieves self-sufficiency with both electricity and fuel and it produces a small energy surplus, which is available for a nearby urban area (Table 3.1).

The energy self-sufficiency that is obtained in Scenario 3 should be seen in perspective of the energy requirements that were not included in the model, e.g energy required upstream for producing and maintaining machinery and buildings, and energy required downstream for processing the food and distributing it to consumers. Energy use for construction of machinery and buildings is particularly relevant for the biogas plant, which requires a significant investment of energy. Further, another study of the total Danish food production system, of which the largest part is conventionally managed, shows that energy consumption at the farm constitutes only 40-50% of the total energy requirement in the food supply system (Markussen and Østergård, 2013).

Table 3.1: Annual net energy production of liquid fuels, electricity, heat and food energy for an agricultural system of 1000 ha in each scenario.

Scenarios (% energy crop)	Liquid fuels (TJ)	Electricity (TJ)	Heat (TJ)	Food energy (TJ)
Reference (None)	-2.37	-4.82	0	12.86
1 (10% Oilseed rape)	0.36	-4.52	0	11.98
2 (10% Grass and clover ley)	-2.60	0.79	6.02	11.62
3 (20% Combined)	0.14	0.91	5.84	10.73

The primary product of a farming system is food. In this case, it is milk and meat and the amount of food produced is directly correlated to the fodder production. In Scenario 1, the fodder production is only 7% smaller than in the reference scenario even though the area for fodder crops is reduced by 10%. This is due to the fodder value of the oil cake residue. In Scenario 2, there are no fodder residues, and, therefore, exactly 10% less fodder is produced when compared to the reference scenario. Finally in Scenario 3, the fodder production is reduced with 17% (i.e. the combination of Scenarios 1 and 2). The food output corresponds to that each person working within the farm community produces food to support 201, 187, 173, and 159 persons, respectively.

4. Conclusion

The aim of this study was to investigate the limitations and potentials for agriculture in providing both food and energy to urban system. The model is based on a number of critical assumptions but as we have used conservative estimates, the resulting energy balances are expected to demonstrate what may be possible. However, in many cases, the requirements would be much more demanding.

According to our farm model, a community of dairy farms of 1000 ha in total can be self-sufficient with fodder and fertilizer as well as liquid fuels, electricity and heat. This is possible if 10% land is used for oilseed rape for vegetable oil production and 10% for grass and clover for co-digestion with manure in a biogas plant. In addition, the system produces a surplus of heat, which may be used in nearby urban areas. This strategy reduces the food production with approximately 17 % when compared to the reference scenario. However, the net output of energy is marginal and in any case insufficient to provide energy for, e.g. downstream processing and distributions of the produced food or any other activities in a surrounding urban economy. In other words, slaughters, dairymen, doctors, teachers, politicians, etc. can be nourished, but not supplied with energy for powering transportation, computers, etc. Overall, it seems unlikely that agriculture can contribute significantly in powering an industrialized economy, as we know it today, based on energy crops. Combining agricultural residues and industrial/municipal waste may be a better strategy for biomass contributing to the future energy supply for rural as well as urban systems. However, many of the technologies for efficient conversion of this kind of biomass into heat, power and liquid fuels are still under development. Further, large changes in societal infrastructure may be required before biomass can constitute a substantial energy source in substituting the present fossil fuel based energy supply and this would include a much stronger interaction between rural and urban systems.

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Energy network science to assess social and ecological resilience and systemic health: Focus on ecosystems, economic systems, and urban metabolism

Brian D. Fath
Biology Department, Towson University,
Towson, MD 21252, USA, 1-410-704-2535
bfath@towson.edu

Energy network science (ENS) is new paradigm that draws from thermodynamics, information theory, and network analysis to assess the organization, patterns, and dynamics of diverse systems such as ecosystems, financial systems, and urban metabolism. In this presentation, ENS is demonstrated for community resilience in terms of 10 measures of regenerative vitality.

These measures can help urban and community planners improve the overall 'metabolic' performance of of the relevant ecological, economic, or social systems. In particular, this approach combines two methods: ecological network analysis and resilience to assess material and energy flow urban performance. Applying ecological network analysis to urban metabolism allows one to investigate the energy relations and structure of an urban network. Case studies of Chinese cities are provided. Regarding resilience, it is important that managers have awareness and preparedness for all stages of the adaptive cycle, including growth, equilibrium, collapse, and reorganization.

We review the different capacities and competencies which are needed during the various stages. This approach builds from the seminal efforts of systems thinkers such as Buzz Holling, Robert Ulanowicz, Jane Jacobs, Joseph Tainter, and Jacob Moreno.

Urban Transition and Global Environmental Change: Lessons and implications for a sustainable future

Shu-Li Huang, Graduate Institute of Urban Planning, National Taipei University, Taiwan

Abstract

Urbanization has many positive and negative consequences and plays a significant role in the interaction between urban areas and global environmental change. Currently, there are more than 50% of population resides in urban areas which generate more than 90% of global economy, consume more than 65% of the world's energy and emit 70 % of global greenhouse gas emission. Urbanization, both as a social phenomenon and a physical transformation of landscapes, is a powerful, often irreversible and highly visible anthropogenic force worldwide. The urban economic and ecological systems are physically connected by the throughput of energy and matter from the natural ecosystems which sustain economic activities, while on the other hand by the goods and services from economic system which augment life-support functions of the ecosystem. These characteristics and the inflows of energy and materials and outflows for exchanging goods and services are equally important in a biophysical view of urbanization. Even though urban areas only account for a small percentage of the Earth's land surface, expanding cities tend to appropriate a disproportionate share of the ecosystems in terms of resource inputs and waste sinks. The loss of agro-ecosystem services also has become a significant issue of peri-urbanization. Land use and land cover change, especially when coupled with climate change, are likely to affect socioeconomic viability and ecosystem function of urban systems in many complex ways. Despite the economic prosperity in cities, the urban and economic growth still cannot mitigate the climate impacts due to the insufficient adaptive capacity and resulted in the challenge to urban resilience and vulnerability. The characteristics of urban form (e.g. density, intensity, accessibility, mixed land use, compact or sprawl, etc.) as effected by urban transition is also an important means to cope with climate change as well. Challenge and opportunities of spatial planning to implement strategies for mitigating and adapting to climate change are also discussed.

European Energy Union and Energy Research Policies: focus on urban systems

Riccardo Basosi
Dept. of Biotechnology, Chemistry and Pharmacy
University of Siena

Abstract

Smart Cities and Communities is one of the main topics of the SET (Strategic Energy Technology) Plan of the EC as well as of the Energy Work Program 2016-17 "Clean, secure and efficient Energy" in the Horizon 2020 research and innovation Program. In fact, as energy efficiency and low carbon sources represent key elements in all the actions of the energy/climate package for the decreasing of climate changing gasses, urban systems have become the most crucial challenge for the EU Energy strategy,

The only clean energy is the one we do not need to use, i.e. the saved one. The content of information for energy resources is specific and not unlimited in nature, with the unique exception of renewable resources. This suggests that the rationale and efficient use of energy is the first pillar of the environmental sustainability. The second pillar is the necessary and urgent replacement of fossil energy resources with renewable sources, directly or indirectly supported by solar activity. Examples of thermodynamic savings and developments of renewable sources suggest a variety of sustainable practices in agreement with the Principles of Thermodynamics. Recent developments in research (H2020) and innovation (Set plan) place efficiency and low carbon technologies in a integrated environment, as driving factors for Energy Union policies toward security, competitiveness and sustainability. Urban systems challenges are also in agreement with expected increasingly top role of European “consumers” in EU energy planning and implementing.

1. Introduction

The world’s urban population is expected to double by 2050. By 2030, 60% of the world's people will live in a city. By 2050 this figure will run to 70% (World Health Organization, 2013). In real terms, the number of urban residents is growing by nearly 60 million people every year. As the planet becomes more urban, cities need to become smarter. Major urbanization requires new and innovative ways to manage the complexity of urban living which demands new ways to target problems of overcrowding, energy consumption, resource management and environmental protection. It is in this context that Smart Cities emerge not just as an innovative way for future urban living, but also as a key strategy to address poverty and inequality, unemployment and energy management. At its core, the idea of Smart Cities is rooted in the creation and connection of human capital, social capital and information and communication technology (ICT) infrastructure in order to generate greater and more sustainable economic development and a better quality of life. Smart Cities can be defined along six characteristics (dimensions) according to an important document presented to EU Parliament in 2014 by the Directorate-General for Internal Policies : Smart Economy, Smart Mobility, Smart Environment; Smart People, Smart Living, Smart Governance. The coordination of policies along these six characteristics reflects the positive feedback between city development and urbanization (K. Desmet and E. Rossi-Hansberg, 2013). Most of the concepts, figures and tables presented in this paper have been taken from the relevant EU documents cited above. Furthermore, the new document on Energy Union of February 2015 in which it is foreseen that citizens will take ownership of the energy transition, reap benefits from new technologies to thereby reduce their energy bills and participate actively in the market. This establishes the urgent need for the spread of information and choice in all the urban communities.

The aspects of economic, societal and environmental development are not scalable as cities expand and their evolution is difficult to predict. In fact, this is such a complex ecosystem which, although resilient, faces serious challenges, including economic and societal inequality, environmental change and demographic transition. Other changes, including increased mobility and greater access to information, may both help and/or hinder this development. All these elements directly affect (P. Nijkamp and K. Kourtit, 2013) the sustainability (N. Dempsey et al., 2011) and the pan-European contributions of urban environments may be turned to advantage by Smart City initiatives. It is evident that their beneficial evolution must be facilitated by a combination of framework conditions and information and communications infrastructures. In some way, a platform is needed to track the evolution of a city. Europe has a particular need for Smart City thinking. In fact, the Europe 2020 strategy (European Commission, 2013) incorporates a commitment to promote the development of Smart Cities throughout Europe and to invest in the necessary ICT infrastructure and human and social capital development. Smart Cities may play a role in helping to meet the targets set out in Europe 2020 and also those more severe of the Climate/Energy package to 2030 by adopting solutions that take advantage of ICT technology to increase effectiveness, reduce costs and improve quality of life.

Figure 1 presents a detailed map of the location of Smart Cities within the EU Member States, depicting all European cities of at least 100,000 inhabitants and those which can be identified as Smart Cities (Figure 1). The leaders are Italy, Austria, the Nordic Member States, Estonia and Slovenia; in the two-thirds of Smart Cities with two or more characteristics, the most common combinations are Smart Environment and/or Smart Mobility, with one or more other characteristics.

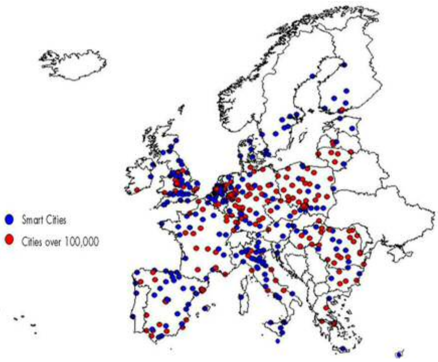

Fig. 1: The location of cities with a population of more than 100,000 that are not Smart Cities and Smart Cities in Europe (Mapping Smart Cities in EU, 2014).

Across the five different priority areas of Europe 2020, environmental issues and green solutions appear to be the key concern for the majority of European Smart City initiatives. Nearly 50% of the initiatives address environmental problems either through implementing technologies to improve energy efficiency in buildings or by developing smarter city transportation options. However, energy solutions are pursued by most cities across Europe, regardless of national incentives and national political and social circumstances.

The success of a Smart City depends on the depth and effectiveness of targeted improvement within each area or initiative and on the coherence or balance of the portfolio of initiatives across the city with different (though often overlapping) focal areas, modalities, participants and constituencies. Many definitions of the Smart City focus almost exclusively on the fundamental role of ICT in linking city-wide services (D. Washburn and U. Sindhu, 2010). While ICT is a definitive component, Smart Cities cannot simply be created by deploying sensors, networks and analytics in an attempt to improve efficiency

(J. Gorski and E. Yantovsky, 2010; MIT, 2013; H. Schaffers et al., 2011). As shown by experience, any success model for a Smart City must also engage the stakeholders. A city can never be Smart, no matter how much ICT shapes its data, without involving people aimed at addressing problems of common interest. Building on the work of the European Smart City Project (M. Batty et al., 2012; R. Giffinger and N. Pichler-Milanovic, 2007; R. Giffinger and H. Gudrun, 2010; D. Schuurman et al., 2012), the six characteristics previously defined are deployed by a number of studies to develop indicators and Smart City strategies (B. Cohen, 2012b) designed to be synergistic and mutually supportive. In general, the most successful Smart City strategies are expected to adopt a multi-dimensional approach to maximize such synergy and minimize negative spill-over effects: for instance, prioritizing a Smart Economy strategy can result to be detrimental to the environment (Cohen, 2012a). The six characteristics of Smart Cities are outlined in Table 1.

Table 1: Overview of the six Smart City characteristics (Mapping Smart Cities in EU, 2014)

Characteristic	***Description***
Smart Governance	Smart Governance means to join up within-city and across-city governance, including services and interactions which link and, where relevant, integrate public, private, civil and European Community organizations so the city can function efficiently and effectively as one organism.
Smart Economy	Smart Economy means e-business and e-commerce, increased productivity, ICT-enabled and advanced manufacturing and delivery of services.
Smart Mobility	Smart Mobility means ICT supported and integrated transport and logistics systems.
Smart Environment	Smart Environment includes smart energy efficiency and renewables, ICT enabled energy grids, metering, pollution control and monitoring, renovation of buildings and amenities, green buildings, green urban planning, as well as resource use efficiency, re-use and resource substitution which serves the above goals.
Smart People	Smart People means e-skills, working in ICT-enabled working, having access to education and training, human resources and capacity management, within an inclusive society that improves creativity and fosters innovation.
Smart Living	Smart Living means ICT-enabled life styles, behavior and consumption.

The characteristics used to classify Smart Cities include the areas addressed by Smart City initiatives, and illustrate the variety of projects and Smart Cities across the EU Member States. Nam and Pardo (T. Nam and T.A. Pardo, 2011) adopt a holistic approach, categorizing Smart City components within three core factors: technology, human and institutional factors.

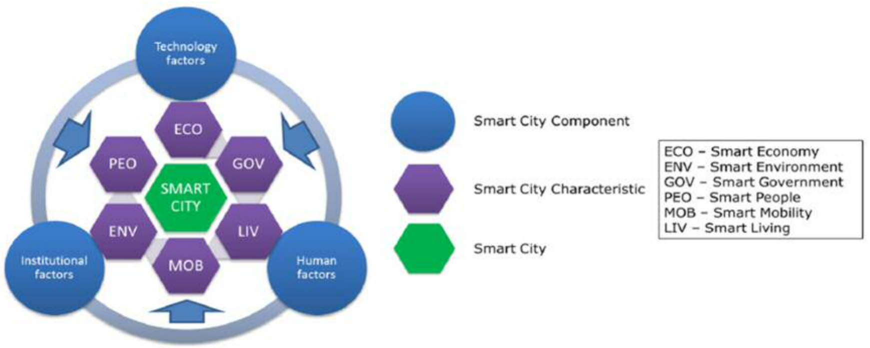

Fig. 2: The relationship between characteristics and components in a Smart City (Mapping Smart Cities in EU, 2014).

Each of these factors consists of some specific characteristics summarized as follows: 1.Technology factors: physical infrastructure, digital networks, smart, mobile and virtual technologies 2. Human factors: human infrastructure and social capital 3. Institutional factors: governance, policy, regulations and directives. The relationship between characteristics and components is summarized in Figure 2. The outer ring shows the components, and the inner ring the characteristics. Rather than each component mapping onto a specific characteristic, a range of technological, human and institutional factors underpins all characteristics. The relationships between components and characteristics can be both direct and indirect. In some cases, the linkage from objectives to characteristics to components is direct. Take, for example, the objective of improving energy efficiency within the city. This objective may be associated with an environmental initiative (characteristic), which makes use of Smart buildings (component) to permit energy network managers to adjust load in order to make efficient use of existing supply capacity. The linkage may also be indirect, if a specific component contributes to more than one characteristic.

EU’s role in Smart Cities

The objectives of the EU Smart Cities are generally aligned with the overarching Europe 2020 targets. The Europe 2020 energy target could be addressed through initiatives that focus on Smart Environment and/or Smart Mobility. The Smart Economy and Smart People initiatives are oriented towards employment and education targets, which includes, of course, e-skills development. The Smart Governance and Smart Living initiatives address poverty and social exclusion through measures including improvements to the quality of life, a focus on citizen connectivity and the use of open data to create citizen services. Europe 2020 targets for the EU as a whole are i. Increasing the Employment to 75% for 20-64 years old; ii. 3% of the EU's GDP (public and private combined) to be invested in R&D and/or innovation; iii. Greenhouse gas emissions to be 20% (or even 40%, if the conditions are right) lower than 1990, 20% (27%) of energy from renewable, 20% (27%) increase in energy efficiency; iv. Reducing school drop-out rates below 10%; v. Decrease Poverty and social exclusion for 20 million people.

A Smart City initiative, actually, makes improvements which can be related to Europe 2020 targets. For instance, a project that enhances mobility may make it easier for individuals to travel to the most appropriate school or job (thus contributing to the employment and education targets). This, in turn, can help alleviate location-based problems of poverty and social exclusion, although the impacts are likely to be less than the primary contribution to the energy and environment targets. Smart Cities contribute to the Europe 2020 targets in different ways: 1. directly, by improving the target-specific performance of that city, and thus its country; 2. indirectly, by demonstration and knowledge transfer to other cities and areas in that country, and to other cities and areas in other EU countries; 3. collectively, by creating a ‘Smart City’ critical mass or community of interest capable of further development, exploiting initiatives in broad deployment and realigning business, government and civil society along ‘Smart’ lines.

Figure 3 shows the ‘technology roadmap’, drawn up by the EC for the European Initiatives on Smart Cities. The focus of this roadmap is on buildings, heating and cooling, electricity and transport. In general, it concerns technologies that aim to improve the environment and therefore does not include all aspects of the Europe 2020 targets. However, Fig.3 usefully illustrates the potential for Smart City initiatives to contribute toward some of the objectives of Europe 2020. Many Smart City initiatives, especially those that span multiple countries, are funded by the EU. This funding occurs predominantly through the *CIP* and PPPs. The European Commission (EC) defines its approach to Smart Cities as ‘coordinated’[1] at international and national levels. For example, the Directorate-General for Communications Networks, Content and Technology (DG CONNECT)[5] has funded Smart City projects through *7th Framework Programme (FP7)* projects and the *ICT-Policy Support Programme (PSP)* which is part of CIP; it has also worked together with the Directorate- General for Research & Innovation (DG RTD) and the Directorate-General for Energy (DG ENER) on cross-cutting PPPs including the *European Green Cars Initiative* and the *Energy-Efficient Buildings Programme* (European Commission, 2012).

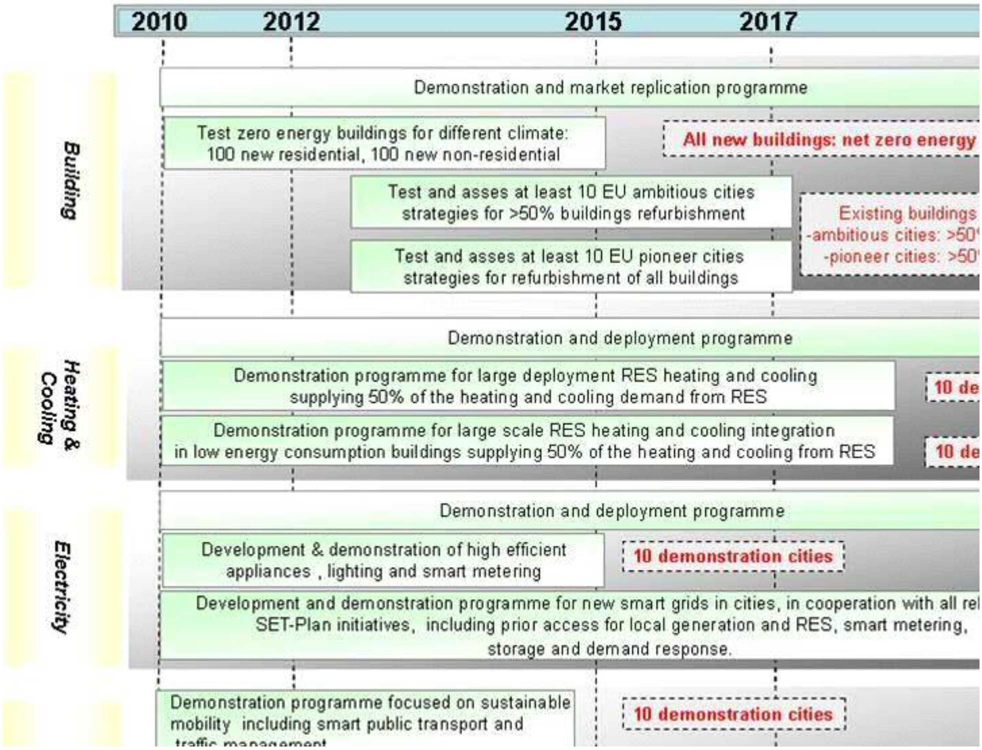

Fig. 3: European initiative on the Smart Cities technology roadmap (Mapping Smart Cities in EU, 2014).

The EC has provided policy support also through policies of the DG MOVE[5] and via several docs specifically referred to the role of Smart Cities. This indicates the nature of these initiatives is not just in improving conditions, but also in showcasing best practice which others could learn from and improve upon. The “Clean, secure and efficient Energy” configuration in Horizon 2020 placed the maximum effort in developing research on: Energy Efficiency (EE), Competitive low-carbon energy (LCE), Smart Cities and Communities – with nature-based solutions (SCC) for a low carbon and efficient energy system. The budget allocation in the first WP 2014-15 and in the incoming 2016-17 for the Smart Energy sector is relevant and stresses that Smart Cities should integrate energy, transport, ICT sectors through lighthouse integrated innovative solutions. The “lighthouse project” approach means that leader cities develop and test integrated innovative solutions at large scale, then follower cities commit to the replication at the end of the project. Each lighthouse city shall: include a "nearly zero energy buildings" district (new/retrofitted) which

[1] http://ec.europa.eu

incorporates RES, deploy a fleet of alternatively fuelled cars, deploy ICT tools for integration, explore the alternative use of innovative nature based solutions project. The high prevalence of the Smart Environment characteristic across cities is mirrored at the initiative level. Over 50% (46) of the initiatives include the Smart Environment characteristic, spanning all the cities with only a few exceptions. The multicity Networking Intelligent Cities for Energy Efficiency (NiCE) initiative aims to decrease the direct carbon footprint of ICT by 30% per city, contributing to the Europe 2020 energy efficiency and CO2 targets. 15 cities are part of the NiCE initiative. Moreover, some cities (e.g. Helsinki in Finland and Eindhoven in the Netherlands) address environmental improvement via their local NiCE projects. The cities with initiatives directly or indirectly aligned with Europe 2020 targets show a prevalence of environmental initiatives (18 cities) related to all others (7 poverty, 4 employment, 2 R&D and 1 education). Transport is the most prevalent area of technological focus (19 initiatives) followed by electricity (8), buildings (5) and heating and cooling (4). Some cities have project portfolios that aim to contribute to EU 2020 targets. For example, in Malmo, Sweden, the NiCE Project aims to decrease the carbon footprint of city contributing to the energy and environmental EU targets. Copenhagen's initiatives (Denmark) focus on energy and those of Oulu (Finland) on sustainability. The coverage of the characteristics by several EU Smart Cities is shown in Table 2.

Table 2: Coverage of Smart City characteristics (Mapping Smart Cities in EU, 2014).

City	Characteristics covered (%) (Europe 2020 coverage score)	Initiatives including each characteristic (%)						Variance
		ECO	ENV	GOV	PEO	LIV	MOB	
Amsterdam	**100%**	67%	33%	67%	67%	67%	33%	2.5%
Athens	63%	0%	0%	100%	33%	67%	0%	14.8%
Barcelona	**100%**	60%	50%	40%	30%	30%	40%	1.1%
Bremen	75%	0%	33%	0%	33%	33%	33%	2.5%
Budapest	63%	0%	100%	0%	0%	50%	50%	13.9%
Copenhagen	**100%**	14%	100%	14%	43%	14%	43%	9.3%
Dublin	**100%**	33%	50%	33%	17%	50%	33%	1.3%
Eindhoven	63%	0%	50%	0%	0%	50%	50%	6.3%
Glasgow	75%	0%	100%	0%	67%	33%	67%	13.6%
Hamburg	88%	20%	80%	0%	60%	40%	60%	7.2%
Helsinki	**100%**	75%	13%	38%	50%	38%	50%	3.5%
Ljubljana	63%	0%	50%	0%	50%	0%	50%	6.3%
Lyon	63%	0%	100%	0%	100%	0%	100%	25.0%
Malmo	75%	0%	67%	33%	33%	67%	0%	7.4%
Manchester	**100%**	20%	30%	40%	60%	60%	20%	2.8%
Milan	88%	0%	83%	17%	33%	33%	33%	6.5%
Oulu	88%	40%	40%	20%	80%	60%	0%	6.7%
Tallinn	75%	50%	100%	0%	0%	50%	50%	11.8%
Tirgu Mures	63%	0%	0%	100%	100%	100%	0%	25.0%
Vienna	75%	0%	67%	0%	67%	67%	33%	9.0%

Successful Smart Cities shows solutions and good practices that are scalable and applicable in a wide range of city context with a real potential to make a significant contribution to the Europe 2020 targets and the new ones of Energy Union. Replication and scaling can lead from Smart Cities to a Smarter Europe. For this purpose new methods are needed to assess the potentialities and to develop innovative energy management able to monitor and manage both the centralized and individual needs ensuring energy savings, environmental upgrading and decreasing of transport burdens in all the urban communities as a significant step toward security and sustainability.

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Exploring the relationship between energy consumption and the CO_2 emissions—A case study of Beijing–Tianjin–Hebei region

Yinghui Ding[1,3], Haizhong An[2*], Xiaoliang Jia[3]

[1] School of Economics, Hebei University, China

[2] School of Humanities and Economic Management, China University of Geosciences, Beijing, China

[3] Key Laboratory of Carrying Capacity Assessment for Resource and Environment, Ministry of Land and Resource, China

Corresponding Author e-mail: dingyinghui219@126.com

Abstract

Beijing-Tianjin-Hebei region (BTH) is planning to grow increasingly integrated. BTH will become an immense megalopolis to rival any in the world with a population five times that of the New York metropolitan area if China's state planners have their way. In spite of high-speed economic growth and rapid urbanization, energy consumption with low carbon emissions is one of the targets for synergetic development in BTH.

In this study, we developed a computer simulation model based on system dynamics, which has been named as ECCE-BTH Model (Energy consumption and CO_2 Emissions Model of Beijing-Tianjin-Hebei), to estimate and forecast the trends of energy consumption and CO_2 emissions in BTH. The energy consumption and CO_2 emissions in these three areas are also compared with the ECCE-BTH Model. The boundary of ECCE-BTH Model is the total administrative area of Beijing, Tianjin and Hebei. The period for the dynamic modeling in the study is from 2010 to 2030. The ECCE-BTH Model is consist of six parts: Agricultural consumption (AC), Industrial consumption (IC), Service consumption (SC), Residential consumption (RC), Transport consumption (TC) and Economy and population (EP). Four scenarios are developed to examine various policies which could affect the trends of energy consumption and CO_2 emissions in BTH.

Results are as follows: (1) the energy consumption in BTH is predicted to reach 1146 million tonnes coal equivalent (Mtce) by 2030; (2) The total CO_2 emissions in 2030 will reach 1123.69 million tonnes CO_2 equivalent (Mt CO_2-eq), 0.73 times higher than that of 2010; (3) The change of energy structure from carbon rich fuel as coal to low-carbon fuel as natural gas and clean fuel as renewable energy will play a very essential role in carbon emission reduction activities of BTH; (4) Service sector will be the largest energy consuming sector, followed by industrial and transport sector; (5) The sensitive analysis suggests that change of economic development mode and control of rational population growth will have a far-reaching influence on energy consumption and on carbon emissions. The Scenarios analysis results also indicate that it is possible to control the CO_2 emissions even under a scenario of high-speed development of economy. The study may help the governments better understand the complex relationship between energy consumption and CO_2 emissions, and develop sustainable economy and urbanization development strategies that better balance energy consumption and carbon emission reduction.

Key words: Energy consumption, CO_2 emissions, System dynamics, Scenario analysis, Beijing-Tianjin-Hebei

Industrial energy and environmental efficiency in China: Analysis based on 36 major cities with undesirable outputs

Mojie Li[1, 2, *], Ke Wang[1, 2]

[1] Center for Energy and Environmental Policy Research, Beijing Institute of Technology, Beijing 100081, China

[2] School of Management and Economics, Beijing Institute of Technology, Beijing 100081, China

Corresponding Author e-mail: lmj@bit.edu.cn

Abstract

China's rapid pace of industrialization has been followed by a huge demand for energy. Industry, as the biggest energy consumption sector in China, draws much attention in terms of energy and environmental efficiency. In China, industries cluster in major cities and the industrialization level of those cities is even higher than the provinces accordingly. Therefore, compared with provincial DMUs' utilization, evaluation based on major cities could perform better in satisfying homogeneity assumption. In this paper we use nonparametric Slack-based Model (SBM) to evaluate the 36 major cities' industrial energy and environmental efficiency during 2006-2010. Both desirable output (industrial add-value) and undesirable outputs (3 kinds of industrial wastes) are considered in this approach, meanwhile, we set energy consumption, fixed assets, and labor force as the inputs. The result shows that: 1) Haikou, Shenzhen, Hohhot, Baoding, and Qingdao have top 5 of industrial energy and environmental efficiency in this study, while the first-tier cities of Beijing, Shanghai, and Guangzhou, cannot catch up with the average efficiency level, thus, we suggest the rest of the cities should not follow the same industrial development path of the first-tier cities. 2) On average, the improvement of all the selected cities' efficiency during our research timeframe proves that the China's industrial policy is effective for energy-saving, but the effect of the policy is various among the different regions, the northeastern cities' efficiency had a sharp growth which performed better than eastern cities. 3) 24 cities which account for more than 66% of the total have a lower-than-average efficiency, indicating that the industrial developments of regions are still lopsided; however, it is not recommended to expand its scale of production because insufficient outputs rather than inputs are the key issues.

Integrating ecosystem services in urban energy trajectories

Ulla Mörtberg, Brian Deal, Vladimir Cvetkovic, Berit Balfors, Juan Azcarate,
Jan Haas, Xi Pang
KTH Royal Institute of Technology
Stockholm. Sweden

Abstract

Changes in urban development trajectories towards renewable energy sources and compact, energy- efficient urban agglomerations will have major impacts on ecosystem services, which cities are dependent on but tend to overlook.
Such ecosystem services can be provisioning, regulating and cultural ecosystem services, around which competition over land and water resources will increase with energy system shifts. Much of the land and water use conflicts can be foreseen to take place within urbanising regions, which simultaneously is the living environment of a major part of the human population today. In order to inform critical policy decisions, integrated assessment of urban energy system options and ecosystem services is necessary.
For this purpose, the model integration platform Land Evolution and impact Assessment Model (LEAM) is built and empowered with models representing urban form, energy supply and use, transportation, and ecological processes and services, all related to the land and water use evolution. These types of analyses of interacting sub- systems require an advanced model integration platform, yet open for learning and for further development, with high visualisation capacity. Case studies are performed for the cities of Stockholm, Chicago and Shanghai, where urbanisation scenarios are under development. In the case study LEAM Stockholm, scenarios for urban compaction and urban sprawl with different energy and water system solutions are being developed, in order to explore the sustainability of urban policy options. This will enable integrated policy assessment of complex urban systems, with the goal to increase their sustainability.

Urban aerosol pollution: a by-product of energy consumption

Marco Casazza[1] *

[1] Parthenope University of Naples, Naples, Italy

Corresponding Author e-mail: marco.casazza@uniparthenope.it

Abstract

All human activities, sustained by a given energy input, produce a certain amount of waste, since there is no process in nature with efficiency equal to 1, as known from thermodynamics. Among the different categories of 'waste', we can include also atmospheric emissions, that constitute a threat to the environment, since they affect the climate system, the biosphere and also the human health. Atmospheric aerosol emissions can be considered among the by-products of energetic consumption, as we can demonstrate, and they represent a known major risk since many centuries. The relation between energy consumptions and aerosol primary and secondary emissions is here discussed. The attention, then, is focused on the urban environment. Aerosol pollution should be regarded as a by-product of energy consumption, while discussing about the different environment constraints within urban planning strategies.

1. Introduction

Contemporary industrial societies use energy sources for manufacturing goods, delivering services to different end-users and building technologies, which support our everyday life. Since there is no process in nature with an efficiency equal to 1, a variable amount of 'waste' is also produced. We should open here a long discussion about the meaning of the word 'waste' within the different cultures and lifestyles, but this would take too much space and would also bring the discussion off topic. Within the immense world of 'waste', there are both reusable things (such as heat or recyclable materials) and non-reusable things, that we might define as by-products of a given product or service. Within the sub-set of 'by-products', we can include also the different types of atmospheric emissions, among which atmospheric aerosols can be included. It is known, in fact, that combustion processes emit into the air gases and particles, whose nature depends on the fuel used.

Many historical documents already report the existence of polluted air in towns prior to the modern industrial era. Traces of air polluted by wood combustion are observable in the towns of Southern France and Northern Italy during the Medieval up to pre-industrial age (Ausset et al. 1998). These are related to different grey crusts (mostly calcitic, and contain wood debris and micrometric siliceous or alumino-silicated spherules) found in Arles and Bologna, which formed in the periods 1180-1636 AD, and 1530-1887 AD, respectively. Past sources of air pollution in the cities of Northern Italy have been investigated, supported by a critical analysis of a 17th-century treatise written by B. Ramazzini[1], a medical doctor interested in the associations between work, environmental pollution and health. The outdoor environment experienced smoke for the combustion necessary for several workshop activities and uncontrolled dangerous emissions (Camuffo *et al.* 2000). The urban pollution was not homogeneous; the craftsmen's activities were organised in different specific areas so that the environmental deterioration potentials changed from site to site inside the same town.

[1] Ramazzini, B.,1700. *De Morbis Artificum Diatriba*. Modena: Capponi.

Particulate Matter (PM hereafter) is a complex and heterogeneous mixture, whose composition (particle size distribution and chemical characteristics) changes with time and space and depends on emissions from various sources, atmospheric chemistry and weather conditions. PM size depends mainly from emission sources: typically those emitted from anthropogenic sources are smaller than those emitted from natural sources (Harrison *et al.* 2012). The coarse fraction (2.5-10 μm) comes predominantly from natural sources (geological material, such as fugitive and resuspended dust, and biological material, such as pollen and endotoxins), and its composition changes depending on the geology of the site. The fine fraction (0.1-2.5 μm) is dominated by anthropogenic emissions: a mixture of carbon particles from combustion processes and secondary particles produced by photochemical reactions in the atmosphere (sulphates, nitrates, ammonium). The carbonaceous fraction consists of aggregates of organic and elemental carbon on which transition metals, organic compounds and biological constituents are adsorbed. Elements are released to the atmosphere from both anthropogenic and natural sources. Anthropogenic sources include fossil fuel combustion, industrial metallurgical processes, vehicle emission and waste incinerations. Natural sources include a variety of processes acting on crustal minerals, such as volcanism, erosion and surface winds, as well as from forest fires and the oceans. Finally we can distinguish between primary and secondary PM, depending on the fact that the aerosols particles are either generated directly in that form or are derived from a gas-to-particle conversion process.

Urban PM pollution is generally composed of coarse and fine PM from different sources (de Miranda *et al.* 2012). Most particulate emissions from combustion sources are $PM_{2.5}$ mass fractions. Fine particles can be directly emitted by sources or produced by condensation, coagulation, or gas-to-particle conversion, the last being common to combustion sources. Detailed descriptions of atmospheric aerosols can be found in the literature (Seinfeld and Pandis 1998; Finlayson-Pitts and Pitts 2000). The transport and distribution of aerosol particles strictly depends on their size, besides on the weather conditions (Poschl 2005; Stone *et al.* 2009). It is possible to observe that PM pollution is more limited in developed and high-developed metropolitan areas with respect to less developed or very poor cities, pointing out the relations among environment, poverty, social justice and quality of life (Conde, 2014). Finally, it is well known that PM plays an important role for the recorded effects on atmosphere and climate, human health and building surfaces degradation (Casazza *et al.* 2013).

This paper has the purpose of showing the relation between the production of both primary and secondary PM and anthropogenic energy-consuming processes. This will be done giving, first, a general framework, based on the most recent available global emission inventories. Then the attention will be focused on urban areas. Finally, conclusions will be drawn under the light of the found evidences.

2. Urban aerosols emissions and energy consumption

Is aerosol pollution mainly a by-product of energy consumption in the case of anthropogenic emissions? In order to give a reference framework with respect to this question, we will analyse the atmospheric primary PM emitted by human activities. For this purpose it is possible to consider the Emissions Database for Global

Atmospheric Research (EDGAR)[2]. EDGAR is a joint project of the European Commission JRC Joint Research Centre and the Netherlands Environmental Assessment Agency (PBL). In particular, it provides global past and present day anthropogenic emissions of greenhouse gases and air pollutants by country and on spatial grid. This database structure allows calculating emissions by country, sector and includes specific technologies for combustion/processing and emission abatement measures. Among the data of EDGAR v4.2 (release: november 2011), it is possible to find the informations about primary PM_{10} emission mass amounts (in tons) from year 1970 to year 2008. PM_{10} is the PM with aerodynamic diameter up to 10 μm. Aerodynamic diameter is defined considering the dynamic of the real aerosol particle to be equivalent to a spherical particle (with a given diameter, which is the aerodynamic diameter) of unit density. This cut-off size is chosen due to the fact that such aerosols are able to penetrate in the respiratory apparatus, generating potential adverse health effects, which are well described in the scientific literature (Romanazzi et al. 2014).

Gridded images of emitted PM_{10} mass (expressed in tons, with a 0.1°X0.1° resolution) are available for the same years indicated above. Furthermore the global sectorial emission data (expressed in tons) are also downloadable from the website. Figure 1 describes the temporal trend, on year basis, from 1970 to 2008, anthropogenic primary PM_{10} emissions by typology, transformed, from the original data (expressed in tons), into values of percentage of the total emitted mass. From the available data it is possible to see that large scale biomass burning, energy industry, and buildings (both residential and others) represent the majority of anthropogenic primary PM_{10} emissions. These sectors are followed by agricultural waste burning and emissions by combustion processes in manufacturing industry. Two sectors represents about 5% each of the total PM_{10} emissions on year base: non-road transport and oil production & refining & transformation. Finally, process emissions during production & application, solid waste disposal (incineration), manure management, fossil fuel fires, road transportation and agricultural soils have primary PM_{10} mass generation lower than 1% of the total emissions on year base. It is evident that, with the exception of 'agricultural soils' and 'manure management', primary PM_{10} emissions are mainly related to combustion processes.

[2] EC-JRC/PBL. EDGAR version 4.2, 2011. Available online at: http://edgar.jrc.ec.europa.eu/ Accessed on: 15th March 2015.

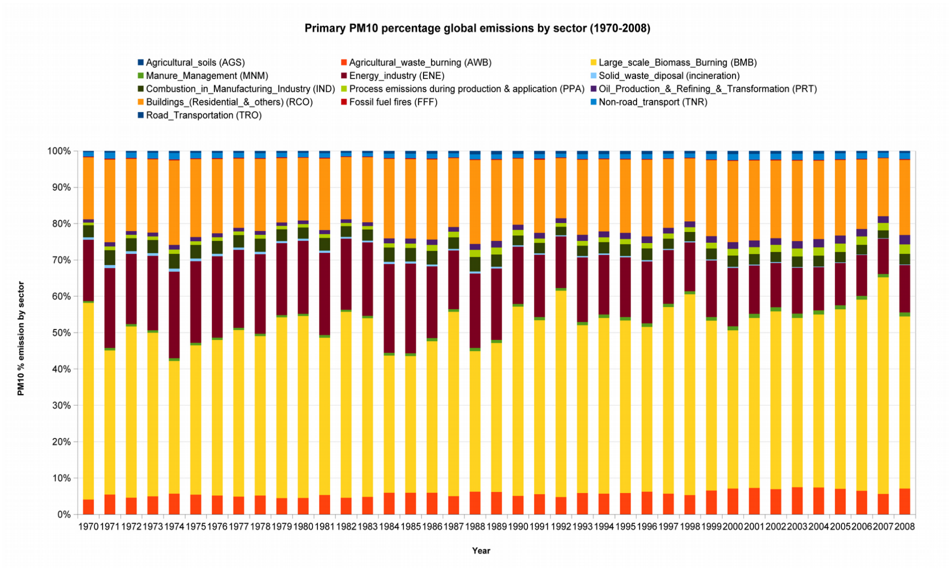

Fig. 1: Temporal trend (on year base, from 1970 to 2008) of sectorial anthropogenic primary PM_{10} emissions expressed in form of percentage of the total emitted mass (originally the data are expressed in tons).

With respect to combustion-derived particles, carbonaceous aerosols are predominately soot produced by incomplete combustion of fossil fuels, biofuels, and outdoor biomass that generally form through condensation of vaporized organic matter (Chylek et al. 2003). However, biogenic emissions from trees, other vegetation, and animals are also sources of carbonaceous aerosols. Carbonaceous aerosols are considered an important factor within climate, due to their interaction with the solar radiation. Elemental Carbon (EC), in the form of graphite, is the main cause of the blackness of soot; it absorbs sunlight strongly and almost uniformly across the solar spectrum. However, the graphite seldom is pure carbon, instead involving varying proportions of other atoms. Furthermore, the carbonaceous aerosols include an enormous variety of organic compounds of carbon. Carbonaceous aerosols are usually divided, rather arbitrarily into categories of black carbon (BC) and organic carbon (OC). This division is based on the aerosol optical properties, not on their chemistry. In the literature, BC or “soot carbon” are often used synonymously for the major light-absorbing component of combustion aerosols (aka “soot”). The carbonaceous aerosols that absorb visible radiation strongly are defined as BC, and the remaining carbonaceous aerosols as OC. OC aerosols may absorb visible light weakly, with this absorption usually increasing toward ultraviolet wavelengths. Recently the evidence of brown carbon (C_{brown}) existence came from carbonaceous aerosols, which have shown the potential of strongly absorbing at visible to UV wavelengths. C_{brown} are distinguished because of their absorption in the UV potentially significant due to their observed high abundance in continental aerosol, which causes the material, or its solution, to appear brown (or yellow). C_{brown} can be originated by: PM from smoldering combustion or from residential coal combustion (especially true for the initial period of the combustion, when yellow particles were released in great abundance); PM formed during the pyrolysis of organic matter, especially during biomass combustion (pyrolysis products can escape without being combusted in flames, and then condense in the cooling plume) and, then, associated with sub-micron particles (they can be geometrically of super-micron size, but, since they are porous and light, their aerodynamic characteristics are typical of sub-micron aerosols); PM from biogenic materials and their low-temperature oxidation and polymerization products; PM formed by the reactions of organic compounds in sulphuric acid particles at low humidities (Andreae and Gelencsér 2006; Updyke et al. 2012; Laskin et al. 2015). A recent emission inventory, specifically created for BC and Primary Organic Carbon (POC) aerosol (Junker and Liousse 2008), reaching back to the year 1860, directly calculated BC and POC emissions from fuel consumption data and appropriate emission factors for BC and POC varying over time. Mission maps have been generated with a 1°×1° resolution based on the relative population density in each country. The results indicate that the industrialisation period since 1860 was accompanied by a steady increase in BC and POC emissions up to 1910. The calculations show a moderate decrease of carbonaceous aerosol emissions between 1920 and 1930, followed by an increase up to 1990, the year when emissions began to decrease again. Changes in BC and POC emissions prior to the year 1950 were essentially driven by the USA, Germany and the UK. The USSR, China and India have become substantial contributors to carbonaceous aerosol emissions after 1950. Data for BC and POC have been quantified (Bond et al. 2007). Emissions of BC increase almost linearly, totaling about 10^6 tons in 1850, $2.2*10^6$ tons in 1900, $3*10^6$ tons in 1950, and $4.4*10^6$ tons in 2000. POC shows a similar pattern, with emissions of $4.1*10^6$ tons, $5.8*10^6$ tons, $6.7*10^6$ tons, and $8.7*10^6$ tons in 1850, 1900, 1950, and 2000, respectively. Biofuel is responsible for over half of BC emission until about 1890, and dominates energy-related primary OC emission throughout the entire period. Coal contributes the greatest fraction of BC emission between 1880 and 1975, and is overtaken by emissions from biofuel around 1975, and by diesel engines around 1990. A gradual increase in BC emissions has been recorded between 1950 and 2000, similar to the increase between 1850 and 1925; implementation of clean technology is a primary reason.

Aerosol optical depth (AOD) retrieved from two satellite instruments, MISR and SeaWiFS, has been used to produce a unified 15-year global time series (1998−2012) of ground-level $PM_{2.5}$ (i.e., a sub-ensemble of PM_{10}, constituted by particles with aerodynamic diameter up to 2.5 μm) concentration at a resolution of 1°x1° (Boys et al. 2014). Four broad areas showing significant, spatially coherent, annual trends are examined in detail: the Eastern U.S. (−0.39 ± 0.10 μg m^{-3} yr^{-1}), the Arabian Peninsula (0.81 ± 0.21 μg m^{-3} yr^{-1}), South Asia (0.93 ± 0.22 μg m^{-3} yr^{-1}) and East Asia (0.79 ± 0.27 μg m^{-3} yr^{-1}). A GEOS-Chem simulation reveals that secondary inorganic aerosols largely explain the observed $PM_{2.5}$ trend over the Eastern U.S., South Asia, and East Asia, while mineral dust largely explains the observed trend over the Arabian Peninsula.

Within urban areas, the relative percentage concentrations of finer fractions, mainly derived from gas-to-particle conversion processes, have a great incidence on PM concentrations, partly due to the newly introduced air quality standards and policies, which helped in reducing the presence of coarse-fraction PM and, in part, due to the difficulty in limiting the secondary aerosol generation (Casazza et al. 2013). Within the lower fraction, an evidence of prevailing presence of nitrates has been found during high level pollution events (Harrison et al. 2004). A study on summertime aerosol in the Po Valley (Italy) reported that the lowest layer of the troposphere (less than 2000 m) contained a large amount of nitrates and a significant presence of secondary organic aerosols (Crosier et al. 2007). Significant trends in sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO) and $PM_{2.5}$ concentrations at the 99% confidence level have also been shown in a study related to Madrid (Spain) urban area (Salvador et al. 2011). An investigation on Beijing sub-micron PM showed that secondary organic matter was the most abundant PM_1 component accounting for 39.7% of the total mass, followed by sulphate (24.5%), BC (14.0%), ammonium (10.2%), nitrate (10.0%), and chloride (1.6%) (He et al. 2011). The formation of secondary organic aerosols in polluted urban areas is also confirmed by other studies (e.g., van Drooge et al 2012). Photochemical activity induces enhances the formation of secondary aerosol (Zhou et al. 2014) and it is an important cause of secondary aerosol formation in urban areas (Casazza 2015). Metals associated to PM are also witnesses of energy-consuming processes (mainly related to combustion) in the urban environment (e.g.: Shafer et al. 2012; Romanazzi et al. 2014; Zereini and Wiserman 2015).

4. Results and conclusions

It is possible to demonstrate, as shown in the previous paragraph, that both primary and secondary PM emissions generated by anthropogenic activities are mainly related to energy-consuming processes. This is also true for the specific case of urban PM emissions, which are related mainly to combustion processes (this happened even before the industrial era). Secondary aerosols largely explain many of the increasing trends of global aerosols. Within the urban areas they constitute the majority of emitted PM and, since they are combustion-derived products, they are related to energy consumption. It is critical to alleviate problems of energy and air pollutants emissions in the urban areas, because these areas serve as economic engines and have large and dense populations. Apart from the consequences of the economic recession, air quality policies have shown an active role both in the reduction of the PM regional background levels and in the emissions levels from specific sources of the urban agglomeration (Salvador et al. 2014). A reduction of the emissions from road traffic and residential heating was produced, as a consequence of the implementation of a number of management strategies promoted and adopted by international and national bodies and administrations (Casazza et al. 2013). Analyses from different perspectives have shown that the key energy-intensive industrial sectors directly cause the variations in urban air pollution by means of a series of energy and economic policies. Population growth is generally the largest driver of energy consumption and air pollutants emissions (Zhang et al. 2015). Since it is known that PM plays an important role for the recorded effects on atmosphere and climate, human health and in the degradation of built environment, we cannot consider PM emissions as a sort of externality, while discussing about the future of urban and industrial way of life. In fact, PM emissions are an output by-product of human activities dealing with energy consumption. In particular, they occur, depending on the availability of energy sources, on energy consumption and on cleaner production technologies and production procedures. Aerosol pollution should be regarded as a by-product of energy consumption, while discussing about the different environment constraints within urban planning strategies.

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Energy and Environmental Sustainability Consciousness in Engineering Education for Urban Systems Planning

Q. Wang 1[1*], T.N. Goh[1], C.H. Tan[1]

[1]Department of Industrial and Systems Engineering, National University of Singapore, 1 Engineering Drive 2, Singapore 117576, Singapore

Corresponding Author e-mail: qiong.wang@u.nus.edu

Abstract

Environmental issues have steadily encroached on businesses' capacity to create value for customers. An organization is more than just a machine that transforms material input into output (Richard, 2003). While consumers increasingly concern sustainability into the products, organizations should respond by pursuing legitimacy for their operations. Like the information technology and quality megatrends, the sustainability imperative will touch every function. And how the executives respond to the challenge of sustainability will profoundly affect the competitiveness of the organizations (Lubin & Esty, 2010). University sustainability education programs in several European countries and the US have been compared to find common characteristics of the curricula in environmental science and engineering programs. The aim of the study is to analyze engineering curricula and find the structure of advanced environmental engineering and science courses in comparison with traditional courses. The study has shown that top universities are following the pace of sustainable development but they are maintaining courses from the precedent approaches, as ecology and environmental engineering are still very important. But they are introducing new disciplines including environmental economics and policy in the U.S. and sustainable technology for energy system and environmental process in European universities. The development in the past has moved from mass and energy balance calculations in context of pollution generation and prevention, resource recovery and life cycle assessment and recently to the sustainability concept comprising economic and societal dimensions of current and future development. Social impacts of technology system design decisions include ethical frameworks, government legislation and health risks. The content of the sustainability curricula reflects the local needs for construction, for instance, the sustainable design for urban planning. It should be noted about the urban attributes while doing the reforms in sustainability courses.

Keywords: Sustainability; Engineering education; Curriculum design

1. Introduction

Over the past 10 years, environmental issues have steadily encroached on businesses' capacity to create value for customers. It is essential for industry to find a reference point when promoting sustainable development; the critical reference point for faculties of engineering is their students. A curriculum design for engineering education, as one of the sustainability objectives for industrial needs, results from the interplay of cultural characteristics and the institutional setting. (Gambini, 2006) Both the culture characteristics (e.g. place and sociocultural factors) and institutional settings (e.g. government and demographics) should affect the promotion of sustainability (O'Neill, Hershauer, & Golden, 2006).

Engineering education is not like an industrial process or a mechanical system that can be improved just by having better data. The point is that engineering education is a human system also facing the unprecedented journey with sustainability as a strategic issue. Sustainability is an emerging megatrend, and thus its course is to some extent predictable. Consequently, engineering education is moving into sustainability. The importance of pollution prevention or cleaner production has been substantial in changing the environmental approach within advanced industrialized countries (Overcash, 2002). Extending this new topic into undergraduate curriculum has been vital to improve the sustainability of cleaner production. However, integration of the sustainability concept into engineering curricula is still one of the highest priorities today.

The engineers are assigned the task of translating theoretical principles of sustainable development into everyday industrial practice (Azapagic, Perdan, & Clift, 2004). The issue of sustainability places particular demands on engineers to become experts of the roots of the problems, in addition to being trained in problem solving techniques that emphasize holistic approaches (Gutierrez-Martin & Hüttenhain, 2003). New ability to understand, to identify, and to evaluate sustainable development problems and tools to design products and processes using systematic analysis are required. To meet industrial needs, multidisciplinary green programs are being proposed to attract students with various types of background and the EU is drawing up policies and legislation for encouraging CSR. The European Commission is supporting the development of joint curricula where several universities from different countries are involved. The European Commission stimulates many initiatives: the Bologna scheme, the Erasmus Mundus, and Marie Curie programs (Glavič, 2006).

The importance of educating engineers in sustainable development principles has been highlighted (Hopkins, 2007; Perdan, Azapagic, & Clift, 2000). Professional institutions, such as the Royal Academy of Engineering, the Institution of Chemical Engineers, Institution of Civil Engineers and Institution of Mechanical Engineers had introduced a number of initiatives to encourage the integration of sustainability into higher education as well as its industrial application. This is emphasized by the requirement placed by these professional institutions on higher education providers seeking accreditation of their courses to demonstrate sufficient provision of embedded teaching of sustainability, health and environment, sustainability and ethics or by the provision of a sustainability metrics tool to help industry assess the impact of their operations and the provision of guiding principles on engineering for sustainable development.

The aim of the study is to analyze engineering curricula and find the structure of advanced environmental engineering and science courses in comparison with traditional courses. The distribution of modern sustainability courses including economical, societal and technological concerns is also evaluated. The results shall be useful to the departments introducing or modernizing sustainable engineering study or courses.

2. Research methodology

Sustainability does not have a universal definition. Sustainable development integrates improvements in human welfare with improvements in the health of the environment. It is societies attempt to solve the degradation that economic and social development has imposed on the environment. To solve environmental crises such as climate change, pollution, or destruction of biodiversity we need to integrate environmental practices into all our activities, pulling together new technologies, lifestyles, economic theories and business practices, and government policies. Sustainability courses look at how this process of integration works at the international, national, and municipal levels and from the organization perspectives of different industrial sectors, businesses, and communities. It is found that sustainability transcends individual disciplines, while resting on a foundation of disciplinary understanding. According to the STARS (The Sustainability Tracking, Assessment & Rating System) guidelines, sustainability courses are categorized as sustainability-focused and sustainability-related: sustainability-focused courses concentrate on the concept of sustainability, including its social, economic, and environmental dimensions, or examine an issue or topic using sustainability as a lens; Sustainability-related courses incorporate sustainability content as a course component or module. In this study, 97 summarized terms formed the basis of the selection criteria for our curricula analysis.

The research design followed content analysis. Content analysis is a systemic, objective, quantitative research method that can measure variables as they naturally occur, without any manipulation of the independent variables. In particular, a conceptual analysis focuses on the frequency of keywords or phrases in a target text to reduce the subjectivity (Jones, Shan, & Goodrum, 2010). However, this study cannot offer a census of all courses; rather, the findings provide directions to help reveal major educational emphases on sustainability.

To analyze undergraduate engineering education from different institutional backgrounds in terms of their sustainability-focused and sustainability-related curriculum designs, the study scrutinized engineering school curriculum designs from the top 100 universities picked out from the QS World University Rankings and Times Higher Education World University Rankings by Faculty of Engineering and Technology in the academic year 2014-2015.

The data collection process consisted of five steps:

(1) Identify the target university's website.
(2) Identify the university's environmental engineering and science programs.
(3) Identify minors and certificates related to sustainability for engineering undergraduate students.
(4) Identify 76 terms in the course titles or course descriptions listed on the website. Any course containing any of the 76 terms was entered as a "1" in the counting column.
(5) Identify the university's course catalog and search the term "sustain". Any course offered for engineering undergraduate students containing any 76 terms was entered as a "1" in the counting column.

As Engineering Areas are broad in scope, for example, the 'Civil, Structural and Environmental Engineering' Area encompasses the three distinct (but related) engineering disciplines in its title. For this kind of course, it was counted in "Environmental engineering" group for once without replication.

To ensure a multidisciplinary approach, courses from different engineering disciplines have been included: environmental, civil, industrial, chemical, structural, construction, energy, nuclear engineering. Environmental, energy, chemistry, geological, agricultural, natural resources, earth, and other science courses as well as technological courses (sustainable innovation, environmental technology) were considered. There are a few dedicated environmental engineering or environmental science programs in the undergraduate programs. And environmental study is most often integrated in other courses, separately available as elective courses in the junior and senior classes. Most of the Internet data allowed not only the title to be studied but also an in-depth analysis of the course content.

3. Classification of courses and main features observed

In this study, courses in undergraduate environmental science and engineering programs have been classified into the following three groups which are tightly linked and interdependent: Group A: Energy, Economics and Policy; Group B: Energy, Environment and Society and Group C: Energy, Science and Technology.

The curriculum analysis included all sustainability-focused and sustainability-related courses, whether required, elective, project or seminar to a major in engineering for an undergraduate degree. Minor courses and courses with certificates for engineering undergraduates were also taken into consideration. 20 Asian universities, 34 European universities, 39 North American universities and seven Australian universities were chosen based on the universities' data availability. 2749 courses searched via the internet from 100 universities have been identified as addressing sustainability.

Fig. 3.1 displays the breakdown of courses of the top 100 universities by region. As can be seen, most of the courses are distributed in North America and Europe. And some universities in Asia have also attempted to design the sustainability courses in each subject. Only a minor fraction of the courses in the region of Oceania cover sustainability.

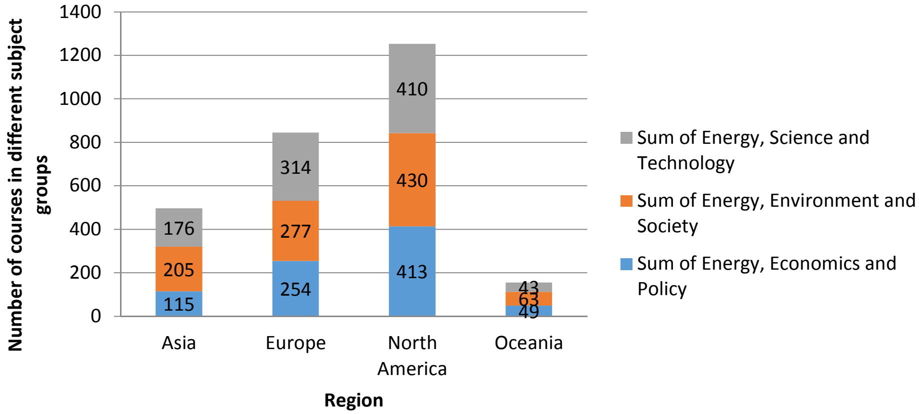

Figure 3.1 Breakdown of different subject groups of sustainability courses by region

Fig. 3.2 presents the distributions of courses in different subjects at universities of the United States. Firstly, the most Energy, Economics and Policy courses are offered in University of Pennsylvania and University of Colorado Boulder. Those courses are available in sustainability ethics, risk communication and the environment, environmental economics, policy, regulatory, management and law, energy market and policy, and sustainability in business etc. Secondly, the most courses in Energy, Environment and Society is introduced in University of Wisconsin-Madison introduces. Courses cover the topics in the social perspective of environment, ecosystem and resource in soil, water and atmosphere, environmental health and risk, environmental systems optimization etc. A special course is Green Screen in which environmental studies are taught through films. Thirdly, the most of Energy

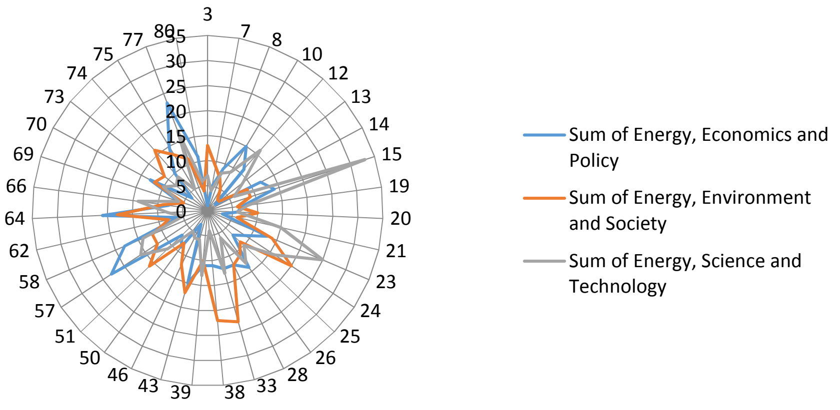

Figure 3.2 Distributions of courses in different subjects at universities of the United States (in numbers)

Science and Technology courses are put forward in Georgia Institute of Technology. Courses are available in sustainable energy system, environmental engineering systems and principles, renewable energy system and nuclear safety engineering, energy conversion, power system analysis and control, and topics among science, technology and culture etc.

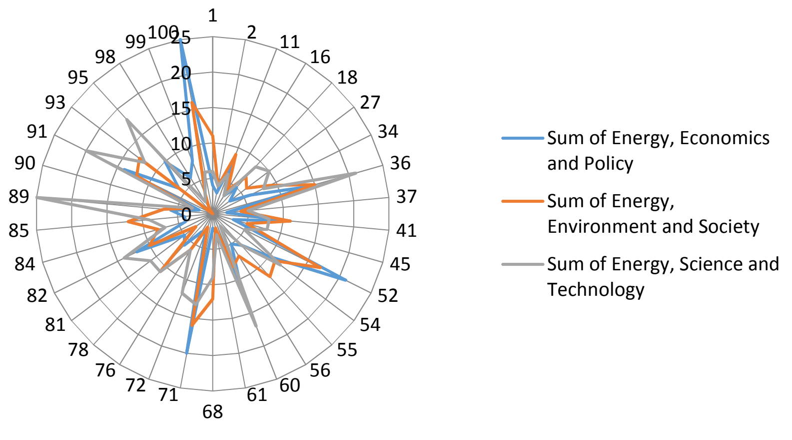

Figure 3.3 Distributions of courses in different subjects at universities of Europe (in numbers)

Fig. 3.3 presents the distributions of courses in different subjects at universities of Europe. First of all, Wageningen University and Research Center is with the most number of courses in Energy, Economics and Policy. Those courses include topics of environment science and society, climate change economics and policy, sustainable development etc. All of the courses are taught in Dutch. In terms of Energy, Environment and Society courses, UCL (University College London) is in the forefront of the subject. Except for the topics of environmental systems and society, resources development, and water treatment, earth resources, disaster reduction and bioprocesses are also taken into consideration. In addition, Universitat Politècnica de Catalunya introduced the most number of Energy, Science and Technology courses among the universities due to its energy engineering program with inter- and multi-disciplinary courses offered for engineering undergraduate students.

Table 3.1 Comparison of top 10 sustainability course contents: the U.S. and Europe

	Top 35 the U.S. universities		Top 34 European universities	
Rank	Course content	Frequency	Course content	Frequency
1	Ecology	43	Sustainable development	44
2	Environmental engineering and science	33	Sustainable technology	41
3	Environmental economics and policy	32	Ecology	33
4	Climate change	30	Processes	33
5	Ecosystem	28	Sustainable society	28
6	Ethics	24	Energy system	25
7	Natural hazard and disaster prevention	24	Environmental engineering and science	24
8	Renewable energy	23	Innovation and entrepreneurship	21
9	Energy system	23	Water and wastewater treatment	18
10	Natural resource	21	Climate change	18

This study also investigated the subjects of sustainability-related courses offered. Table 3.1 contains the 10 most common topics in sustainability-related courses. In the United States, the top three topics are ecology (15%), environmental engineering and science (12%), and environmental economics and policy (11%). Most of these courses focus on the human side of sustainability, environmental processes analysis and effects on society and ecosystems which are the topics of Group A and Group B. However, unlike engineering programs in the U.S., European universities pay more attention to sustainable development (15%) and sustainable technology (14%). Those courses focus more on the application of processes in techniques that aim to improve the energy system and environmental quality.

4. Discussion and conclusion

This research has aimed to develop the sustainability consciousness in undergraduate engineering education and investigate the differences among the top universities worldwide in different institutional settings with regard to sustainability-related courses. The study has shown that top universities are following the pace of sustainable development but they are maintaining courses from the precedent approaches, as ecology and environmental engineering are still very important. But they are introducing new disciplines including environmental economics and policy in the U.S. and sustainable technology for energy system and environmental process in European universities. The development in the past has moved from mass and energy balance calculations in context of pollution generation and prevention, resource recovery and life cycle assessment and recently to the sustainability concept comprising economic and societal dimensions of current and future development. Social impacts of technology system design decisions include ethical frameworks, government legislation and health risks.

International organizations promote the need for sustainability education and advocate accreditation-led reforms in sustainability curriculum design (Læss∅e, 2010). The content of the sustainability curricula reflects the local needs for construction, for instance, the sustainable design for urban planning. It should be noted about the urban attributes while doing the reforms in sustainability courses.

It has been made an effort to develop sustainability consciousness in engineering education in this study. Energy and environmental studies can be integrated into various discipline of Engineering for effective educational purposes. In the discipline of Energy, Economics and Policy for Engineering Management, courses like sustainability ethics, risk communication and energy economics should be introduced; in the discipline of Energy, Environment and Society for Engineering Studies, courses are suggested to cover topics in the social perspective of environment, ecosystem and resource in soil, water and atmosphere, environmental health and risk, environmental system optimization etc.; in the discipline of Energy Science and Technology for Engineering Application, sustainable energy system, environmental engineering systems and principles, renewable energy system and nuclear safety engineering etc. are recommended for effective engineering educational purposes.

Energy is a key part of multilateral relationship and the graduation of engineering students who intend to work in energy industry will lead on energy reporting and analysis across the stakeholders in different countries. Engineers who are trained in statistics for energy will help to inform developed countries' polies to accelerate developing countries' shift away from coal to gas, nuclear, and renewables in order to both reduce greenhouse gas emissions and to increase energy security. It will also help to identify potential commercial opportunities. Engineers with knowledge of energy policy and sectors, including an ability to analyze statistical data, will be able to produce most up to date energy analysis and will lead for the team on relations with energy analysts and experts across government, industry, and academia.

However, there are several limitations for future research. Firstly, courses are offered with local cultural difference. For example, Japan introduces a lot of courses in topics of natural hazard reduction and prevention due to its physical features. Secondly, some universities' syllabi were unavailable online. The results are only based on the data available. Thirdly, the effectiveness of the sustainability-related courses is unknown.

The future work is to concentrate on the more detailed work: search including teaching methods, textbooks, case studies, seminars, projects and laboratory. Networking in educational issues related to sustainability is expected for the future coordination of activities. Then further research could evaluate sustainability-related courses in more detail to understand undergraduate students' learning performance and satisfaction. Understanding students' performance with integration of sustainability courses into their future actions would provide critical implications for the development of sustainability in engineering education.

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An innovative urban energy system constituted by a photovoltaic/thermal hybrid solar installation: design, simulation and monitoring

Amaya Martínez Gracia[1], Alejo del Amo [2], Angel A. Bayod-Rújula * [3]

[1] Department of Mechanical Eng. University of Zaragoza

[2] Endef Engineering

[3] Department of Electrical Eng. University of Zaragoza

Corresponding Author e-mail: aabayod@unizar.es

Abstract

The case study presented in this paper is an innovative urban energy system constituted by a hybrid solar system

The photovoltaic/thermal hybrid solar collectors (PVT) constitute a very interesting renewable technology to be implemented in urban building, since they produce both electricity and heat from one integrated component. PV systems turn on average less than 20% of the sunlight into electricity, while the remainder is turned into heat in conventional PV modules. Utilising this untapped energy is the key value for hybrid systems. It makes possible to improve the energy yield per area unit of roof or façade. Additionally, the versatility of the conversion allows optimizing electricity or heat depending on the demand requirements.

A significant amount of research and development work on the PV/T technology has been done for the last four decades. Many innovative systems and products have been put forward and several publications focused on the PVT module can be found in literature.

Along this work a theoretical model of the PVT panel was develop based on proved methods and including the particularity of the addition of a transparent insulating cover (TIC) in collaboration with an industrial partner (Endef Engineering). It was validated with results obtained with the ones in the test bench. Then, all the other components of the installation were simulated as well and the complete model was implemented in the software Trnsys in order to analyze the energy production to meet the domestic demands in residential buildings (electricity and hot sanitary water).

As a further and fundamental step, the monitoring of a real working installation is used in this paper to validate the model. The presented case study is located in Zaragoza (Spain), in a residential apartment block, with an electrical installed power of 4.14 kWp and 20.5 kW of thermal capacity. The work done began with the redesign of the hybrid solar plant, which supplies hot water individually to each housing and power for common consumption of the building, including a charging system for electric vehicles. Heat and electricity production and efficiency of the whole system could be found with error lower that 5%.

Techno-economic feasibility of distributed electricity generation from residential rooftop SPV projects in New Delhi, India

Kapil Narula*‡, B. Sudhakara Reddy**

*National Maritime Foundation, Varuna Mess Complex, Airport Road,
New Delhi - 110 010, India
kapilnarula@yahoo.com

** Indira Gandhi Institute of Development Research,
Goregaon (E), Mumbai - 400 065, India
sreddy@igidr.ac.in

‡ Corresponding Author Tel: +91 9810514169, Fax: +91 1126156520

Abstract

Distributed electricity generation from Solar Photo Voltaic (SPV) rooftop projects with grid integrated net metering, is fast emerging as an attractive option for powering cities. It has four unique advantages: Increasing security of electricity supply, bridging the supply-demand gap with clean energy, cutting down on transmission and distribution losses and decongesting the load on the grid. Self generation of electricity therefore holds much promise and potential in the cities of India which are endowed with above average solar radiation across the major part of the year. However, there are certain technical, financial and institutional barriers which limit the growth of these options and need to be examined.

In order to promote distributed electricity generation in New Delhi (India), Delhi Electricity Regulatory Commission (DERC) has issued regulations for 'net metering' based SPV rooftop projects. The paper aims to examine the techno-economic feasibility of the notified scheme for residential consumers based on the current costs and applicable electricity tariff in Delhi. The 'self-owned' and the 'solar leasing' models are evaluated for different SPV system sizes which are suitable for installation on residential rooftop spaces. The paper compares the Internal Rate of Return (IRR) based on cash flows for different cases using a deterministic financial model. Results indicate that with the current costs, smaller systems (2.5 and 5 kWp) are suitable for self ownership, but require the existing 30% subsidy in order to be financially viable. However, the return on larger self-owned systems (10 kWp and above) is sufficiently high and does not warrant the subsidy. On the other hand, third party ownership (solar leasing) is commercially unfeasible for smaller systems, while returns on larger systems are sufficiently high to attract commercial interest. The paper while analyzing the IRR for various cases concludes that there are certain drawbacks in the scheme as it does not allow optimal utilization of rooftop spaces for generation of electricity. These limitations if relaxed, can improve the financial viability of the scheme and can encourage decentralized generation of electricity in Delhi. The net metering scheme should therefore be seen as one of the solutions for transition of urban energy systems and should be adequately tweaked to enable widespread deployment of rooftop SPV in cities.

Keywords- Solar Photo Voltaic (SPV); net metering; solar leasing; Internal Rate of Return (IRR)

Urban Rooftop PV Electricity: Is this the answer to India's solar question?

Hippu Salk Kristle Nathan* and Dilip R Ahuja
National Institute of Advanced Studies (NIAS)
Indian Institute of Science (IISc) Campus
Bangalore - 560012, INDIA
Phone: +91-80-22185052, +91-8904714396, Fax - +91-80-22185076
*Corresponding Author
Email: hsknathan@nias.iisc.ernet.in, happyhippu@gmail.com

Abstract

Many scholars put solar as an important panacea for crises in India's energy future. However, the penetration of solar in India has been far from satisfactory. One of the reasons for slow progress in solar in India can be attributed to misplaced policy emphasis of solar for rural electricity.
Some of the recent studies show that the priority of solar PV in rural areas explained to large extent its failures because remote rural locations suffer from the lack of supply chain, financial capacity, and skilled human power. This naturally triggers for an alternative strategy where solar PV is promoted in the urban areas first, and then a mass use in the urban area might organically push the technology to rural area, who can then take the advantage of scale.

Under the above backdrop, this study assesses the realistic potential of solar rooftop PV for urban India. The analysis divides the urban built up areas into four sectors - (i) commercial and industrial buildings with diesel gensets, (ii) Institute and government buildings, (iii) commercial and industrial buildings without diesel gensets, and (iv) residential buildings. The study presumes policy prioritization in a way that solar rooftop PV gets adopted in urban areas above-mentioned sequence. It is expected that with a little support solar PV can compete well with diesel gensets and institute campuses can provide the necessary ecology for solar PV implementation to succeed.

For forecasting potential, the study plots experience curves (i.e., learning curves) of solar PV and competing conventional options by examining the historical performance of these technologies in India. The study acknowledges that learning continues to take place not only solar PV, but also in competing fossil fuel based technologies. With explicitly stated assumptions, the study estimates the aggregate amount of learning investments required as a difference from two experience curves - one for competing solar rooftop PV and other for the established fossil fuel based electricity. Based on the observations from experience curves, the study recommends design changes and incentive programmes for adoption of solar rooftop PV in India's urban areas.

An Integrated Assessment of the Performances of Photovoltaic Power Stations for Electricity Generation

Samuele Lo Piano*[,1,], Kozo Mayumi[2]

[1]Scuola Normale Superiore of Pisa, Italy

[2]Faculty of Integrated Arts and Sciences, The University of Tokushima, Japan

Corresponding Author e-mail: s.lopiano@gmail.com

Abstract

EROI is the ratio of the amount of net energy acquired from a source to the amount of energy expended to obtain that net quantity. Therefore, EROI can be used as an indicator of energy transformation performance. Unfortunately, EROI is a far from satisfactory means by which (or way) to evaluate the overall energy and material balance associated with important aspects of quality and quantity check of alternative primary energy sources. To this end, in this paper we propose a general accounting scheme applied to photovoltaic technologies for electricity generation. The proposed methodology is based on the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) approach. MuSIASEM is an accounting scheme based on the three pioneering fields of works: Georgescu-Roegen's flow-fund model in bioeconomics; hierarchy theory in ecology; and hypercycle theory by Eigen and Ulanowicz; the methodology is an attempt to evaluate three types of viability of energy and material transformations: Biophysical, technological and socioeconomic. Biophysical viability refers to the availability of thermodynamic potentials that permit the exploitation of a given primary energy source and the disposal of the waste. Technological viability refers to the conditions required to create a new energy sector that could give a feasible balance of energy for the society. A stable societal metabolism also requires a balance between the production and the consumption sides, therefore, it is crucial to know how much energy is secured for the consumption activities. Socioeconomic viability refers to this kind of equilibrium, i.e. the ability to meet the energy and material demand of specific types of societies. We shall address the demand of direct and indirect production factors (silver, energy carriers, human time, land and water) in photovoltaic power stations based on wafer crystalline silicon cells.

1. Introduction

The fossil fuel bonanza of the last two hundred years has boosted the current material affluence of modern societies. However, the depletion of fossil primary energy sources in easy recoverable forms[1] and the increasing volume of carbon dioxide emissions deriving from their combustion are two issues of primary importance. Therefore, it is imperative to evaluate the potential of alternative and renewable energy resources. One of the most promising is undoubtedly solar photovoltaics, which directly converts solar radiation into electricity. The technique has several advantages (Jungbluth et al. 2012) with no emissions or moving parts -which could cause noise during the operational stage- and an easy scalability according to the power needs (with applications ranging from a few milliwatts, e.g. in watches, to recently developed solar power plants with hundreds of megawatts of power capacity). Furthermore, silicon is the second most abundant element in the Earth's crust and it is nontoxic.

In order to evaluate the potentiality of solar photovoltaics for large-scale electricity generation, we adopted in this paper the MuSIASEM methodology in this paper as a means by which it is possible to deal with the multiple relevant scales and

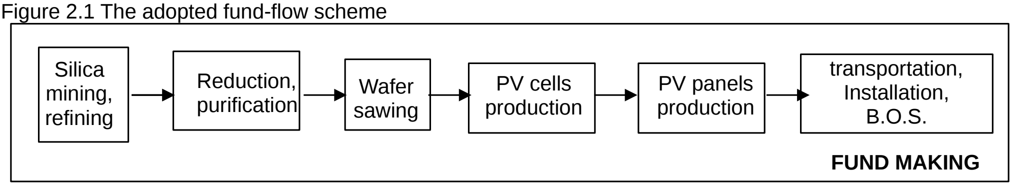
1 http://peak-oil.org/wp-content/files/Oil_Abundance-Not_So_Fast_2014.10.24.pdf

dimensions involved in the sustainability discussion. The approach has already been successfully applied to several case studies assessing the performances of alternative energy sources (Diaz-Maurin and Giampietro 2013, Giampietro and Mayumi 2009, Diaz-Maurin et al. 2014). The methodology accounts for the different dimensions involved, avoiding the oversimplification of reductionist approaches dealing with single indicators obtained from standard algorithms. Also, the existence of multiple relevant scales is acknowledged through the evaluations of several types of viability: biophysical on the macroscale (the compatibility with physical boundary conditions outside human control); desirability (the socioeconomical viability on the mesoscale, considering the allocated human labor as production factor and benchmarking it with the defined metabolic pattern of a given society on the national, regional or local scale); technological viability on the microscale (i.e. the use of energy carriers for the electricity generation process).
The paper is organized as follows: section 2 introduces the methodology used and the source of data, section 3 shows and analyzes the findings obtained and section 4 draws some conclusion, illustrating potential further improvements as well.

2. Data and methodology

The system is analyzed through the flow-fund approach: The fund describes the identity of the system, whereas the flow represents what the system does. Therefore, the resources are listed according to the step in which they are allocated: Either the fund making process (mining, manufacturing and installation of the PV panels) or the flow generation (operation and maintenance of the power plant). The variables are expressed as intensive quantities, in relation to the electricity produced (per GWh_{el}). The evaluated variables are human activity, land, water, energy carriers (electricity, fuel and heat), besides the element silver (Figure 2.1). Other parameters could also be included for a thorough accounting scheme (for the detailed description of a general accounting scheme, see Mayumi and Giampietro 2014).

Figure 2.1 The adopted fund-flow scheme



Indirect requirements (fund making)

Funds: **Power capacity, labour, (Richardian) land;**

Flows: **Energy carriers, water,** materials**, silver,** wasted heat, pollution, waste material

Direct requirements (flow generation)

We evaluated only utility-scale and ground-mounted, fixed-tilt, solar power plants, constituted of crystalline silicon wafer-based solar cells, which represent the most adopted technology worldwide, with a market share above 90%[2]. In spite of the research that led to the development of second generation (thin-film) and third generation solar cells, the share of crystalline silicon wafer-based solar cells remains firmly predominant, with no apparent sign of decrease.

For the electricity production, it is assumed an average solar radiation of 1460 kWh m^{-2} y^{-1} (Feltrin 2008), however a sensitivity analysis of the parameter has been performed, considering a wide range of solar irradiations (850 – 2500 kWh m^{-2} y^{-1}), ranging from high-latitude low insolations to the highest values typical of deserts. A factor of 0.7 has been adopted to account for the conversion losses, including mismatch of modules, reduction of efficiency due to dust, transmission and grid losses and so on. An average efficiency of 15% has been considered, with a lifetime of 30 years. The assumed solar panels power density is 150 W/m^2.

The data used for the accounting scheme refer to measured experimental values. Models/extrapolations have been excluded from the accounting, privileging bottom-up data from technical documents over top-down statistics whenever possible. However, especially for some quantities (human labour and water), data is affected by a rather high amount of uncertainty, due to the absence of systematic and accurate investigations in the literature.

The values for human activity are taken from Llera et al. (2013), multiplying the coefficient of jobs/MW_p by the worked number of hours per year (1,800 h). In the account of land use, the total occupied area has been considered; the data was taken from two publications related to PV solar power stations in the US (Fthenakis and Kim 2009, Ong et al. 2013). The data for water use as well as those for the energy carriers derives from several technical reports and life-cycle assessments (de Wild-Scholten and Alsema 2007, Mason et al. 2006, Frankl et al. 2005, Jungbluth et al. 2012, Prieto and Hall 2013, Yang et al. 2015). Finally, the assumed data for silver consumption per unit of installed power, 38g/W_p, refers to the average commercial technologies in 2013 (Semi PV group Europe 2014).

The intensive variables have been gained by dividing the unitary value of each item per MW_p installed by the lifetime production of the plant, expressed in GWh_{el}/MW_p.

3. Results and discussion

The specific intensive benchmarks are reported in Table 3.1. Depending on the solar irradiation, the specific electricity production is included in the range 18 – 53 GWh_{el}/MW_p. The quantities are reported in relation to the gross electricity production; in principle, the variables should be acknowledged in relation to the net supply of the energy carrier, however the electricity used in the flows generation is negligible in comparison to production. On the contrary, the quantity is extremely relevant in the fund-making. The first emerging aspect is that most of the resources are not surprisingly allocated in the fund-making stage. By contrast, the specific input of productive factors were definitely higher in the flows generation stage in a published work about a grammar assessing the performances of power-plants based on nuclear energy and fossil fuels (Diaz-Maurin and Giampietro 2014).

With regard to biophysical constraint, the power of solar radiation does not represent *per se* a limit with an average value of 174,000 W reaching Earth, of which 21,840 TW reaching the surface of ice-free land. Should this last last quantity be entirely converted into electrical energy, roughly one hour of supply would be enough to meet the current annual world demand of this energy carrier. On the other hand, a limiting

2 http://www.ise.fraunhofer.de/en/news/news-2012/fraunhofer-ise-publishes-photovoltaics-report

factor could be represented by the employment of silver in the PV cells manufacturing: The metal is used in a specific paste for the contact metalization of silicon wafer-based cells. Albeit the decrease of consumption per cell has been remarkable in the recent years, down to $38mg_{Ag}/W_p$ in the average commercial technologies in 2013 (Semi PV group Europe 2014). In the case of a large deployment of solar PV power plants, the total usage of the commodity could reach 37% of the currently estimated world reseves of the metal (Lo Piano and Mayumi *forthcoming*, and references therein), for an electricity production corresponding to the 30% of the current yearly global demand. Some supply of the metal could be provided for by using old scrap, though whether the metals from disposed solar panels will be recoverable, and to what extent, is still unclear[3]. Conversely, water does not represent a limitation in the photovoltaics deployment: Most of its use takes place in the production process. A small amount is also required for the panel cleaning, with a number of washing cycles estimated between two and four per year (Jungbluth et al. 2012, Prieto and Hall 2013). Generally, for this type of application higher-value demineralized, if not deionized, water, is required. Although globally water consumption for cleaning could not represent an issue, its scarcity could be a limiting factor in very highly insolated, desertic and arid areas. However, the usage in this stage is reduced in the extreme in comparison with other solar techniques, likewise concentrated solar thermal (CSP), whereby water has a more prominent role in the cooling phase. As a matter of fact, the consumption is three orders of magnitude higher for CSP in the flows generation stage in comparison to photovoltaics (Diaz-Maurin et al. 2014). With regard to land use, 520 – 1500 m^2 are required to produce 1 GWh_{el} for PV solar power plants. This figure corresponds to an average power density of 37 W/m^2. By comparison, the supplied power density in fossil fuel power plants is one order of magnitude higher (Smil 2008). Typical power densities for energy consumption are included in the interval 20 - 100 W/m^2 for houses, up to 3 kW/m^2 for high-rise buildings (Smil 2008). In spite of the fact that solar photovoltaics is the renewable form of energy with the highest power density, the mismatch with the power density demand of urban systems, having a high population density, is absolutely evident. This “power dilution” could potentially drive a significant land rush as remarked in Scheidel and Sorman (2012) in case of a significant deployment.

In relation to the viability, the highest share of energy carriers is used in the fund-making, this is especially true for electricity with a consumption two orders of magnitude higher in the fund-making in comparison to the flows generation. Most of electricity is consumed in the manufacturing process, especially for the purification of the metallurgical grade silicon and the wafer sawing. In terms of power capacity, a relevant criticality of solar power plants is represented by the low capacity factor (i.e. the fraction of hours of the year of actual use of the converter). For this study, it has been assumed an average value of 0.17 for this parameter, with a 0.10 – 0.26 range, however it can be as modest as 0.05 for particularly cloudy regions. For comparison, the utilization factor for fossil fuels-based power plants is included in the range 0.8 – 0.9 (Palmer 2014). This average low capacity factor implies that in order to produce a certain amount of electric energy, the required power capacity is substantially higher in comparison to fossil fuel power plants. In addition, the production of electricity is concentrated in a limited fraction of hours, namely those corresponding to the highest solar irradiation. In general, these hours could not match the spike in demand characteristic of diurnal activity cycles, especially typical of urban systems. Therefore,

3 A recovery rate of 30-50% is reported in the literature (Paiano 2015), however the number of systematic studies on PV modules recycling is really exiguous.

electricity generation from photovoltaic power plants could be not particularly useful to respond to peak in demand. On the other hand, in countries where high-penetrations in the electric grids have already taken place, several cases of over-loading and over-voltaging issues have already been documented (IEA-PVPS 2014). The proposed solution relies on the implementation of smart grids for a better coordination of the intermittent production from renewable energy sources and the consumption side.

Table 3.1 Specific technical coefficients

Solar irradiation (kWh m^{-2} y^{-1})	**1460**		**850**		**1100**		**1800**		**2150**		**2500**	
	Specific direct requirement (fund)	Specific indirect requirement (flow)	Dir.	Indir.	Dir.	Indir.	Dir.	Indir.	Dir.	Indir.	Dir.	Indir.
Human labor (h GWh_{el}^{-1})	1300	97	2200	170	1700	130	1000	79	850	66	740	57
Land (m^2 GWh_{el}^{-1})	890	N.A.	1500	N.A.	1200	N.A.	720	N.A.	600	N.A.	520	N.A.
Water (m^3 GWh_{el}^{-1})	580	12	1000	21	770	16	470	9.7	400	8.1	340	7.0
Electricity (MWh_{el} GWh_{el}^{-1})	39	0.17	67	0.29	52	0.22	32	0.14	27	0.11	23	0.10
Heat (GJ_{he} GWh_{el}^{-1})	17	1.8	29	3.0	22	2.3	14	1.4	11	1.2	9.8	1.0
Fuel (GJ_{fu} GWh_{el}^{-1})	9.5	1.7	16	3.0	13	2.3	7.7	1.4	6.5	1.2	5.6	1.0
Silver (kg GWh_{el}^{-1})	1.2	N.A.	2.1	N.A.	1.6	N.A.	1.0	N.A.	0.84	N.A.	0.72	N.A.

On the desirability side, modern societies are characterized by the allocation of a very limited fraction of human labour (paid work) in the agriculture and energy and mining sector. This allows the investment of large fractions of paid work hours in the service and government sector, besides the availability of a significant quantity of time for leisure activities, where the resources produced are consumed. That is to say, in order to allocate more time in the consumption activity, the production of resources has to be met with a minimal fraction of human labour. For instance, the typical benchmark for the energy and mining sector labour productivity is 20 $GJ\_{Energy\ Carriers}$/hr for modern societies (Giampietro et al. 2012). For comparison, photovoltaics result in a much more labor-intensive system, with a supply of only 2.7 GJ_{el}/hr, up to 4.5 GJ_{el}/hr in the case of very high insolation (2500 kWh m^{-2} y^{-1}), corresponding to one order of magnitude less than the above benchmark.

4. Conclusion

This grammar represents a first attempt to analyze the performances of solar power system based on the photovoltaic technology for electricity production; the potential criticalities with regard to some production factors have been flagged. The biophysical viability of the technology could be constrained by the availability of silver for the PV cell manufacturing stage. Furthermore, the low power density of photovoltaics installation could drive a remarkable land rush. In relation to the technological viability, the most significant fraction of the energy carriers is consumed in the fund-making stage. Finally, with regard to the socioeconomic viability, the human labor indirectly allocated in the fund making process is a serious constraint in respect of the requirements of the metabolism of modern societies. The uncertainty of some data and the extreme heterogeneity of the sources would require a more systematic survey of the allocated productive factors with a contextualization in a definite national, regional or local system. A more circumstanced level would allow the definition of a precise value for the solar irradiation besides the homogeneous identification of specific productive factors for a certain industrial system. For instance, it would be very interesting to apply the methodology at the national scale to China and Japan, which are the countries where the highest share of the solar photovoltaic power capacity is manufactured, and also currently installed (with a provisional figure of annual added capacity in 2014 of 10.6 and 9.7 GW_p, respectively[4]). Further work will also include the adoption of a thorough accounting scheme (Mayumi and Giampietro 2014) that will address also the sink side, i.e. emissions and generated waste in relation to the issue of biophysical constraint.

4 www.iea-pvps.org/fileadmin/dam/public/report/technical/PVPS_report_-_A_Snapshot_of_Global_PV_-_1992-2014.pdf

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Life Cycle Assessment and Net Energy Analysis: analysing scenarios of large-scale deployment of PVs in urban systems.

Enrica Leccisi[1,2]*, Marco Raugei[1], Christopher Jones[3], [1] Department of Mechanical Engineering and Mathematical Sciences, Oxford Brookes University, UK

[2] Department of Science and Technology, Parthenope University of Naples, Italy

[3] Tyndall Centre for Climate Change Research, University of Manchester, UK

Corresponding Author e-mail: enrica.leccisi@brookes.ac.uk

Abstract

Distributed electricity generation by rooftop photovoltaic (PV) panels and, where appropriate, integrated battery storage systems, offers new possibilities for the built environment to be more self-sufficient in energy, and to reduce the environmental impact of the electricity grid. However, in order to correctly assess the full consequences of the deployment of up to 50 GWp of distributed rooftop PV systems, the scope of the analysis needs to be expanded to three system levels:
(1) the impacts of material and energy flows to provide the PV modules, the inverter, and the batteries;
(2) any new infrastructure that may be required to adapt the distribution network and transmission grid to variable and dispersed PV electricity production;
(3) the co-evolution of the rest of the grid, since the impact on electricity grid emissions from distributed PV generation ultimately depend on what electricity generation technologies are displaced by PV output.
This paper presents a novel approach to integrate two independently developed but arguably complementary methodological approaches, namely Life Cycle Assessment (LCA) and Net Energy Analysis (NEA), and apply them to the common goal of a prospective consequential life cycle analysis of large-scale PV deployment in the UK (this work is part of the UK EPSRC funded 'WISE PV' project). Specifically, two stakeholder-informed deployment scenarios are considered, both leading to a cumulative installed capacity of 50 GWp of PV in 2035: a 'network-focused' scenario with a high proportion of ground mounted PV and without building-scale battery storage; and a 'user-led' scenario, in which PV is predominantly deployment on rooftops, and battery systems are used to enable high levels of self-consumption. We focus here on the latter scenario, and present the method for a unified life cycle inventory underpinning both the LCA and NEA, thereby ensuring internal consistency.

1. Introduction and background

Electricity generation accounts for around 28% of UK GHG emissions (DECC, 2013). The recent growth in the UK PV sector has stimulated interest in the involvement of a high level of installed capacity on the UK electricity system. The UK grid has potential for large-scale deployment of PVs in urban systems. The EPSRC funded Whole System Impacts and Socio-Economics of Wide Scale PV Integration (WISE PV) project is an investigation of ambitious levels of PV in the UK using a range of technical, environmental, economic and social assessment methods – one goal of the WISE PV project is to assess the environmental effects (focusing on GHG emissions) of electricity systems and the energy return on energy invested (EROI). A combined prospective consequential life cycle assessment (CLCA) and Net Energy Analysis (NEA) approach is proposed here to investigate the whole-system impacts of a set of future national electricity generation scenarios in which high levels of PV are achieved by 2035. The subject of the analysis is the entire electricity system in a particular state rather than a product, such as a unit consisting of PV modules, inverter and batteries. Scenarios with high levels of PV are necessarily based on assumed future UK energy systems whereby high levels of deployment can be reasonably achieved. The system-level view increases how comprehensive the analysis is in terms of the emissions covered and primary energy harvested, but this and the prospective outlook into the future also increases the number of assumptions needed to define key elements. The increase in uncertainty regarding output values that arises from this is acceptable because the purpose is to compare between scenarios in order to assess the implications of a particular pathways regarding PV. Ultimately the goal of the methodology is to provide decision makers with a more informed understanding of the consequences of changing to more distributed generation with the urban environment, from a whole system perspective.

2. Methodology

2.1 Consequential LCA (CLCA)

The research approach used for this study is that offered by consequential life cycle assessment (CLCA), which broadens the scope and boundary of ALCA to consider the direct and indirect effects on processes and products (T. Ekvall, B. Weidema, 2004). Attributional analyses is focused on direct environmental impacts of a product through its life cycle (cradle to grave), while CLCAs define a life cycle assessment that incorporates the impact of changes to products and processes that are directly or indirectly related to the unit of study (Brander, Tipper et al., 2008). CLCA is therefore a more appropriate approach to studying change within a system.

2.2 Net Energy Analysis (NEA)

This study is based on a combined LCA methodology with Net Energy Analysis perspective – the purpose of NEA is to quantify the extent to which a given energy source is able to provide a net energy surplus to the end user – after accounting for all the losses occurring along the processes chain (extraction, delivery, etc.) as well as for all the additional energy investments that are required in order to carry out the same chain of processes (Slesser, 1974; Leach, 1975; Chambers, 1979; Herendeen, 1988; Cleveland, 1992; Herendeen, 2004).

3. The analysed system

This research is focused on two scenarios where 50 GW of PV is deployed, and a third scenario with low levels of PV deployment (20GW) is used as a comparison case. The low PV scenario is based on the National Grid's 'Gone Green' Future Energy System scenario. The two high-PV scenarios are termed, respectively: 'user-led' – in which PV is predominantly deployment on rooftops, and battery systems are used to enable high levels of self-consumption – and 'network-focused' – a scenario with a high proportion of ground-mounted PV and without building-scale battery storage. Common assumptions about non-PV generation mix and electricity demand are applied to all three scenarios, including shifts to transport and heating services electrification.

3.1 User-led scenarios

This scenario focuses on high levels of self-consumption of rooftop PV generated power through small-scale battery storage. The scenario assumes that battery storage costs continue to fall along the lines of optimistic industry and analyst expectations. Overall, average self-consumption of PV output increases from 44% to 75% for domestic rooftop installations and to 90% for non-domestic rooftop installations. As a result, growth in installations is mainly in the rooftop sector, with a more moderate rate of growth assumed for ground-mounted arrays.

Table 1: User-led Scenario

PV Installed Capacity	***[GW]***
Domestic rooftop and BIPV	22.5
Non-domestic rooftop and BIPV	12.5
Ground-mounted	15
Energy Storage Capacity	***[GWh]***
Domestic battery	16
Grid storage pumped hydro	4.8

4. Structure of the analysis

Inspired by Ekvall and Weidema's (2004) concept of consequential impacts radiating out within a system, like a ripple in a lake, the scope of this project is structured around three 'scales' of analysis (fig. 1):
(1) the impacts attributed to the material and energy flows to provide the PV modules, the inverter, and the batteries;
(2) the aggregated impacts of multiple PV systems at the local electricity distribution network level, such as any new infrastructure that may be required to adapt the network and transmission grid to variable and dispersed PV electricity production;
(3) Changes to the operation of the electricity grid due to PV output, specifically changes in grid emission intensity.

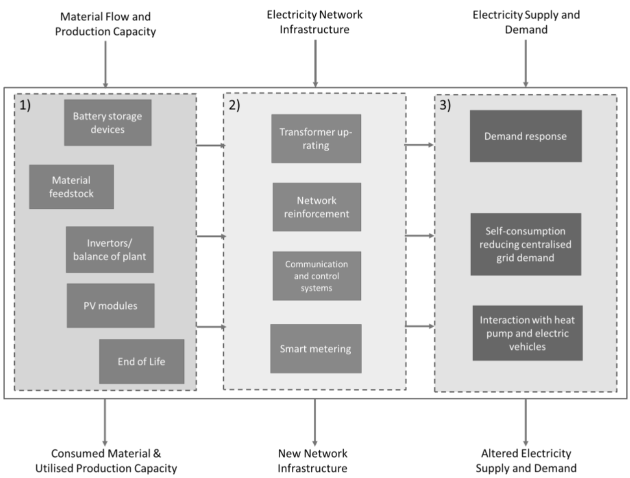

Fig. 1: Levels of the analysis (Jones and Raugei et al, 2014)

The overarching research question is thus: “What would be the whole-system environmental consequences of opting for different pathways of large-scale deployment of PV in the UK urban system grid when compared to previously developed future grid scenarios without PV?”

The chosen functional unit of the study is 1 kWh of electricity produced by the whole grid. Furthermore, the CLCAs compare and contrast three scenarios for the UK energy system from 2015 to 2035 – the analysis is based on medium- to long-term scenarios and the ‘prospective’ LCA is a novel aspect, as it is less common in the literature.

4.1 Level 1: PV systems

PV systems include three components: a PV cell, a module frame/mounting, and a power inverter.

PV cell and module frame

A wide range of cell options are available, with differing implications for the module frame/assembly. The research will focus on mono- and poly-silicon PV which is currently still dominant in the UK market because of combined cost, efficiency and stability attributes (IEA PVPS, 2013). CdTe PV will be considered as a proportion of ground mounted capacity within the scenarios. Future PV module characteristics and production methods are expected to keep improving based on the reasoned extrapolation of past trends (Frischknecht et al., in press). Time ‘steps’ of five year intervals are used to incorporate these changes into the LCA, so that PV systems deployed in the future reflect expected changes in production and efficiency. A module lifetime of 30 years is assumed in much of the LCA literature for PV (Hsu, O’Donoughue et al., 2012). Over time module efficiency is predicted to decline by a rate of 0.5% per year.

Power inverter

Power inverters that convert the direct current from PV cells to alternating current suitable for most electronic equipment and for export to the electricity network are required. There is also a choice between inverters and micro inverters depending on the module type and other factors. Central ‘string’ inverters located away from the PV array have been common; however, micro-inverters that are affixed to each model in a PV installation are also now available, and are offered by a number of domestic PV installers. This study will also include battery storage that is integrated with the PV user’s system, which is an important component of the user-led scenario. New and more cost-effective manufacturing techniques and lifetime extensions are being developed with regard to battery storage, and in particular, lithium-ion technology, largely in response to the automotive sector (IEA, 2013). Inverters are expected to fail over the 30 year lifetime of PV systems. There are a range of uncertainties around failure rates, however it is assumed here that the inverter is replaced once in the first instance, while in the sensitivity analysis more frequent replacement is explored.

End of life

According Nugent and Sovacool (2014), only five of the 23 LCAs of PV they reviewed include a decommissioning stage, with recycling only assumed for CdTe. Hammond, Harajli et al. (2012), for example, state that there is insufficient data on PV system decommissioning and recycling for it to be included in their study. Therefore, development of recycling processes will be included where appropriate. In the UK, PV modules are legally classified as waste electrical and electronic equipment (WEEE). This means that PV module sellers have an obligation to take back modules at end of life and ensure they are recycled. Most of the module weight is glass (85% for C-Si, 90% of Cd-Te modules), which can currently be used for fibreglass, and potentially for other purposes in the future. PV CYCLE – a group set up to develop PV recycling in Europe – has a recycling target of 85% by 2020; however, this is to be calculated by weight, much of which would be covered by glass and aluminium recycling.

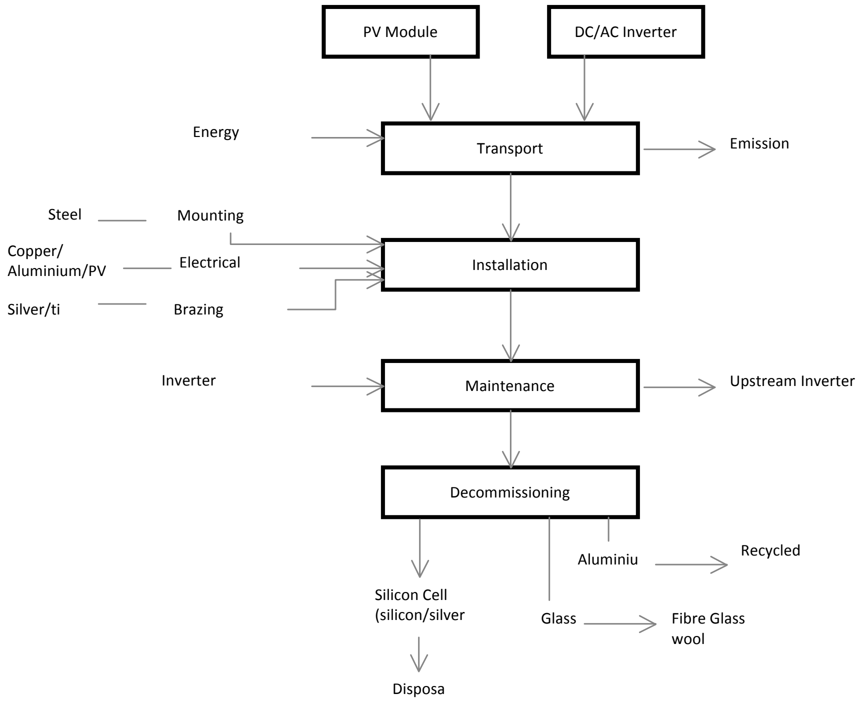

Figure 2: Flow diagram of rooftop PV System

4.2 Level 2: Local distribution networks

Where the capacity of PV systems connected to the electricity distribution network exceeds certain thresholds there is a need to implement changes in the network to integrate the PV power flow. The key interventions in the electricity system to integrate high levels of PV are:
• PV curtailment – i.e. the peak output from PV power inverters is limited, for example to 70% as practiced in Germany (Wirth 2014).
• Additional power electronics – i.e. there are a range of ‘tap’ and capacitor power electronic products to regulate voltage and smooth frequency and harmonic distortions on power networks.

• Adding storage at the distribution level to smooth voltage, frequency and utilisation variations.
• Upgrading power transformers and power lines.

Project partners on the WISE PV project will provide a power system impact assessment model that will be used to determine and quantify distribution network changes corresponding to the scenarios. These results will be included in the LCA through attributional LCAs of the assets that are assumed by the impact assessment model.

4.3 Level 3: National transmission network

At the macro level the study is focused on the analysis of future changes to UK power flows due to higher levels of PV in the grid, in terms of both electricity generation and demand. The amount of PV deployed in each scenario is expected to have consequences for the high-voltage electricity transmission grid and ultimately the emissions associated with the grid electricity. Understanding the impact of aggregated levels of PV on overall electricity grid emissions is a key component of WISE PV. In common with previous CLCA approach such as Pehnt, M., M. Oeser, et al. (2008), a power dispatch model developed by WISE PV partners will be utilised to investigate changes in generation profile used to meet electricity demand as a result of PV generating capacity and self-consumption.

5. Conclusions

The assessment of the system environmental impacts of ambitious levels of PV in the UK from a whole system perspective requires a consequential approach so that wider impacts across the system are included. The CLCA to be carried out builds on different elements in the existing literature, and draws on power system models developed through WISE PV. This novel approach integrates CLCA and Net Energy Analysis, and requires that careful consideration be given to scope, both in terms of system boundary and the timeframe being considered. This research is in progress – the results will be presented in the full version of this article.

Acknowledgements

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Metabolic patterns of the industrial sector across Europe: studying the forgotten maker of Service Cities

Raúl Velasco-Fernández*[1], Mario Giampietro[1,2]

[1] Institut de Ciència i Tecnologia Ambientals (ICTA), Universitat Autònoma de Barcelona, 08193 Bellaterra, Spain

[2] Institució Catalana de Recerca i Estudis Avançats (ICREA), Passeig Lluís Companys 23, 08010 Barcelona, Spain

Corresponding Author e-mail: velasco.raul@gmail.com

Abstract

The metabolic pattern of energy of any socio-economic system can be explained by the metabolic pattern of (the functions expressed by) its main compartments: the household-, service-, industrial (building and manufacturing)-, and primary production (agriculture and energy and mining) sectors. In turn, the metabolic pattern of each of these sectors depends on the characteristics of its (lower-level) sub-compartments, and so on. Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) proposes an integrated analysis of this hierarchical set of relations, by analyzing, combining and confronting different types of quantitative information using two logical distinctions: (i) extensive variables (size of relevant flow and fund elements) versus intensive variables (intensity of flow/fund ratios for the considered elements); and (ii) bottom-up information (technical coefficients calculated on unitary operations at the local scale) versus top-down information (statistics referring to the large scale).

In the present study, we focus on the metabolic pattern of energy of the industrial sector, it being the main driver of urban development. European urban systems are often considered ‘service cities’ because industrial activities have become less visible, having been moved to the urban periphery or externalized to other countries. However, it should be recalled that industry has given rise to the birth of the modern city and still is what makes urban metabolism viable.

We present here a comparison of the performance of the industrial sectors of selected EU countries. We consider three types of energy carrier (flows), electricity, process heat and fuel, and two fund elements, human labour (required to control power generation) and power capacity (technological capital able to convert energy inputs into useful tasks). We use matrices of end-uses, at the level of specific sub-sectors (heavy industry, textiles, etc.), and at the level of the industrial sector as a whole. At the latter level, the matrix of end-uses does not only depend on the efficiencies of the different technical processes used to express the various tasks, but also on the profile of distribution of flow and fund elements over the various sub-compartments.

An essential aspect of our approach is that it is not based on just one scale, one dimension, or one flow at the time (as in conventional analyses), but on a pattern of inputs and outputs (generated by the conversion of energy) characterized at different levels. Indeed, expression of a given task in a given process or of a given function in a given sub-sector requires a well-defined combination of flow and fund elements, i.e., a vector of end uses. An accounting system based on vectors and matrices permits us to detect metabolic patterns across levels (processes, sub-compartments and whole compartments).

Negotiated Modeling and Simulation Framework for Quantitative Target Setting for Urban Energy Systems

Omar Shafqat*[1], Per Lundqvist[1], Örjan Svane[2], Jaime Arias[1]

[1] Dept. of Energy Technology, Royal Institute of Technology KTH, Brinellvägen 68, 10044 Stockholm, Sweden

[2] Dept. of Enviornmental Strategies Research, Royal Institute of Technology KTH, Drottning Kristinas väg 30, 10044 Stockholm, Sweden

Corresponding Author e-mail: omars@kth.se

Abstract

Urban energy systems are characterized by high-energy intensity and are therefore responsible for a large part of global emissions. Due to their complexity, in-depth planning is required both for the transformation of existing as well as for building new systems. Due socio-economical as well as environmental considerations need to be taken into account while involving a multitude of stakeholders in the process. In addition, a rigorous target setting process needs to be included in the planning phase in order to achieve positive outcomes.

This paper presents a methodology to facilitate the involvement of stakeholders in the target setting process in urban energy systems. The methodology is based on the scenario approach and results in explorative scenarios generated by involving the various stakeholders in a two-step process. In the negotiated modeling stage, the stakeholders are included in the modeling process while in the negotiated simulation stage the input parameters are negotiated with the stakeholders in order to generate scenarios. The resulting scenarios represent the joint vision of future of the stakeholders.

The New Chautauqua Game: Designing the renewable city and region with e[m]ergy accounting

William W. Braham*[1], Luke Butcher[2], Jill Sornson Kurtz[3], Mostapha Sadeghipour Roudsari[4]

[1] TC Chan Center, University of Pennsylvania, Philadelphia, PA

[2] Feilden+Mawson, Cambridge, UK

[3] Re:Vision Architecture, Philadelphia, PA

[4] Thornton Tomasettii, New York, NY

Corresponding Author e-mail: brahamw@design.upenn.edu

Abstract

This paper presents the results of a simplified method for reconfiguring a small city and rural county to support its current population on the environmental energies available within the boundaries of the county. It is configured as a game, based on the simplifying assumption that the collection and concentration of renewable energies is almost entirely a matter of surface or land area, so that a renewable economy becomes a matter of competing land uses, of tradeoffs between land used for the production of food, fuel, electricity, and so on. E[m]ergy accounting was used to translate different forms of consumption into equivalent land areas, while the many forms of production and consumption were reduced to 25 parameters that can be varied to test alternate scenarios for the county. The results have been coded into a web site for playing the game.

1. Introduction

The growth and operation of our massive metropolitan system relies as much on the quality of energy supplies as on their sheer quantities. The capture of equivalent amounts of lower density, environmental energies not only requires substantial land areas, but involves additional work, resources, and time to concentrate them into usable fuels, electricity, or other services. E[m]ergy synthesis accounts for all the upstream work and resources involved in contemporary life and offers a powerful tool for understanding the radical urban and economic reorganization necessary to shift to a renewable economy.

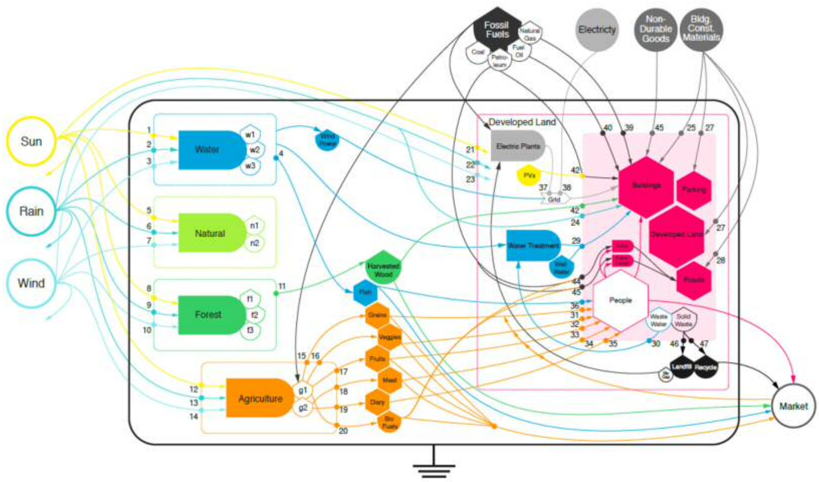
As Odum (1983), Brown (1980, 2003), Huang (2001) and others have demonstrated, the development of renewable resources is largely a matter of competing land uses—of land used for producing food, biofuels, electricity, or manufactured products—with low density resources captured in large areas and concentrated into higher quality products and services for use in smaller, developed land areas. Though there can be some overlapping land uses—photovoltaics on building roofs for example—when considered at scale, the development of a renewable economy will involve a considerable re-allocation of land uses.

Arguable, any city before about 1750 was mostly based on renewable resources, but our question is not how to return to the agricultural patterns of the past, but how to maintain as much of the health, education, and leisure of metropolitan life as possible. To explore that question, this paper uses an e[m]ergy analysis of Chautauqua County, NY, to ask what form of reorganization it would take to support the current population on the renewable income of the County. To keep the study simple, we simply sought to balance the supply and demand of the county, though any real economy would need to produce surpluses with which to trade.

2. Chautauqua County Accounting

Chautauqua is a largely rural county of 960,115 acres (including water area) in the western part of New York State, bordering Lake Erie and largely defined around Lake Chautauqua, a freshwater lake of about 13,000 acres situated 700 feet above Lake Erie and draining into a separate watershed that ultimately empties into the Gulf of Mexico. Although the county maintains a useful GIS database, much of the resource information needed for a comprehensive e[m]ergy accounting is not tracked at the county level, so data was assembled from a mixture of the National Land Cover Database (NLCD), Census Data, EPA eGrid, normative data for consumption, and inspection of aerial photographs of the urban areas. The information was structured to facilitate the testing of different scenarios by indexing the various forms of production and consumption to units of population and land areas.

Figure. 2.1. E[m]ergy diagram, Chautauqua County



For this model, four sources of renewable resource inputs were considered, sunlight, the chemical and geopotential of rain, and wind. There is some potential in the area for both wave power on Lake Erie and deep geothermal heat, but the focus was limited to the sources that involved tradeoffs in land area. For the e[m]ergy analysis of the existing county five basic land uses were considered: forest (35.3%), water and wetlands (33.7%), agriculture (21.9%), developed land (5.2%), and natural or unallocated land (3.9%). The total e[m]ergy inputs to the county are shown in Table 1 and total 7.99E+21 sej/yr. Using the average annual, renewable e[m]ergy inputs per acre, it was estimated that the county would require an additional 8.94 counties of land area to power the county on renewable resources. This is a rough and conservative simplification, since the forms of the renewable resources, dominated by the e[m]ergy content of rain, don't directly match the forms of consumption, and also the available resources could not be wholly diverted to human uses. Despite the simplification of the land area calculation, it makes visible the tremendous value of the concentrated fuels currently used to drive the county economy.

Table 1: Emergy Evaluation of Original and "Changed" County

	ORIGINAL COUNTY			Changed County*		
	E[M]ERGY	**Primary Land**	**Support Land**	**E[M]ERGY**	**Primary Land**	**Support Land**
WATER	*sej / year*	*acres*	*acres*	*sej / year*	*acres*	*acres*
Renewable Inputs	**4.66E+20**			**3.76E+19**		
Purchased Inputs	**2.22E+19**	**323,981**	**2.75E+04**	**2.37E+19**	**46,404**	**29,272**
Wind - Power	-			7.96E+17	1,601	
Fish	2.22E+19			2.29E+19	44,803	
NATURAL						
Renewable Inputs	**5.21E+19**	**37,062**				
FOREST						
Renewable Inputs	**4.76E+20**			**1.05E+20**		
Purchased Inputs	**8.29E+18**	**338,758**	**1.02E+04**	**5.94E+18**	**129,470**	**7,343**
Firewood	8.29E+18			5.94E+18	129,470	
AGRICULTURE						
Renewable Inputs	**2.96E+19**			**4.05E+18**		
Purchased Inputs	**5.68E+20**	**210,464**	**7.02E+05**	**1.52E+20**	**169,537**	**228,809**
Biofuels	2.28E+19			3.29E+19	3,179	
Vegetables	5.30E+16			1.71E+19	56,230	
Fruit	6.71E+19			5.99E+18	3,471	
Meat	5.54E+18			1.51E+19	89,606	
Dairy	1.20E+19			1.06E+19	10,558	
Grains	4.60E+20			1.03E+20	9,671	
DEVELOPED						
Renewable Inputs	**1.65E+19**			**4.05E+18**		
Purchased Inputs	**6.35E+21**	**49,850**	**7.84E+06**	**6.51E+19**	**5,009**	**80,634**
Built Environment	2.32E+19			1.99E+16	4,978	
Solar PV	-			1.28E+19	31	
Other Fuels	5.46E+21			0.00E+00	-	
Gasoline	3.26E+20			0.00E+00	-	
Water	3.52E+19			6.29E+18	-	
Goods	4.53E+20			4.55E+19	-	
Solid Waste	5.22E+19			1.45E+17	-	
Recycled Waste	3.17E+18			3.19E+17	-	
SUMMARY						
Renewable Inputs	1.04E+21			1.50E+20		
Purchased Inputs	6.95E+21			2.47E+20		
Total Inputs	7.99E+21			3.98E+20		
Primary Land		960,115	*acres*		350,419	*acres*
Support Land		8,583,358	*acres*		346,058	*acres*
Total Land		9,543,473	*acres*		696,478	*acres*
In-County Land		960,115	*acres*		696,478	*acres*
Out-of-County		8,583,358	*acres*		0	*acres*
Multiples of County		9.94			0.73	

* Changed county parameters, % of base: Developed Land Density, 1000%, Energy Demand - per capita, 10%, Energy Mix - Solar PV, 5%, Biomass, 5%, Wind Power , 90%, Fossil Fuel, 0%, Food Demand, 90%, Food Production Efficiency Improvement, 200%, Diet Mix: Vegetable, 21%, Fruit, 9%, Meat, 5%, Dairy, 5%, Fish, 10%,

Grain, 50%, Vehicle miles - per capita, 10%, Vehicle efficiency - MPG, 200%, Biofuel Production Efficiency, 200%, Vehicle Fuel Mix: Biofuels, 100%, Fossil Fuel, 0%, Goods Purchased, 10%, Waste Produced, 30%, Waste Recycling - diversion rate, 95%, Water Usage - per capita, 30%

2.1 Scenario Builder: Primary and Support Land Areas

To explore the scenarios for a county based only on renewable inputs, twenty-five parameters (more to be activated soon) were identified to describe aspects of change in the human patterns of consumption, transportation and settlement. These are shown in Figure 2.2, and for each category of land use, they were used to determine the amounts of primary and support land areas required to meet that level of consumption. The primary land areas are the actual areas required for a particular level of activity, for example the agricultural land required to provide a specific quantity of crops or the area of photovoltaic panels to provide a quantity of electricity. For resource flows involving modest or non-exclusive use land, no primary land was allocated, but the support land area was determined.

To determine the support area, the total e[m]ergy inputs for each activity were divided by the average renewable inputs per acre of county to estimate the amount of additional land that would be needed to capture and concentrate environmental energies for the primary land use. For example, each acre of forest used to provide harvested wood requires an additional .057 acres to capture the energies used for harvesting and transporting the wood. In contrast, each acre of photovoltaic panels requires an additional 512 acres of land to capture the energy and resources needed to provide new panels at the end of their useful life, illustrating the difference in cost and quality between biomass and electricity.

Broadly speaking there are two kinds of parameters that were included, efficiencies of production and efficiencies (or reductions) of consumption. Both will be needed to achieve the reduction in land area required, and are currently combined for some factors. For example building energy consumption decreases as the Density of Develop Land is increased, combining a reduction in building area and greater efficiency of construction and systems. The most significant simplification in this model is the effect of transportation distances, which are linearly connected to density. Incorporating a more nuanced calculation of commuting distances for different settlement patterns would add significantly to the accuracy of the model.

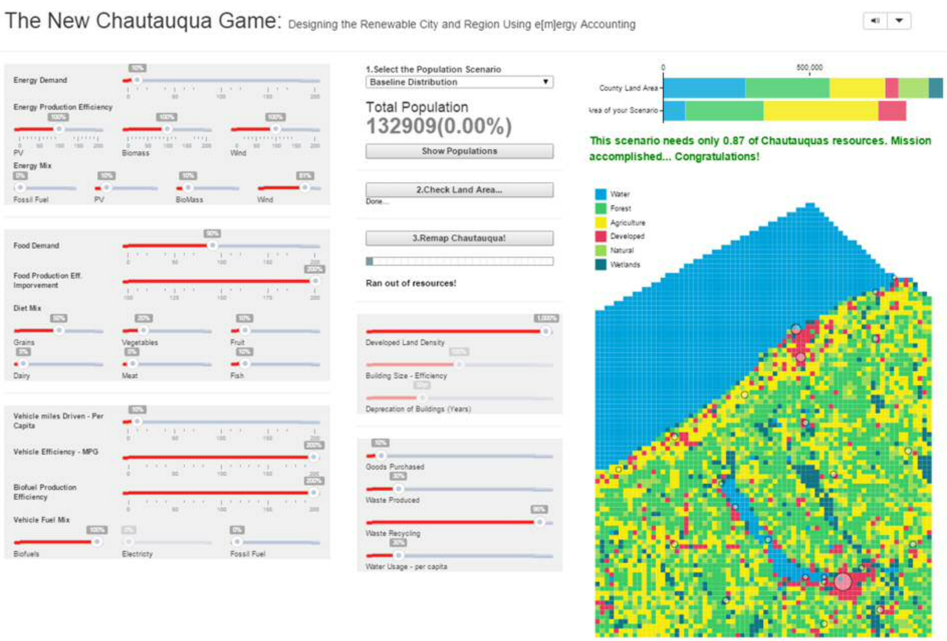
2.2. Land Allocation

In order to test the impact of the identified lifestyle and efficiency changes, and determine the primary and secondary land areas to support those choices, a scenario planning tool has been constructed that provides a graphic output of the changes that would need to take place to land allocation within the county. A base map was established with current land allocation based on GIS land cover data, with each pixel equating to 159.46 acres. Superimposed on this map are the 17 major settlement points in Chautauqua County, ranging in scale from Jamestown (population 31,146) to Sunset Bay (population 637). It is from this baseline position that the impact of changing the twenty-five parameters can be investigated.

For each settlement point a land “demand” is calculated based on the population of that settlement point. To remap the county two “passes” take place. The first finds the nearest available pixels of each land type required to supply the settlements with what they need, without taking any from a neighboring settlement. If there is a shortfall identified at this stage (where available land has been distributed equally based on population demand) a second pass takes place wherein the nearest unallocated point is identified and that pixel is reallocated to a new land use, based on any shortfall in demand for that settlement point. There is a further hierarchy embedded during this phase that first looks at natural, then forest, then agriculture, and then developed land, based on the 'ease' with which these land uses can be converted to other uses. For example, if Sunset Bay requires 10 pixels of agriculture land (or 1,594.6 acres) it first looks for the 10 nearest available agriculture pixels on the baseline map. If, after the demand of Silvercreek and Forestville are taken into account, only 8 pixels are available it will then look for the nearest 2 unallocated pixel and convert that to agricultural land. If a shortfall still exists after this then it is clear that the settlement cannot be supported within the current limits of the county border.

It is this reallocation, or remapping, of the county that creates the changed map and it is this map, in combination with the revised inputs, that can be used as a tool in the decision making processes that shape the future of our cities and regions. Variable testing can be undertaken wherein the impact of changing each parameter can be measured. Furthermore, analysis can take place about the impact of changing population distribution across the county, for example what happens if the population of Jamestown increases by 50,000, is that sustainable in the long term given a particular lifestyle? Further questions can be asked about whether or not the location of existing settlements is correct, should new settlements be built?

Figure 2.2: New Chautauqua scenario builder with parameter sliders and results



2.3. Scenario Planning as a Design Tool

The use of maps in assisting the allocation of space has a rich history and sits alongside the allocation of metrics to these maps to assist in how we perceive concepts external to our typical (human) scale of understanding and interaction. Arguably the most important development in this field in the last fifty years was the "McHarg Method" (McHarg, 1969) that demonstrated how urban planners could take a more environmentally conscious approach to both evaluating and implementing development. With the proliferation of big data, a new “intelligent terrain” (Dunn, 2013) is emerging wherein open-source data, provided by governments and private institutions, is linked to geospatial information, creating the opportunity for new scenario planning tools that are cross platform and free at the point of use. These new digital platforms can connect citizens and involve them directly in the decision making processes that shape their lives and enable them to take action to improve them.

For any individual actively involved in shaping a ‘renewable’ future it can at times be difficult to comprehend the consequences (both positive and negative) that their decisions will have. Scenario planning is one possible tool that can help determine the extents of this indeterminacy, although it does not predict the future it does help to establish both limitations and possibilities. Tools such as this are needed to help contextualize and visualize the dynamic tradeoffs that must take place and it is within this framework of possibilities that the New Chautauqua Game has been developed, providing a simulated environment where the implications of calibrating a county around twenty-five parameters can be played out, reviewed, debated and re-tested. Design professionals (and citizens) can determine the correct point to step away from analyzing a situation (whether through mapping or otherwise) and augment that situation with their design skills.

While this method strips away some of the potential that a live connection would offer the resulting scenario builder, linked as it is to a static database, it is still a powerful demonstrator of the potential. A major driver for this is that each pixel on the resulting maps generated by the scenario builder equates to 159.46 acres in the real Chautauqua County, alongside a wealth of other performance metrics. Given greater computing power and more data this figure could be reduced so that one pixel was equal one acre or less, so that decisions could be planned on a more readily understandable (and accessible) scale, shrinking the point of analysis from the region to the city. Performance metrics such as these allows the built environment to be quantified into a series of inputs and outputs that can be checked against original intentions, afford better tracking of information, and ultimately lead to be more informed decisions being taken.

3. Conclusion

The ambition to build a renewable city is a complex and difficult task, especially as the cities and the citizens tasked with designing and living in it have to understand the rich ecosystems upon which they depend. E[m]ergy accounting provides a method with which to account for the flows of energy within these systems and the New Chautauqua Game provides an accessible platform within which the impacts of changing these flows can be understood.

This method reveals the strengths and limits of e[m]ergy accounting as a projective tool. Its great power is to make explicit the tremendous upstream work and resources used in our current patterns of living. Conversely, true redesign means that the many forms of production and concentration embedded in e[m]ergy intensities have to be unpacked. Translating the vast flow of modern living into the equivalent land areas needed to shift to renewable resources quickly shifts the debate about a sustainable future from questions about consumption and morality to the more immediate questions of supply, demand, and land use.

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Urban Energy Poverty in India: A household level analysis

Lakshmikanth Hari[1] and Hippu Salk Kristle Nathan[2]

[1]Centre for Sustainable Development
K J Somaiya Institute of Management Studies & Research (SIMSR)
Mumbai-400087, INDIA
E-mails: hlkanth@yahoo.com

[2]National Institute of Advanced Studies (NIAS)
Indian Institute of Science (IISc) Campus
Bangalore - 560012, INDIA
Emails: hsknathan@nias.iisc.ernet.in, happyhippu@gmail.com

Energy play crucial role in development of a country. Providing the continuity of energy supply to meet the demands of rapidly growing population and urban aglomarizations is one of major challenges faced by developing country like India. Urban areas, with its rapid growing population, economic activities and expectations puts immense pressure on administration for providing services to all. Urban areas in developing countries are characterized by extreme luxurious lifestyles in one end and pathetic living in informal settlements in other. India's case is no exception.

In this backdrop, it is interesting to analyse household level energy poverty in urban area. Unlike the conventional method of single economic poverty line, we use two energy level lines - 'energy sustenance line' and 'energy affluence line'. We do this so as to avoid a situation where people close to an energy poverty line on either side are forced to categorize themselves poor and non-poor though they do not have any significant difference in their energy consumption pattern. Also, a two-line approach does not make poverty line very sensitive where a slight change in poverty leads to millions of population going in and out of the poverty. We determine energy sustenance and energy affluence levels on normative basis following physical threshold approach. Classifying the activities of the households, we determine the energy fuel basket for sustenance and affluence levels. Then, using NSS (national sample survey) data, we calculate the energy poverty rates for urban areas of different sates of India. Following Foster-Greer- Thorbecke (FGT) measure of poverty, we calculate the incidence of energy poverty (number of people below energy poverty line), the intensity or depth (energy poverty gap index), and severity or distribution (squared energy poverty gap index). We conclude the analyses with comparative pictures from different states in terms of energy poverty and touching on the underlining policies influencing such outcome.

Developing urban energy scenarios – morphological analysis in the participatory backcasting framework

Kateryna Pereverza*, Oleksii Pasichnyi, David Lazarevic, Olga Kordas

KTH Royal Institute of Technology, Division of Industrial Ecology

e-mail: Kateryna.pereverza@abe.kth.se

Abstract

This paper describes a procedure of solution ('internal scenario') development within the participatory backcasting (PB) framework, which considers technical and value-based dimensions. The procedure, based upon the morphological approach, allows for the generation of a complete space of all possible solutions for a socio-technical system and the reduction of this space using project-specific requirements and cross-consistency analysis. The set of possible solutions is based on data collected through participatory workshops with stakeholders and experts. The paper presents results of the implementation of this procedure in two PB projects focused on providing comfortable indoor climate for citizens in 2030 cities in Ukraine and Serbia.

1. Introduction

1.1. Enabling sustainable transitions of urban socio-technical systems

Cities account for the largest share of economic activities and production, and are responsible for more than 67% of total global energy consumption and two thirds of global CO2 emissions from final energy use (IPCC AR 5). Furthermore, the urban energy demand is being predominantly met by fossil fuels that have negative environmental impacts, and, in many cases, promote the dependence of foreign fuel imports. This poses the great challenge in the development of pathways toward more sustainable energy systems in cities starting with measures for enhancing energy efficiency and increasing the share of renewables in the energy mix.

As cities can been described as a complex system of multi-sectorial socio-technical systems, with the attached norms, values and sometimes conflicting interests of various stakeholders, urban energy systems should be studied in this context. This complexity requires adequate methods and tools for developing strategies and solutions for the transitions to sustainable urban energy systems. Various scenario methods are broadly used to inform decision-making and to enhance strategic thinking. For example, backcasting has been identified as an appropriate approach for developing alternative transition pathways based on technological and social change (Hofman et al. 2004).

Participatory backcasting (PB) provides a framework for the development of a desirable future vision and corresponding pathways to achieve this vision with the broad involvement of stakeholders (Robinson et al.; 2011; Holmberg and Robèrt, 2000; Quist and Vergragt, 2006; Kordas et al., 2014).

1.2. Scenarios development within the Participatory Backcasting framework

PB framework consists of several stages, which can be tailored to suit the requirements of specific applications. For example, the PB framework, with different modifications, has been implemented for long-term planning and decision-making at the city and national levels (Carlsson-Kanyama et al., 2008; Kok et al., 2012; Phdungslip, A., 2011; Zimmerman et al., 2012; Tuominen et al., 2014); identification of niches for new technology development (Quist and Vergragt, 2006; Quist et al., 2011); looking for new ways to fulfil societal needs or testing possible alternatives for their fulfilment in more sustainable way (Doyle and Davies, 2012; Svenfelt et al., 2011; Nuvonen et al., 2014).

The stage of scenario development is an essential part of the all reported cases that implement the PB framework. According to (Slaughter, 2002), "scenarios are internally coherent pictures of possible futures". For the purpose of this paper, it is useful to distinguish *'internal'* and *'external'* scenarios. Whereas *internal scenarios* refer to the possible realizations of a socio-technical system under study in future (hereinafter called 'solutions'), *external scenarios* refer to possible futures formed by external conditions with respect to this system.

Generally, the development and selection stage of both internal and external scenarios are not clearly described or are implemented using rather intuitive creativity techniques, for example brainstorming, storyboarding, mind mapping and checklists (Higgins,1996). As argued by Ratcliffe (2000), a common problem is that unexperienced scenario developers tend to select three scenarios for analysis: a 'good' and 'bad' at the extremes, and an 'average' in the middle, which leads to losing all the advantages of a multiple-scenario method. Therefore, there is a need for the design of a stringent procedure for scenario development and selection, particularly in the scope of the PB framework.

1.3. Aim and objectives

This paper focuses on the development of solutions (internal scenarios), whereas the development and analysis of external scenarios are not considered.

It aims to develop a stringent procedure, which considers the entire space of all possible solutions including both technical and value-based dimensions of the socio-technical system considered.

The objectives of this paper are to:

- describe a procedure based on the morphological approach that allows:
    a) to generate a complete solution space, and
    b) to reduce the solution space for further analysis within the PB framework;
- demonstrate the results of two PB projects that have implemented this procedure when developing solutions for the provision of sustainable and comfortable indoor climates for citizens.

This procedure was initially created during the theoretical development of the transdisciplinary PB framework, and was later refined during the course of two PB projects in the cities of Bila Tserkva, Ukraine, and Niš, Serbia.

2. Designing the procedure for scenario development and analysis

2.1. The tailored PB methodology

PB is an open framework, which can be tailored to suit particular needs and contexts of future oriented studies (Quist 2006). The PB methodology utilised in this study is described in Kordas et al. (2013) is comprised of twelve stages: (1) problem formulation; (2) identifying needs and setting goals; (3) defining system boundaries;

(4) stakeholder analysis; (5) current situation analysis; (6) driver analysis; (7) developing a future vision; (8) elaborating and quantifying criteria for the vision; (9) creating solutions; (10) solutions analysis, including robustness test using external scenarios and testing against elaborated criteria; (11) design of a combined solution for implementation; (12) developing pathways for implementation of the designed solution.

This paper focuses on the procedure of creating *solutions* at the stage 9 of the tailored PB methodology. As can be seen from the sequence of the tailored PB framework stages, the input information for the stage 9 is partially taken from the previous stages and output of the stage 9 are used at the following stages of the framework.

2.2 Morphological approach

The morphological approach was introduced by the Swiss astrophysicist Fritz Zwicky (1948) as a method for the analysis and construction of a technical device. The basis of the morphological approach is to create a morphological box or *manifold* Zwicky (1948; 1969), which consists of all possible solutions to a particular problem / system.

According to Zwicky (1969) the morphological approach consists of five stages. The first stage is concise formulation of the problem under study. The second stage includes identification of all relevant parameters (*"dimensions"* in terminology of this paper). The third stage consists in construction of a morphological box (*"morphological table"* in our terminology), which contains complete space of the possible solutions. The fourth stage supposes evaluation of all solutions from the morphological box. The fifth stage is selection of "optimally suitable solution" and its practical application.

Initially, the approach was used in the field of aerospace engineering, but was later developed for wider applications in engineering, defense, policy analysis, etc. (Zwicky, 1969; Ritchey, 2006; Godet and Durance, 2011). It is an integral part of the French *la prospective* school of scenario planning (Godet, 2004). Recently computer-aided morphological analysis tools have been developed (Godet, 2006; Ritchey, 2006) to deal with the increasing number of potential future scenarios.

Morphological approach is *"a powerful tool for inventions based on a holistic view of a system or problem"* (Zwicky, 1969), it can be also used to *"explore possible futures in a systematic way by studying all the combinations resulting from the breakdown of a system"* (Godet, 2004). Ritchey (2006) distinguishes two complementary morphological fields: 'external world' ("contextual environment") and 'internal world' ("strategy space"), similar view is proposed in recent book of Godet and Durance (2011). While internal scenarios were traditionally used in design and construction (Hviid and Svendsen, 2007), external scenarios were prerogative of future studies and strategic planning (Schwartz, 1992). In the PB framework developed by authors (Pereverza et al., 2014) these complementary areas of the problem are linked through application of morphological approach to both solutions' (internal scenarios) and external scenarios' development and selection.

2.3. Stakeholder participation

Stakeholder participation is an essential part of the PB framework. Ensuring stakeholder participation and considering stakeholder knowledge, values and attitudes at all stages of the PB process, leads to creation of socially-robust and solution-oriented knowledge, ownership and legitimacy of decisions and mutual learning (van der Kerkhof and Wieczorek, 2005).

For the solution generation stage, it is important to include stakeholder knowledge and values in order to get a complete description of the socio-technical system under study.

2.4. Scenario development procedure refinement during the course of two PB projects

The procedure of scenario development was refined during two PB projects aimed at solving the problem of providing comfortable indoor climate for citizens in 2030, firstly in Ukrainian city Bila Tserkva and later in the Serbian city Niš.

In the Bila Tserkva case, the procedure was based on a holistic analysis of the system and the experts' suggestions regarding its technical dimensions of this system. For each dimension, experts identified a set of possible states. Extreme states were further included in the morphologic table.

In the Niš case, stakeholder norms and values were included in the problem structuring stage. In this stage, a 'story-telling' exercise within a creativity workshop was conducted. Stakeholders were divided into three homogenous groups; comprising representatives of the city council, local companies and citizens. Each group was asked to describe their interaction with a comfortable indoor climate in 2030.

The stories created by stakeholders were later analysed by the authors. The analysis led to the extraction of the dimensions which characterize the future system. Initially, the extracted dimensions represented possible states of overarching dimensions of the system. As soon as these overarching dimensions were identified, then 'extreme' states were described by experts. Only these extreme states were included to a morphological table.

After the morphological table was created, based on all identified dimensions (both extracted from the stakeholders stories and initially provided by experts), it was analysed in order to exclude inconsistent solutions. Cross-consistency analysis performed by experts led to the identification of inconsistent states of dimensions and further exclusion of the inconsistent solutions from the morphologic table.

Further, some project-specific criteria were used to exclude more solutions from the space in order to make it manageable for further analysis. For example, not-desirable states of dimensions (for instance, fossil fuels-based system) were excluded. In such a way, the solution space was reduced. The solutions from this reduced space were further evaluated in order to select between 5 and 7 different solutions for consideration by stakeholders at the stage 10 of the PB process, namely solutions analysis against criteria and on robustness. The following criteria were used to select solutions: novelty, creativity, relevance, and difference (these criteria are suggested in literature on scenario analysis, for example in Godet, 2006; Amer et al., 2013; Ratcliffe, 2000).

The refined solution development and reduction procedure, as a result of the two cases, comprises of the following steps:

(a) identification of the core elements of a socio-technical system ('dimensions'), including both technical parameters of a problem and stakeholders opinions and values;

(b) description of the 'extreme' states for each 'dimension';

(c) creation of a morphological table, which constitutes a complete set of solutions – all possible combinations of the identified dimensions' states;

(d) basic reduction of the solution space using cross-consistency analysis; and

(e) further reduction of the solution space using case-specific criteria and such criteria as novelty, creativity, relevance, and difference of the solutions.

Using the described procedure the limited number of the solutions can be identified. These solutions are proposed for robustness testing (against external scenarios) and testing against previously elaborated the criteria.

3. Results of implementation

3.1. Bila Tserkva case

In the Bila Tserkva case, implementation of the described procedure led to the creation of a holistic space of possible solutions to the problem, mainly considering the technical dimensions proposed by experts. Particularly, three dimensions and extreme states for each were identified, these were: (1) *Level of centralization* (individual *vs* fully centralized system); (2) *Diversification of resources* (renewable resources *vs* natural gas only); (3) *Type of ownership* (public property *vs* private property vs private property with significant city influence).

Figure 1 shows the morphological table created for this case. The results excluded due to the cross-consistency analysis are shown in grey. All other scenarios were proposed for analysis during the workshop with experts, which led to a reduction of the solution space constraint to a smaller number of alternatives based on the criteria described above. The selected solutions were further tested by stakeholders during a creativity workshop. Consequently, stakeholders elaborated a combined solution, which was suggested for implementation in the city.

Solution	Centralized (0) vs individualized (1)	Renewable resources(0) vs natural gas(1)	Public property (0) vs city influence(1) vs private (2)	Solution name	
1	0	0	0	"Smart city management"	
2	0	0	1	"Smart city influence"	
3	0	0	2	"Private & smart"	
4	1	0	0	*inconsistent*	
5	1	0	1	"Smart citizens supported by city"	
6	1	0	2	"Smart citizens"	
7	1	1	0	*inconsistent*	
8	1	1	1	"Gas individuals supported by city"	
9	1	1	2	"Individual gas consumers"	BAU
10	0	1	0	"Gas city"	
11	0	1	1	"Controlled concession /privatization"	
12	0	1	2	"Uncontrolled concession/ privatization"	

Figure 1. Solution space created in the Bila Tserkva case

3.2. Niš case

In the Niš case, four dimensions were identified based on the experts suggestions, and the results of the "creating-stories" exercise performed with stakeholders' participation. Consequently, the following four dimensions with 2 or 3 states for each were identified: *Level of system centralization* (individualized *vs* current DH *vs* expanding & connection of DH); *Input resources used* (fossil imported *vs* fossil local *vs* renewable resources); *Advancement of technologies* (Low Tech *vs* Smart High Tech); *Energy efficiency of buildings* (Low *vs* High or Passive buildings); *Natural-focus* (not-focused *vs* focused).

Figure 2 shows the morphological table for this case. It includes 72 solutions, which represent comprehensive set of all possible solutions. It also shows that a combination of solutions from the morphological table can be further created, when analysing the morphological table.

Solution	Individualized (0) vs minimum/current DH (1) vs expanding+ connection of DH (2)	fossil imported (0) vs fossil local (1) vs renewable resources (2)	Low tech (0) vs Smart High tech (1)	Low EE of buildings (0) vs High EE or passive buildings (1)	Not focused on nature (0) vs Nature-focused (1)	Solution name
1	0	0	0	0	0	
2	0	0	0	0	1	
…						
	0	1	1	1	1	Advanced natural-based
	1	2	1	1	1	
…						
…						
….	3 x 3 x 2 x 2 x 2 = 72 solutions					
….						
71	2	2	1	1	0	
72	2	2	1	1	1	

Figure 2. Solution space created in the Niš case

As mentioned in section 2, to make solution analysis manageable, only extreme/critical states for each dimension were included in the morphological table. On the one hand, such approach prevents the possibility to get limited by the 'average' solutions corresponding to intermediate states. On the other hand, these intermediate states appear on the following stages of the PB process when stakeholders elaborate the combined solutions for in-depth analysis. The full range of possible states of the options can be represented as it is shown on the Figure 3.

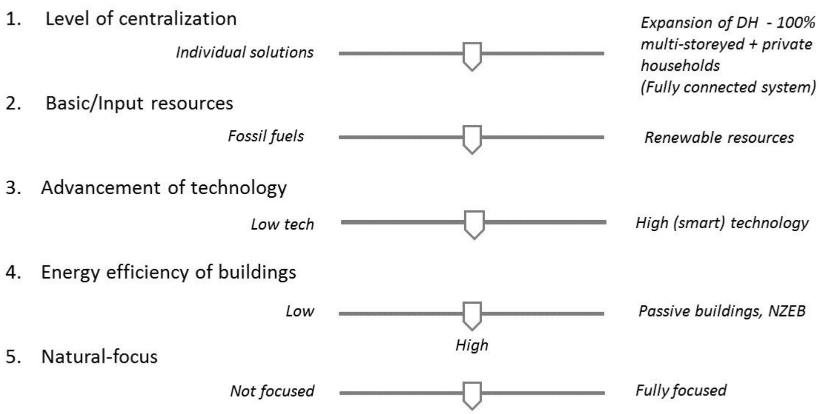

Figure 3. Visualization of the full range of the dimensions states for the Niš case

4. Discussion and Conclusions

This paper describes the design of a procedure for solution development and selection within the PB framework, based on the morphological approach, which considers both technical and value-based dimensions of a system/problem. Furthermore, the paper demonstrates the results of the implementation of this procedure in two cases, Bila Tserkva, Ukraine and Niš, Serbia. Both cases led to the creation of a comprehensive set of solutions, ensuring rigorous and transparent selection of the solutions for further analysis by stakeholders.

Completeness and consistency of the constructed solution space can be verified through allocating a plausible combination of dimensions corresponding to the BAU solution. Alternatively, if a valid solution is identified that is not a part of the space (and not a combination of solutions from the space) then a relevant dimension should be added to the basis of the morphologic space.

Communication of the procedure of solution development to stakeholders through morphological tables can be facilitated by demonstrating a BAU solution in the morphological table, as illustrated in figure 1.

The procedure was designed for solution (internal scenarios development, but it can be implemented in a similar way for the elaboration of external scenarios. The Global Business Network-matrix approach proposed in Schwartz (1992) is commonly used for the construction of external scenarios. However, such a reductionist approach limits the exploration of selected solutions' robustness to a more narrow set of possible future conditions. Thus, future developments on the extension of the morphological approach for the development and selection of external scenarios, within the PB framework, remains for further research.

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The study of carbon dioxide emission abatement quota mechanism in coal resource area of China

Kejia Yang[a,b]; Yalin Lei[a,b,*]

[a]School of Humanities and Economic Management, China University of Geosciences, Beijing 100083, China

[b]Key Laboratory of Carrying Capacity Assessment for Resource and Environment, Ministry of Land and Resources, Beijing 100083, China

Abstract

Carbon dioxide emission brings out serious environmental problems for China. And it has attracted extensive attention of the world. The Chinese government made a commitment that by 2020 the intensity of CO_2 emission would drop 40%-45% on the basis of emissions in 2005. Unfortunately, this commitment didn't take the diverse of the carbon dioxide emission reduction cost in different areas which have disparity of resources endowment and industrial structure into consideration. Previous studies generally focused on carbon reduction cost on national level or regional level. However, Carbon dioxide emissions in a certain area in production or consumption haven't been considered comprehensively. In addition, comparative studies on typical areas haven't been included.

Then, this study develops a directional distance function model based on difference of regional resource endowment and development status to measure the carbon dioxide emission abatement cost of typical coal resource districts and non-resource, developed districts. The results will provide basis for the carbon dioxide emission abatement quota mechanism and relevant policies to be formulated.

Keywords: carbon dioxide emission abatement cost; regional difference; distance function; quota mechanism; policy suggestion

The Evolution of International Fossil Fuel Trade Patterns: an Emergy and Network Analysis

Weiqiong Zhong[1,2,3], Haizhong An*[1,2,3], Xiangyun Gao[1,2,3], Di Dong[1,2,3]

[1] School of Humanities and Economic Management, China University of Geosciences, Beijing, China

[2] Key Laboratory of Carrying Capacity Assessment for Resource and Environment, Ministry of Land and Resources, Beijing, China

[3] Lab of Resources and Environmental Management, China University of Geosciences, Beijing, China

Corresponding Author e-mail: ahz369@163.com

Abstract

A better understanding of the international trade pattern of fossil fuel is crucial to energy security and policy optimization. This study aims to quantitatively analyze the international trade pattern of fossil energy. We transform the trade quantity of coal, crude oil and natural gas into emergy by transformity and the sum of the three emergies is used to measure the emergy of fossil fuel. We build up network models of fossil fuel as well as coal, crude oil and natural gas and then detect the clustering of the countries by network analysis. We find that the number of fossil fuel trade clusters is 4~7 during the year 2000~2013, and the degree of partition is at the same level; crude oil trade pattern is the main factor impacting the fossil fuel trade pattern; and there are mainly 3 types of clusters: America-North Africa cluster, Russia-Europe cluster and Asia Pacific-Middle East clusters.

1. Introduction

Fossil fuel is the most important energy in the modern society. Because of the uneven distribution of its production and consumption, fossil fuel flows between countries by international trade. A better understanding of the international trade pattern of fossil fuel is crucial to energy security and policy optimization. This study aims to quantitatively analyze the international trade pattern of fossil energy by complex network analysis and emergy transformity.

International trade pattern of fossil fuel is the pattern of relations among countries. In the international trade, countries are clustering into groups, namely some countries are closely related while some others are loosely related. Study the clustering of countries can help us understand the international trade pattern. Trade bloc such as European Union (EU) and North American Free Trade Agreement (NAFTA) are well-known clusters formed by trade agreements and political strategies. However, in the real world, do the relations among countries follow the same pattern? International trade is a huge system with numerous countries and complicated relations. Complex network modeling has the advantage of analyzing numerous nodes and links. It provides a detailed quantitative analysis of the trade patterns. Recently, some researchers studied the regional energy security and global oil trade patterns by complex network analysis [1-4].

The main commodities of fossil energy are coal, crude oil and natural gas with different forms and units. Emergy analysis is a technique measuring the values of resources, services and commodities in common units of the solar energy it took to make them [5, 6]. Thus, we can transform the trade quantity of coal, crude oil and natural gas into emergy by transformity (in units of seJ/J). The sum of the three emergies can be used to measure the emergy of fossil fuel.

In this study, we built up network models of fossil fuel as well as coal, crude oil and natural gas. Then, the clustering of the countries can be detected by network analysis. Comparing the evolution of fossil fuel with the single commodity can reveal the underlying patterns of the world energy market.

2. Data and method

The data of international trade of coal, crude oil and natural gas is from the website of UN Comtrade, which contains all export and import flows among 197 countries in the world. The trade quantities are measured by the units of kilogram or liter. We selected the annual trade data of all the available countries from 2000 to 2013. The transformity of coal, crude oil and natural gas [6] are shown in table 1. We transformed the trade quantities of the three fuels into emergy and the sum of them is the emergy of fossil fuel.

We built up 4 types of network models based on the transformed data. The nodes are the countries, the edges are the trade relations, the directions of the edges are the direction of the trade flows, and the weights of the edges are the values of emergies.

Table 2.1: Transformity of coal, crude oil and natural gas

Fuel	**Transformity (seJ/J)**
Coal	8.17E4
Crude oil	1.48E5
Natural gas	1.71E5

3. Results and analysis

3.1 Clustering of the countries

We introduced an algorithm to detect the clustering of the countries in the 4 types of networks [7]. The algorithm is based on a variable called modularity which measures the density of links inside communities compared to links between communities. It is a scalar value between -1 and 1. The higher value of modularity the network has, the more obvious the clustering is. The number of clusters of the 4 types of network is shown in Fig. 3.1 and the modularity of the 4 types of network is in Fig. 3.2. We can see that the number of clusters in the fossil fuel trade is between 4 and 7, different from the situation of the three single fuel trades. The natural gas trade has the biggest number of clusters (between 6 and 10). The modularity of the fossil fuel trade network is between 0.4 and 0.5, similar to the modularity of crude oil trade network.

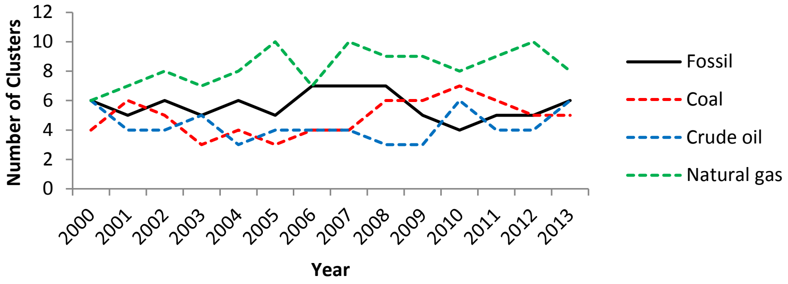

Figure 3.1: Number of clusters of the 4 types of network

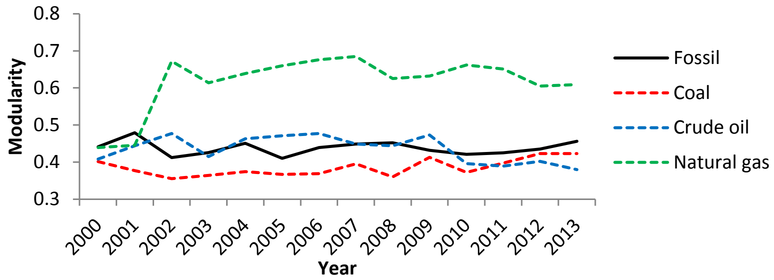

Figure 3.2: Modularity of the 4 types of network

3.2 Stability of the clusters

Normalized Mutual Information (NMI) is a measure to quantify the statistical information shared between two distributions [8]. It can indicate the similarity of two partitions we obtained by the algorithm. The higher the value of the NMI is, the more similar the two partitions are.

The NMI between $Year_{(i)}$ and $Year_{(1)}$ can indicate to what degree the clusters vary form the first observation year 2000. We can see the results in Fig. 3.3. The pattern of clusters in fossil fuel trade is deviating from the pattern in 2000. However, the trends of coal, crude oil and naturel gas are much different. The crude oil is deviating during the whole period, the coal is deviated quite far away in 2005 and 2007, and the natural gas is coming closer to the 2000 pattern since 2010.

The NMI between $Year_{(i)}$ and $Year_{(i+1)}$ can reflect the stability of the clusters as time goes by. It measures to what degree the members of clusters are changing from one year to the next year. The results are shown in Fig. 3.4. What worth to be noted is that the stability of fossil fuel trade clusters during year 2010~2011 is the lowest, which means this is the turning point of the evolution of fossil fuel trade pattern.

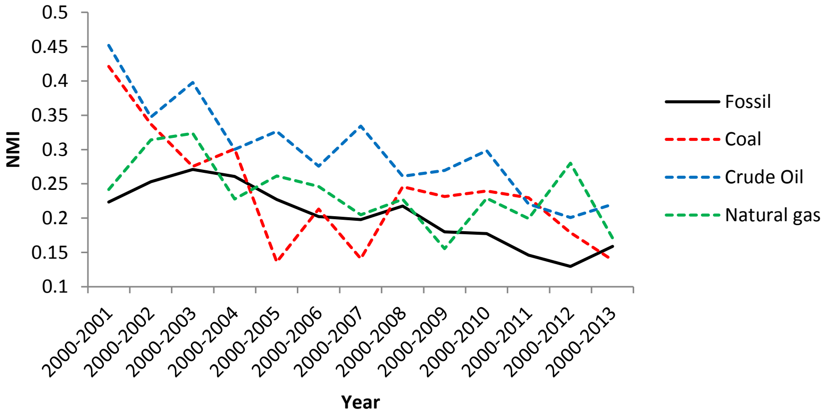

Figure 3.3: NMI of the first year 2000 and the other years

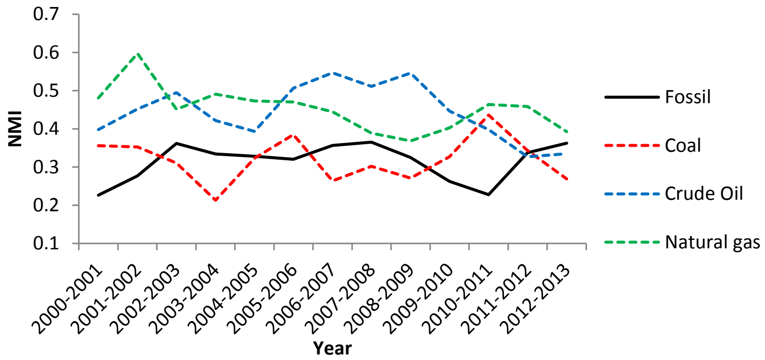

Figure 3.4: NMI of the neighboring years

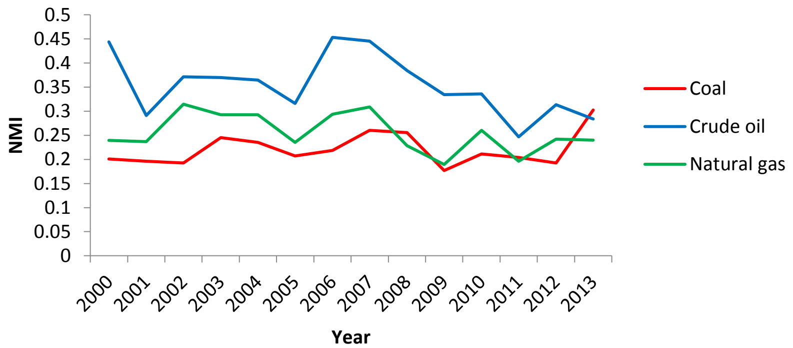

Figure 3.5: NMI of fossil fuel trade clusters with clusters of coal, crude oil and natural gas

3.3 The main factor

The NMI between fossil fuel clusters and the single fuel clusters can reveal the similarity of the fossil fuel trade pattern and the three single fuel trade patterns respectively. Thus, we can figure out which fuel is the main factor impacting the world fossil fuel trade pattern. The results are shown in Fig. 3.5. We can see that the NMI between fossil fuel clusters and crude oil clusters is the highest, which means crude oil trade pattern is the main factor for the evolution of fossil fuel trade pattern.

3.4 Evolution of the relations among countries

According to the result in Section 3.2, the fossil fuel trade clusters experienced the most variation from year 2010 to 2011. There are 4 clusters in 2010 with some geographical features (please see Table. 3.1). We traced the changes of countries with high emergy flows in Fig. 3.6. The red squares are importing countries and the blue squares are exporting countries. Countries fromm the two Asia Pacific-Middle East clusters formed a new cluster, and many other countries changed their clusters. However, the main pattern didn’t change. The international fossil fuel trade pattern still showed the geographical feature with an America-North Africa cluster, a Russia-Europe cluster and three Asia Pacific-Middle East clusters.

Table 3.1: Clusters of fossil fuel trade in 2010

Cluster No.	Geographical region	Major importing countries	Major exporting countries
1	America-North Africa	USA Netherlands Germany Spain	Canada Mexico Brazil Colombia Nigeria Algeria
2	Russia-Europe	France Belgium Poland Turkey Sweden Greece	Russia United Kingdom Norway Kazakhstan
3	Asia Pacific-Middle East	China Japan Italy Israel Belarus	Iran Venezuela Australia South Africa Azerbaijan
4	Asia Pacific-Middle East	Other Asia, nes[1] India South Korea Singapore Thailand	Saudi Arabia United Arab Emirates Indonesia Kuwait Qatar

[1] In *UN Comtrade*, The partner "Other Asia, nes" is used (a) for low value trade and (b) if the partner designation was unknown to the country or if an error was made in the partner assignment. The reporting country does not report the details of the trading partner in these specific cases. Sometimes reporters do this to protect company information.

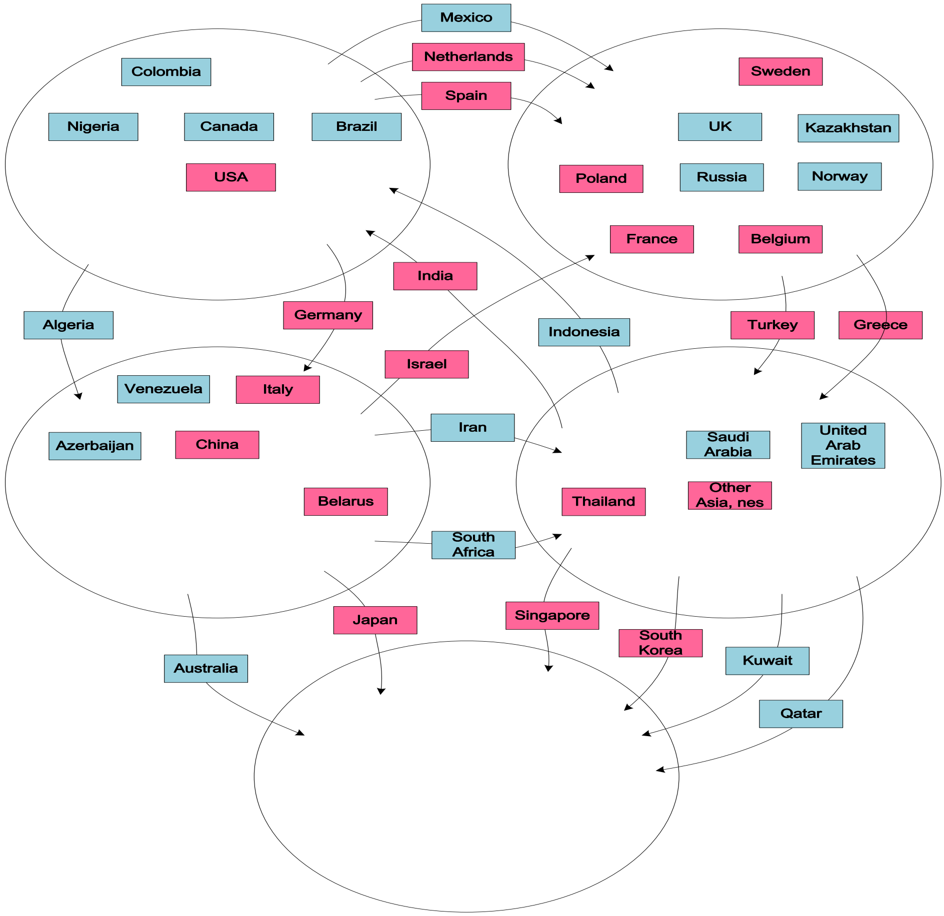

Figure 3.6: The migration of countries between clusters (fossil fuel trade from 2010 to 2011)

4. Conclusion

In this study, we transformed the trade quantity of coal, crude oil and natural gas into emergy and summed them to obtain the emergy of fossil fuel trade. We built up 4 types of network models (fossil fuel, coal, crude oil and natural gas) based on the value of emergy. After study the clustering of the countries, we found 3 major features of the evolution of the international fossil fuel trade pattern. First, the number of fossil fuel trade clusters is 4~7 during the year 2000~2013, and the degree of partition (modularity) is at the same level. Second, crude oil trade pattern is the main factor impacting the fossil fuel trade pattern. Third, although the stability of the clusters is fluctuated, the overall fossil fuel pattern is stable. There are mainly 3 types of clusters: America-North Africa cluster, Russia-Europe cluster and Asia Pacific-Middle East clusters.

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Cost Optimization Model of Resued Flowback Distribution Network of Shale Gas Development: The Case of Bradford County of Marcellus Shale in Pennsylvania

Huajiao Li 1[1,2,3,4], Haizhong An [1,2,4]*, Wei Fang [1,2,4], Meng Jiang [1,2,4]

[1] School of Humanities and Economic Management, China University of Geosciences, Beijing 100083, China

[2] Key Laboratory of Carrying Capacity Assessment for Resources and the Environment, Ministry of Land and Resources, Beijing 100083, China

[3] Department of Energy and Mineral Engineering in the College of Earth and Mineral Sciences, The Pennsylvania State University, PA 16802, USA

[4] Lab of Resources and Environmental Management, China University of Geosciences, Beijing 100083, China

Corresponding Author e-mail: ahz369@163.com

Abstract

Water is one of the essential factors for shale gas extraction. Each well demands several millions gallon water being injected into the fractured well to get the efficient and economical flow of gas. Along with the hydraulic fracturing, lots of flowback water returns to surface and it will be stored temporarily near the shale gas well. According to the former researches, there is 4%-40% fracturing fluid return to the surface, and in Pennsylvania, around 90% of the flowback water is current being reused in shale gas fracturing in Marcellus Shale. For the reused flowback water, two main costs need to be concerned while transported from one shale gas well to others, the storage cost and transportation cost. We need to construct a optimization storage and transportation model to minimize the total cost of both the storage cost and the transportation cost considering distance based on latitude and longitude of the shale gas wells, the time difference between any of the two shale gas wells, the storage cost per unit (day), the transportation cost per unit (mile), the quantity of flowback water each shale gas well (gal), the quantity of demand water each shale gas well (gal), and do on. Then according to the empirical data of the case chosen in this paper, Bradford County in Marcellus Shale, we can get the regional cost optimization reused flowback distribution network based on the optimization model. Meanwhile, we also use complex network method to show the visualization result and topological features of the flowback distribution network.

1. Intruduction

Along with the hydraulic fracturing development and “shale gas boom” in America, both the American domestic energy market and the global energy market have gone through big changes (Rogers, 2011). As one of the essential factors of hydraulic fracturing, the main shale gas extraction approach, millions of water are demanded to get efficient and economical flow of gas. Although most injected water is left underground after being injected, there is still a large volume of water with high concentrations of total dissolved solids, also known as “flowback”, returns to the surface which will be stored temporarily near the shale gas well (Gregory et al., 2011). There is around 4%-40% of the injected water returns to the surface according to different studies, while 32%-90% of the flowback has been reused in Marcellus Shale, Pennsylvania since 2007(Gregory et al., 2011) (Hansen et al., 2013) (GE, 2011) (Arthur et al., 2014).

Usually, for the stored reused flowback, there are four main different ways to be treated, being used for nearby shale gas well, being injected into underground wastewater wells, being sent to brine/industrial waste or municipal sewage plants. In

Pennsylvania, more and more flowback has been reused in shale gas local development (Arthur et al., 2014). For the reused flowback water, besides the treated costs, there are two other main costs, transportation cost and storage cost (Curtright et al. 2012), which will be different as the flowback reused by different shale gas wells due to the different development time periods and distances. Both the potential transportation paths and the real transportation paths can form different flowback distribution networks.

In this paper, we use complex network method (Li et al., 2014) and linear programming to construct the potential transportation networks and the optimizing distribution networks based on the both the storage cost and the transportation cost, by considering distance between any of the two shale gas wells, the time difference between any of the two shale gas wells, the storage cost per unit (day), the transportation cost per unit (mile), the quantity of flowback water each shale gas well (gal), the quantity of demand water each shale gas well (gal), and do on. Then according to the empirical data of one of the important counties of shale gas development in in Marcellus Shale, Bradford County, we use the model to get the the regional cost optimization reused flowback distribution network and its topological features. It is important for the developer to cut the costs of shale gas development in a holistic point of view, and it is also provide an effective basic for the environment departments to enhance the flowback reused and freshwater economy.

2. Method and Data

2.1 Method

There are two basic elements for complex networks, node and edges. Here, we take each shale gas well as a node, the potential transportation path as edge (see Figure 1). For each node, it has six different attributes (variables), Table 1 shows both the attributes and its descriptions about shale gas well Wi. Meanwhile, there are three different attributes (variables) for the edges between any of the two shale gas wells, Wi and Wj, they are the time difference t_{ij}, the distance d_{ij}, the reused flowback distribution volumn, x_{ij}, they are calculated by Formula (1), Formula (2) and Formula (3) respectively. The edges in the distribution network are directed.

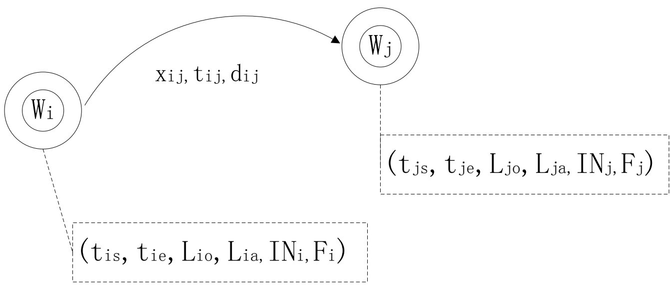


Fig. 1: The basic elements of the reused flowback distribution network

Table 1: The attributes and descriptions of shale gas well Wi

Attribute	Description	Attribute	Description
t_{ie}	The drilling start date of shale gas well Wi	t_{is}	The of drilling end date of shale gas well Wi
L_{ia}	The latitude of shale gas well Wi	L_{io}	The longitude of shale gas well Wi
IN_i	The injection water demand of shale gas well Wi	F_i	The flowback water volumn of shale gas well Wi

$$t_{ij} = \begin{cases} t_{js} - t_{ie} & t_{js} \geq t_{ie} \\ \text{Null} & t_{js} < t_{ie} \end{cases} \quad (1)$$

$$d_{ij} = m * R * \text{Arccos}(\sin(L_{ia}) * \sin(L_{ja}) * \cos(L_{io} - L_{jo}) + \cos(L_{ia}) * \cos((L_{ja})) * \pi/180 \quad (2)$$

where m is the transformation coefficient between kilometer and mile, 1km=0.621371192mile, R is the radius of the earth, R= 6378.137 km

$$C_{ij} = S_{ij} + TR_{ij} \quad (3)$$

$$S_{ij} = x_{ij} \times s \times t_{ij} \qquad x_{ij} \leq IN_i \times f \times r \quad (4)$$

where s is the unit storage cost for flowback water per gallon, f is the flowback percentage (%) of injected water each well, and r is the reused percentage (%) of total flowback water of each well.

$$TR_{ij} = x_{ij} \times tr \times d_{ij} \quad t_{js} \geq t_{ie} \quad x_{ij} \leq IN_i \times f \times r \quad (5)$$

where tr is the unit transport cost for flowback water per mile.

Based on the analysis above, we can construct the Cost Optimization Model of Resued Flowback Distribution Network as followed. Formula (6) is the objective function of the model, and Formula (7) is the constraint of the model.

$$\text{St. } f(C) = \text{Min} \sum_{i=1}^{N} \sum_{j=1}^{N} C_{ij} \quad (6)$$

$$\begin{cases} \sum_{j=1}^{N} x_{ij} = IN_i \times f \times r \\ \sum_{i=1}^{N} x_{ij} \leq IN_j \\ t_{ij} \neq \text{Null}, i \neq j, x_{ij} \geq 0 \end{cases} \quad (7)$$

where we assume that the shale gas well can only use the flowback water from the shale gas wells whose drilling end date are not late than the drilling start date of the target well.

There are lots of different topological features to display the structure and inner relationships of the complex network, here we use in-degree (see Formula (8)), out-degree (see Formula (9)), weighted in-degree (see Formula (10)), weighted out-degree (see Formula (11)) to show the basic roles of each well in the reused flowback distribution network. According to the formulas, the in-degree means the quantity of wells the given well get reused flowback from, and the out-degree means the quantity of wells the given well transports reused flowback to. Meanwhile, the weighted in-degree and weighted out-degree indicate both the potential directions and also the weights of the edges in and out.

$$R_i^{in} = \sum_{j=1}^{n} e_{ji} \qquad i \neq j \quad (8)$$

where e_{ji}=1 when j has edge directs to i, and e_{ji}=0 when j doesn't direct to i.

$$R_i^{out} = \sum_{j=1}^{n} e_{ji} \quad i \neq j \tag{9}$$

where e_{ij}=1 when i has edge directs to j, and e_{ij}=0 when i doesn't direct to j.

$$WR_i^{in} = \sum_{j=1}^{n} w_{ji} \quad i \neq j \tag{10}$$

where w_{ji} is the weight of the edge from i to j.

$$WR_i^{out} = \sum_{j=1}^{n} w_{ij} \quad i \neq j \tag{11}$$

where w_{ji} is the weight of the edge from j to i.

2.2 Data

In this paper we use Bradford County as case, to do empirical study. Bradford County is an important place for Marcellus Shale, an organic-rich, sedimentary rock formation in the Appalachian Basin of the north-eastern United States that contains significant quantities of natural gas (Soeder, 2010). It has more than 3000 shale gas wells permits from 2007 to 2014[1], and one third of them has been drilled and under production[2].All the sample data in this paper were get from Fracfocus[3] ,which is an important shale gas development information disclosure website managed by the Ground Water Protection Council and Interstate Oil and Gas Compact Commission of America, on October 28th, 2014, we choose all the 191 shale gas wells with complete information of drilling start date, drilling end date, total base water volume (gal), longitude, latitude, as well as the API Number, operator name, and so on from February 2013 to October 2014.

3. Calculation and analysis

3.1 The potential distribution network

The potential distribution network indicates the network with all the possible paths between any of the two nodes. As mentioned above, we assumed that the shale gas well can only use the flowback water from the shale gas wells whose drilling end date are not late than the drilling start date of the target well, so we can get the potential distribution network by analyzing the date differences between t_{js} and t_{ie}, Figure 2 shows the visualization of potential flowback distribution network (PFDN for short) of Bradford County from February 2013 to October 2014 as well as the in-degree and out-degree cumulative distribution of PFDN.

[1]http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?/Oil_Gas/Permits_Issued_Detail
[2]http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?/Oil_Gas/Wells_Drilled_By_County
[3] http://www.fracfocusdata.org/DisclosureSearch/

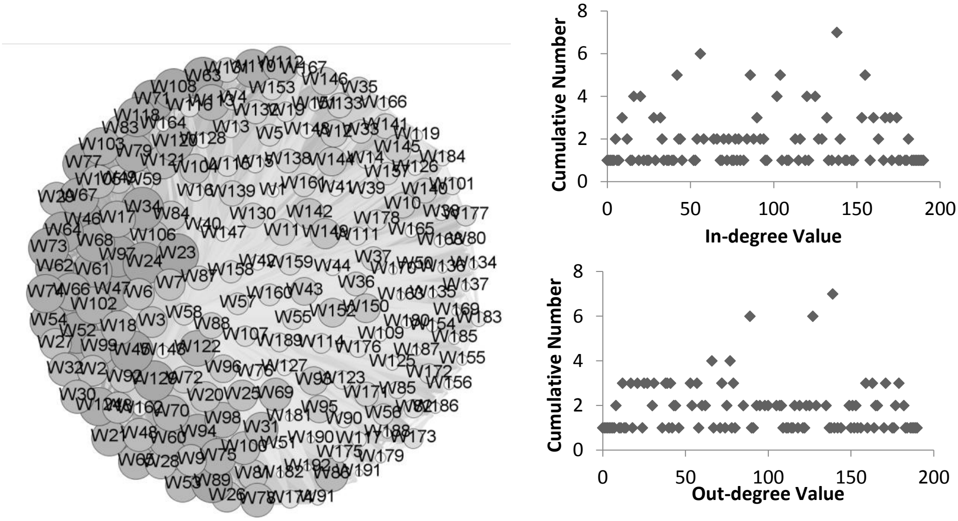
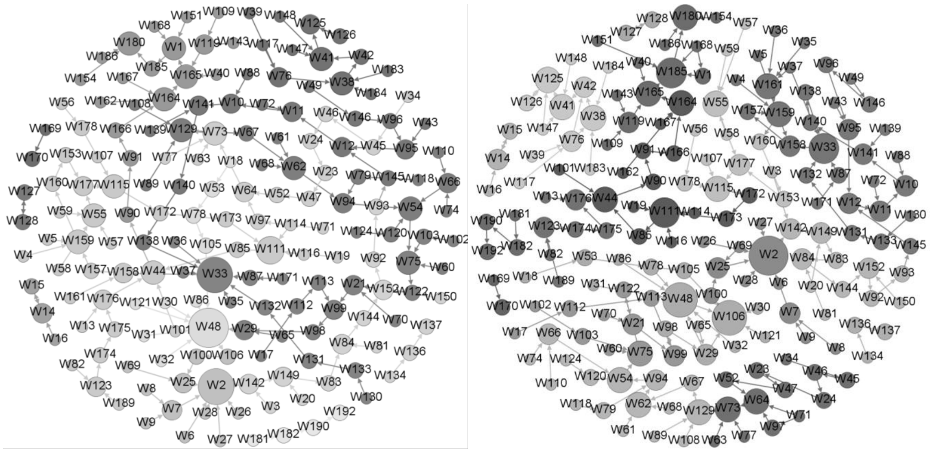


Fig. 2: Visualization of PFDN (n=191) and In-degree & Out-degree cumulative distribution of PFDN

3.3 The storage and transportation cost optimizing distribution network

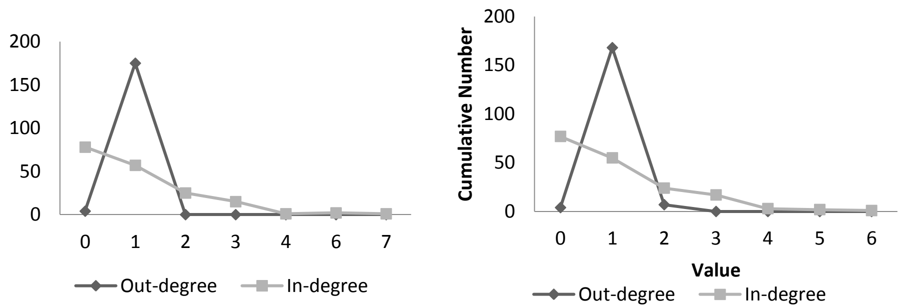
Based on the PFDN and Formula (6) and Formula (7), we can get the storage and transportation cost optimizing flowback distribution network (FDN for short) by different values of flowback. Here we mainly analyzed two different scenarios, one assumed f=0.06, and r=0.32 (Hansen et al., 2013), another assumed f=0.20 (GE, 2011), and r=0.90 (Arthur et al., 2014). The unit storage cost s=0.012 dollar/gallon day, and tr=0.024/gallon hour mile (Curtright et al. 2012), we assumed hour mile=30 miles. In the constraint, we assumed the reused flowback of the last three months is unlimited. By linear programming we got two different global optimal solutions for the two different scenarios. Figure 3 are the visualizations of two optimizing FDNs.



(a) f=0.06, r=0.32 (b) f=0.20, r=0.90

Fig. 3: Visualizations of flowback distribution networks by different flowback and reused percentage

According to the linear programming results, the two different global optimal costs are \$687,981 and \$6,949,940 respectively, it raises larger than the real reused flowback percentage (f*r). According to Figure 4, all of the reused flowback of a given shale gas well is transported to only one shale gas well in scenario 1, and only a little flowback of a given shale gas well is transported two shale gas wells in scenario 2. Meanwhile, in order to realize the cost optimizing, more than 40% of the shale gas wells don't need use reused flowback. In scenario 1, the produce reused flowback volume is from 1203.1488 gallon to 323,714 gallon per well (WR_i^{out}), and the used volume for each later development shale gas well (WR_i^{in}) is from 0 to 7,797,594 gallon per well. In scenario 2, the produce reused flowback volume is from 11279.52 gallon to 2568714.12 gallon per well, and the used volume for each later development shale gas well is from 0 to 7,797,594 gallon per well.



(a) f=0.06, r=0.32 (b) f=0.20, r=0.90

Fig. 4: The In-degree & Out-degree cumulative distribution of FDNs

4. Discussion and conclusion

In this paper, we integrated complex network method and linear programming as well as the distance calculation methods to construct the cost optimization model of resued flowback distribution network of shale gas development, and its topological features, and we used the case of Bradford County of Marcellus Shale in Pennsylvania to do empirical analysis. Next step, we will study the non-linear relationship between reused flowback cost and the real reused flowback percentage, and we will also study the role of each shale gas well and its attributes.

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Energy independence in the Galapagos Islands

Rony Parra[1], Jaime Cevallos[1], Bolívar Quispe[2]

1. Centro de Prospectiva Estratégica (CEPROEC). Instituto de Altos Estudios Nacionales (IAEN), Ecuador.

2. Secretaria Nacional de Planificación y Desarrollo (SENPLADES), Ecuador.

Abstract

Galapagos is located in the Pacific Ocean about 1000 km from the west coast of Ecuador and consists of 127 islands and islets. Thanks to the characteristics of biodiversity of the archipelago, is considered by UNESCO as the only living museum and showcase of evolution on the planet, this is why the importance of conservation their ecosystem.

The Galapagos energy system is characterized by a strong component of energy from fossil fuel transported from the continent, both for electricity generation and for thermal use in different sectors of production. Approximately 9.9 million gallons of diesel, 3.2 million gallons of gasoline and 1,053 tons of LPG entered the island in 2012 (EP Petroecuador, 2012) and consumed about 36.2 GWh, 21% higher than electricity consumption in 2010.

Electricity generation in 2012 was largely diesel and a 6.8% share of renewable sources. It is important to mention that the diesel consumed in the islands is mainly imported, since refining infrastructure Ecuador does not cover domestic demand.

Taking into consideration the sensitivity of the Galapagos ecosystem and its energy model characterized by a high dependence on energy supplies from the mainland, a growing energy consumption, a concentrated system of electric generation from thermal sources and poor use of renewable sources, is born the need to rethink the model to better alternatives for sustainability.

The aim of the work is based on characterizing and analyzing the energy system of the island from a holistic perspective, considering not only the supply of fossil fuels and renewable sources, but also analyze the energy demand by type of consumer, this involves characterizing the system from human behavior in the use and availability of resources.

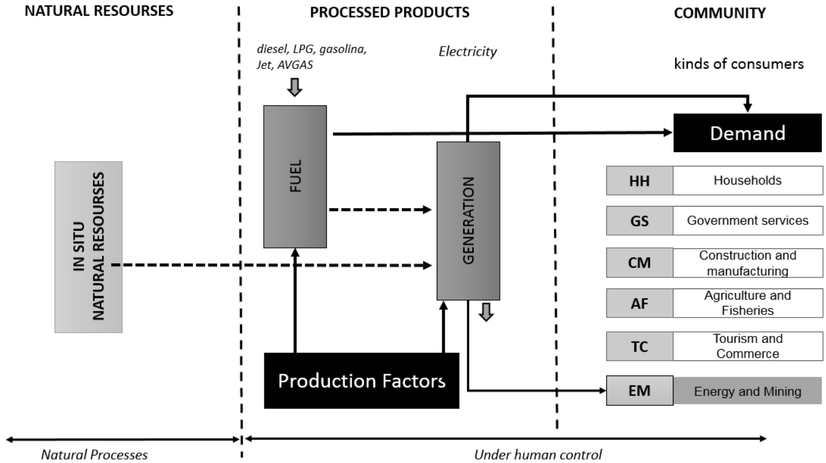
The study will perform a biophysical diagnosis of input energy flows considering the potential alternative sources (largely wind and solar), flows that are transformed and lost in the process to finally identify outflows of consumption in the social activities (households, government services, construction and manufacturing, agriculture and fisheries, energy and mining, and tourism and trade). After will be calculated consumption trends, energy sufficiency and renewability and will be proposed mechanisms to diversify supply and consumption patterns at the Galapagos energy system.

1. Energy Grammar

The economic development and population growth in Galapagos has caused a significant increase in the consumption of goods and services by residents and floating populations who visited the islands (Rueda et al, 2008). In 2012, the population of the island were 25,120 residents between permanent and transient population (approximately 2,500 tourists).

During the last century, Ecuador´s mainland has predominantly exploited natural resources like oil and hidro-electricity to provide energy products and services to the citizens. This reality is not the same in the insular region, where the main source of electricity generation comes from the consumption of fossil fuels transported from the continent and a small portion coming from renewable sources such as solar radiation and wind.

Figure 1: Grammar Energy of Galapagos



Source: own

Like many other islands in the world, the Galapagos Islands rely on fossil fuels for transportation and electricity generation. The fuels are shipped once per month from the Refinery located in Santa Elena, to the storage tanks located in the Baltra Island. Afterwards the fuel is distributed to the three islands with service stations. In 2012 around 325 thousand barrels of fuel were transported to the islands, and diesel fuel accounted for almost three quarters of that amount. The price of fuel for residents of the islands has the same cost as on mainland, sharing the same subsidy.

The commercialization of the fuel is made only by the company EP Petroecuador[1]. In 2012 they carried to the Islands 9.9 million gallons of diesel, 3.2 million gallons of gasoline, 1,053 ton of LPG and 170,000 gallons of Jet and Avgas. For the analysis of energy consumption as five economic categories were considered: Households, Government services, Construction and manufacturing, Agriculture and Fisheries, Tourism and Commerce, Energy and Mining.

[1] EP Petroecuador: The public company that transports oil from Ecuador, refines and markets oil and fuel on behalf of the State.

Table 1. Characterization of the energy system Galápagos (TJ)

	Types of consumers		Electricity (TJ)	Gasoline (TJ)	Diesel (TJ)	GLP (TJ)	Jet y AVGAS (TJ)	Fuels (TJ)
Demand	Galápagos	WS	141	375	1.376	49	22	1.822
	Households	HH	54	59	4	36	-	100
	Government services	SG	32	41	92	-	-	134
	Construction and manufacturing	BM	1	12	36	12	-	60
	Agriculture and Fisheries	AG	-	136	-	-	-	136
	Energy and Mining	EM	11	-	392	-	-	392
	Tourism and Commerce	TC	43	127	851	-	22	1.000
Supply	Production		141	-	-	-	-	-
	Entry		-	375	1.376	49	22	1.822

*1x10^{12} J=TJ; TJ was used to better understand the data

** In electricity consumption in Energy and Mining's included technical losses of the system

Source: ELECGALAPAGOS, 2014; ANT, 2014; CONELEC, 2014; ARCH, 2014, EP PETROECUADOR, 2014.

Diesel is the most representative fuel consumed in Galapagos (75.5%), then gasoline (20.6%) and LPG, Jet and AVGAS completes the remaining 3.9%. The increased fuel consumption is on the island of Santa Cruz with 70% .This has the largest tourist infrastructure on cruise ships and sailboat, plus electricity generation using this fuel. The second island is San Cristobal with 23% and finally Isabela and Floreana shares the remaining 7%.

Electricity generation in Galapagos is decentralized. On each island thermal power plants were installed to cover domestic demand. The energy sources for electricity generation in 2012 were mainly diesel fuel, wind and solar. 93.2% of electricity generation in Galapagos using diesel as the primary source and the highest concentration is in Santa Cruz Island with 62% of the total. Only 6.8% of electricity generated from renewable sources. In 2012, the generation, transmission and distribution of electrical energy had 10.8 TJ (3 GWh) in technical losses and auto consumption of electricity in the system.

Table 2. Electricity generation by island

Island	Thermal (TJ)	Wind (TJ)	Photovoltaic (TJ)	Nut oil (TJ)	Total (TJ)
Santa Cruz	87	-	-	-	87
San Cristóbal	31	9	0	-	40
Isabela	13	-	-	-	13
Floreana	1	-	-	0,3	1,3
Total	132	9	0	0	141

Source: ELECGALAPAGOS, 2014; CONELEC, 2014.

The sectors with higher energy consumption in the islands are mainly tourism and trade with 53% and energy and mining sector with 20.5% of the total energy supplied. In the first sector, the maritime and land transport are the main consumers, approximately 1,000 TJ and 150 TJ respectively. In the second sector, the main consumer is the generation of thermal energy 392 TJ. The current electric system uses thermal diesel generators to produce most of the electricity in the islands. In the same year, only 6.8 % of the electricity were generated by renewable sources, but ongoing projects will be able to increase its stake to 40%.

In Ecuador there is a subsidy policy for the sale of energy products and services. In 2012, the State subsidized in the Archipelago, a total of US $ 27.6 million, including US$ 17 million for domestic marketing of fuels and US$ 10.7 million for transportation of fuels from the mainland to the Galapagos.

Table 3. Impact of subsidies

FUEL	SHIPPED (Millions of Gallons)	INTERNATIONAL PRICE (Millions US$)	COLLECTED (Millions US$)	GRANT (Millions US$)
DIESEL gal	9,87	32,59	22,97	9,62
EXTRA gal	3,17	11,34	4,69	6,65
AVGAS gal	0,05	0,13	0,13	
JET A-1 gal	0,12	0,30	0,18	0,12
GLP kg	0,99	0,80	0,11	0,70
TOTAL		45,17	28,07	17,09

*Fuel costs: 1,479 $/gall of gasoline extra; 1,037 $/gall of diesel; 1.62 $/gall of Jet; 2.2 $/gall of Avgas; 0.10666 $/Kg of GLP.

** Existed 5.2 million gallons of diesel (cruise ships and boats loaded into the storage station Baltra) and 54.1 thousand gallons of AVGAS (planes) that not received subsidy in marketing (EPPETROECUADOR, 2014).

Source: ELECGALAPAGOS, 2014; CONELEC, 2014; BCE, 2014

2. Renewable Energy Potential

The Archipelago has several sources of renewable energy, especially solar and wind energies show great potential benefits. Although geothermal and tidal resources are also present in large quantities around the islands, their usage is limited due to their location inside the Galapagos National Park. The GNP covers around 97% of the surface on the islands, and the marine reserve around them, leaving only limited areas where human society can take advantage of the resources available.

Statistic data of wind and solar resources display sufficient amounts to make any renewable energy project economically feasible. An average of the direct normal irradiance DNI of 6.2 KWh/m2 per day (NASA, 2015), and wind speeds superior to

6 m/s (MEER, 2013), exceed considerably the minimum requirements of current technologies.

To determine the suitable areas for renewable energy projects, an analysis of energy potential was carried out using tools of geographic information system GIS and spatial data of the region, similar to the one performed by Fluri in 2009. Three mature technologies were considered for the analysis: Solar Photovoltaic PV, Concentrated Solar Power CSP and Eolic, taking into account the following criteria and constraints:

- The average wind speed data of the islands were retrieved from the Eolic Atlas of Ecuador (MEER, 2013). The spatial imagery display monthly wind speeds at 30, 50, and 80 meters above ground level. The areas selected as suitable are the ones with wind speeds superior to 6 m/s for a minimum period of 6 months.
- The annual average solar radiation over the archipelago was obtained from the NASA Surface meteorology and Solar Energy (SSE) in his website. The data shows world's Direct Normal Irradiance (DNI) and Global Horizontal Irradiance (GHI) information with 1º resolution. Here, areas considered suitable varies according to the technology to be used: for PV the areas with GHI superior to 4 KWh/m2/day, and for CSP the areas with DNI superior to 6 KWh/m2/day.
- The Digital Elevation Model of Ecuador was used to identify the areas with suitable slope. Each technology requires different slope constraints: for CSP the maximum slope allowed is below 2%, PV allows a terrain inclination up to 5%, and Eolic technology allows a wider range up to 10%.
- The suitable areas for human intervention were defined using the coverage area of the GNP.

Figure 2.a and 2.b show the result of the model, which show the areas with enough wind/solar resource, suitable slope and located outside the GNP. As it can be seen, even with the area limitation, each inhabited island has enough potential areas for renewable power plants.

Figure 2.a. Eolic potential areas at 50 & 80 meters

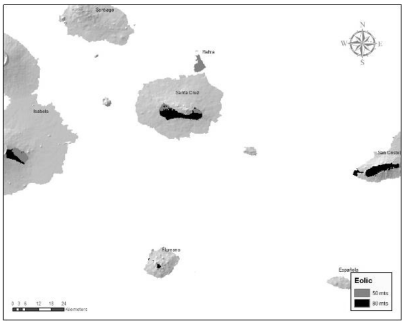
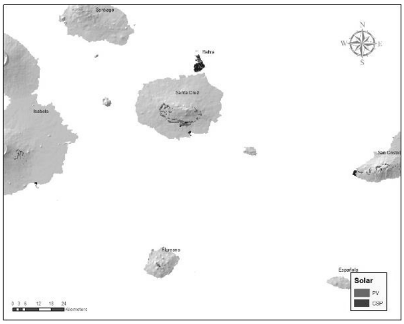


Figure 2.b. PV and CSP potential areas



Source: MEER, 2013; NASA, 2015; Fluri, 2009

CSP is the technology with less suitable areas, due to its slope requirement. The islands show at least 2,588 hectares with potential for CSP plants, although most of the area is concentrated in the Baltra Island. Its main advantage is the capacity to produce electricity 24 hours per day, if the plant is equipped with a thermal storage system (Brand, 2012).

Solar PV technology displays more suitable areas than CSP. This technology has almost 9,000 hectares considered suitable for PV power plants. In this case, the reduction in the slope limitation increases the suitable area to the regions closer to highlands.

Wind is the resource with largest potential areas, especially for heights above 80 meters, where most of the areas available for human intervention display suitable areas (as seen in Fig 2.a). In total, 21,800 hectares are considerate suitable for the implementation of this technology.

3. Conclusions

- The largest consumer of fuel is the tourism and trade sector, addressed to transport, which represents approximately 70% of the consumption in Galapagos. Within this group, ships consume approximately 7 million gallons of diesel and rent trucks use 0.9 million gallons of diesel for land transportation.

  There are other sectors with representative consumption like "government services", which consumed about 9 percent of energy in the islands. This sector uses 24% of electricity in the institutions and public services such as street lighting. The Households sector accounted for near 8% of energy consumption. Here, 40% of the energy used is for private transport, almost one third is consumed in the form of electricity, and the rest was devoted to the production of heat in kitchens and water heaters. A small amount of diesel fuel for private generators and chainsaws were used.

- In 2012 the rate of energy sufficiency[2] in Galapagos was 7.2%. This indicator shows that Galapagos is dependent of the energy transported from mainland, mainly diesel, gasoline, LPG, Jet fuel and AVGAS. The renewability rate[3] in 2012 was 0.4%. This indicator shows that the supply of fossil energy accounts for 99.6% of total energy offered in Galapagos.

- The potential of electric generation calculated from the use of photovoltaic and wind sources far exceed the demand of electricity in Galapagos. The islands takes about 39 GWh to maintain its economic dynamics. As an example, if only

[2] THE sufficiency index is the ratio between the energy produced and the total energy supplied.

[3] Renewability index is the ratio of the offered renewable energy and the total energy supplied.

the total effective area of the photovoltaic potential would take advantage, it could generate around 175 GWh, this is about eight times the energy demand of the islands.

- The availability of resources and advanced technologies should not be a problem to reach energy sustainability in the islands. On the one hand, this study has presented sufficient potential for electric generation from renewable sources, and on the other hand, there are several islands in Europe, Asia, Oceania and the Caribbean that have launched initiatives to promote the use of renewable energy to produce electricity. An example of these islands Bonaire, which seeks to produce 100% of its energy from renewable sources.

- The main concern for Ecuador is to get funding for future RE projects. As an example, the replacement of diesel power plants for renewable technologies displace approximately 2 million gallons of diesel. The Ecuadorean Government would save $ 10 million annually for import concepts. This category could easily finance the implementation of new renewable generation plants.

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Eco-cities: Energy and Water Nexus

Zhifeng Yang[1,*], Gengyuan Liu[1]

[1] State Key Joint Laboratory of Environment Simulation and Pollution Control; Key Laboratory of Water and Sediment Sciences, Ministry of Education; School of Environment, Beijing Normal University, Beijing 100875, China

Corresponding Author e-mail: zfyang@bnu.edu.cn

Abstract

Cities are undergoing vast changes in the galloping process of industrialization, urbanization, and globalization, which have brought mounting environmental problems including climate change, acid rain, water shortage, pollution, hazardous waste, smog, ozone depletion, loss of biodiversity, and desertification that pose severe challenges to sustainable development of our human life. Such changes provide environmental considerations assuming greater importance to the urban planning processes of an increasing number of governments around the world. Researchers and urban planners of urban systems are increasingly concerned to know whether urban areas are capable of adapting to these drastic biological, geophysical, and social changes. A widespread paradigm shift in response to the changes urban areas face is a move toward sustainability, which can be defined based on two standards: (1) the ability to improve the quality of human life while living within the capacity of ecosystem support; and (2) the ability to meet contemporary needs without compromising the ability of future generations to meet their needs. Both definitions invoke three equal facets: social equity, economic viability, and environmental functionality. Eco-cities planning knowledge is crucial to advancing sustainability, and sustainability places eco-cities planning knowledge in the context of integrated socio-ecological dynamics.

The emerging paradigm of sustainability in eco-cities planning worldwide is signaled by policies enacted by specific cities, counties, regions, and states. The sustainability paradigm is reflected in urban metabolic researches aimed at adapting to changing environmental, social, and economic conditions in the cities we study. Such eco-cities plans themselves have become part of the changing local and regional context, and like climate change, economic globalization, regional and international migration, and other large forcing functions, they must be taken into account in understanding eco-city plans. The ecological network models will draw on existing social, energy, ecohydrological, and ecosystem service modules but will be refined and operated for enhanced cross-disciplinary integration and prediction. These eco-city practices will enhance the understanding of eco-cities and eco-landscape as integrated, spatially extensive, complex adaptive systems and offer a sampling of planning practice common in this field.

1. Introduction

1.1 Urban development stages and characteristics

Urban evolution has its own stages, not only concerning social and economic development levels, but also for emerging environmental problems in the socioeconomic background. The World Bank classified urban eco-environmental problems into two types: problems “related to poverty” and those “related to economic growth and richness” (Yang et al., 2004). In contrast, Satterthwaite (1997) classified urban eco-environmental problems into five types: environmental hazards, excessive exploitation of renewable resources, excessive depletion of nonrenewable resources, huge waste, and excessive utilization of environmental capacity. We summarize and classify urban eco-environmental problems into three types, including problems related to poverty, production, and consumption.

Generally speaking, cities will seek an ideal developmental mode after the aforementioned three stages, when influenced by both internal conditions and external surroundings. From the perspectives of environmental protection and sustainable development, the final ideal stage of urban evolution is a mature stage named “eco-city”, in which economic development, social progress, and environmental protection develop in a harmonious way, there are no problems related to poverty and production, and the impact of problems related to consumption is minimal.

1.2 Eco-city perspective: definition and characteristics

After reflecting on the urban developmental stages and emerging eco-environmental problems since the advent of industrialization, the eco-city concept has been regarded as an urban development paradigm in the global wave of ecological civilization. In an eco-city, it is believed that the environment will be properly protected and maintained while the society and economy develop smoothly, which promotes human development. Seriously considering the relationships between humans and nature led to the final conclusion that humans must develop in harmony with nature to realize their own sustainable development.

There are different understandings of what exactly an eco-city is. Yanistky (1981) states that an eco-city is an ideal habitat with a benign ecological circulation, in which technology and nature fully merge, human creativity and productivity reach a maximum, the residents’ health and environmental quality are well protected, and energy, water, and information are efficiently used. Register (1987) regards an eco-city as an ecologically healthy city in which the objective of ensuring the health and vigor of man and nature reasonably guides human activities. Influenced by the theory of the social-economic-natural complex ecosystem proposed by Ma (1984), Chinese scholars have generally considered an eco-city as a stable, harmonious, and sustainable complex ecosystem that makes possible “all-win” development among social, economic, and environmental factors, full fusion of technology and nature, maximal motivation of human creativity, increasingly improved urban civilization, and a clean and comfortable urban environment.

In addition, there are also different emphasized points for eco-city planning and construction. One report of Man and Biosphere, a program launched by UNESCO, put forward five key points of eco-city planning, including an ecological protection strategy, ecological infrastructure, residents’ living standard, protection of history and culture, and merging nature into the city (Yang et al., 2012). Wang (2001) states that eco-city construction includes a high quality environmental protection system, efficient operation system, high level management system, good greenbelt system, and high social civilization and eco-environmental consciousness.

2. Urban Metabolism: Energy and Water Nexus

By analyzing the components of the eco-city, it is possible to determine the direction of the eco-flows through the system and define its metabolic pathways. The multiple roles played by the components of the system create complicated functions for these components, which mean that the direction of eco-flows among the components is not a chain, but rather a network. For this reason, we have constructed a conceptual model of an ecological network for the urban metabolic system.

Ecological networks resemble biological networks, and describe the structure of the flows of materials, energy, and currency between different components of the system. The basic units of ecological networks are "compartments" and "pathways". Compartments perform a specified function, and thus serve as the functional units of the ecosystem, whereas pathways serve as transmission channels for water, energy, and currency between compartments.

In this part, we have developed a five-compartment ecological network model for the urban metabolic system. In this model, compartment 1 represents the internal environment of the urban metabolic system, compartment 2 represents its external environment, compartment 3 represents the agricultural sector, compartment 4 represents the industrial sector, and compartment 5 represents the domestic sector (i.e., domestic life of the city's citizens). We have defined 19 metabolic pathways that reflect the exchange of eco-flows among these five compartments (Figure 1). Note that in this diagram, f_{ij} represents the flow from compartment j to compartment i, and z_i represents the overall input flows through compartment i, for example $z_1 = f_{12} + f_{13} + f_{14} + f_{15}$.

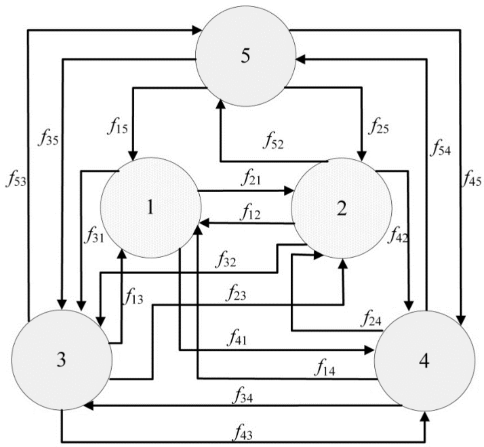

Figure 1 Conceptual model of the ecological network of an urban metabolic system.

Notes: Compartment 1, the internal environment; compartment 2, the external environment; compartment 3, the agricultural sector; compartment 4, the industrial sector; compartment 5, the domestic sector; f_{21} represents the trans-boundary transfer of pollutants; f_{31} and f_{41} represent the resources provided by the internal environment for agriculture and industry, respectively; f_{51} represent the service function the environment provides for domestic life, here it does not be considered; f_{12} represents the total resource inputs from the external environment; f_{13}, f_{14}, and f_{15} represent the pollutants discharged by agriculture, industry, and domestic life, respectively; f_{32}, f_{42}, and f_{52} represent the resource inputs from the external environment for agriculture, industry, and domestic life, respectively; f_{23}, f_{24}, and f_{25} represent the output of agricultural products, industrial products, and labor services, respectively; f_{43} and f_{53} represent the agricultural raw materials consumed for industrial production and domestic consumption, respectively; f_{34} and f_{35} represent the industrial products and labor services consumed by agricultural production, respectively; f_{54} represents the industrial products consumed by domestic consumption; and f_{45} represents the labor services used for industrial production.

2.1 Ecological network model of urban energy metabolism

Using models to analyze an urban system is a direct and effective method (Zhang et al. 2006). By abstracting and summarizing the traditional energy utilization systems, this approach can identify the key links in urban energy metabolic processes, permitting the development of a conceptual model of these processes (Figure 2).

The conceptual model of urban energy metabolic processes reflects the basic relationships involved in exploitation and utilization of urban energy. In this model, there are links among three key trophic levels that are analogous to those of a natural ecosystem: the energy exploitation sector functions as an energy producer; the energy transformation sector functions as a primary consumer of this energy; and terminal consumption sectors (here, industry and households) function as secondary consumers. In urban energy metabolic processes, the energy produced by the energy exploitation sector is the primary energy source, and provides energy for both the transformation and terminal consumption sectors; it can also produce outputs to areas outside the system. The energy transformation sector, which includes oil refining, power generation, and cogeneration, can utilize the primary energy produced locally or input (imported) from regions outside the system to produce the energy that will be used by secondary consumers, and part of this production is output (exported) to regions outside the system. The terminal consumption sectors, which include both industries that utilize energy and households within the city, utilize the primary and secondary energy from internal and external sources. In addition, urban energy metabolism includes recovery processes related to the recovery of byproduct resources, including the recovery of energy from primary and secondary energy production processes and from industrial and household processes.

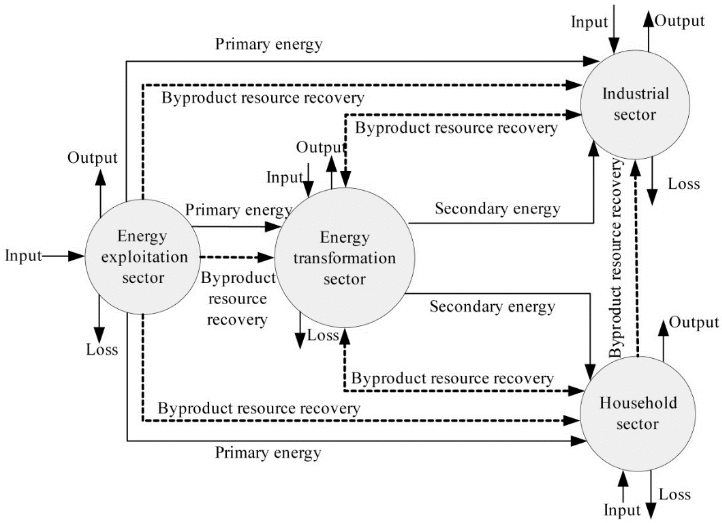

Fig. 2 Conceptual model of Urban energy metabolic system

2.2 Ecological network model of urban water metabolism

Using the trophic levels of natural ecosystems as a reference, we defined the compartments of the urban system as producers, consumers, and reducers, and determined the water flows among the system's components. Although urban systems are clearly not the same as natural systems, comparing them to natural ecosystems provides a simple metaphor that makes it easier to understand the meaning of the components and the flows among them. Based on this research, we developed a conceptual model of the processes in the urban water metabolism (Figure 3). In this model, the producers are the ecological environment and the artificial rainwater collection system; the consumers are the industrial, agricultural, and domestic sectors; and the reducer is the wastewater recycling system. Due to the complex chain of relationships among these components, each component may play different roles at different times; for example, although the ecological environment serves as a producer, it must also consume water resources to sustain its own operation and it must reduce wastewater that it receives from the urban system. Similarly, the wastewater recycling subsystem (the reducer) both purifies urban wastewater and provides regenerated (recycled) water to support the operation of the urban system (i.e., acts as a producer). These changes in the roles of components result in a reticular system structure rather than a linear structure. Although metabolism is a purely biological concept, it can be applied by way of analogy to cities because the urban water metabolic system is also a mechanism for processing resources and producing wastes. In this sense, cities function as “urban superorganisms” (Park 1936) that exhibit metabolic processes. Using the trophic levels of natural ecosystems as a reference that makes the large flows of matter and energy less abstract, we defined the compartments of the urban water metabolic system as producers, consumers, and reducers, and determined the water flows among the system's components.

In our model, there are clear links among the three key trophic levels: the local ecological environment, the terminal consumption sectors, and the wastewater recycling sector. The model follows all flows of water resources among these levels, but mainly reflects the utilization of fresh water, recycled water, and rainwater, as well as the reuse of water and the discharge of wastewater. The local ecological environment provides fresh water for the industrial, agricultural, and domestic sectors, but sometimes must also receive water from the external environment. The external environment includes neighboring regions located upstream from the study area within the same basin and other regions that are transferring their water resources to the study area as a result of large-scale hydrological engineering projects. In the case study we will subsequently discuss for Beijing, the external environment therefore includes upstream regions near the study area, such as the upper basin of the Hai River in areas such as Hebei Province, Shanxi Province, and Inner Mongolia. Water is also being transferred to Beijing through projects such as the Gangnan, Huangbizhuang, Wangkuai, and Xidayang reservoirs in Hebei province. Other transfers include the project to export water from the Chetian Reservoir in Shanxi Province, the Yangtze River, and the Huanghe River under the South-to-North Water-transfer Project.

Under the currently limited water supply, the city must consider in depth how best to utilize fresh water and reuse wastewater. The industrial wastewater and domestic sewage are all discharged into the wastewater recycling system. Part of the treated wastewater can be recycled to recharge the ecological environment and for irrigation of municipal green space, washing of streets, agricultural irrigation, and industrial utilization. Rainwater can also be collected to recharge the ecological environment and provide supplemental water for the industrial, agricultural, and domestic sectors. In addition, the industrial sector reuses much of its water to solve the problem of high water consumption. During the utilization of water resources, there is discharge of wastewater produced by the industrial, agricultural, and domestic sectors.

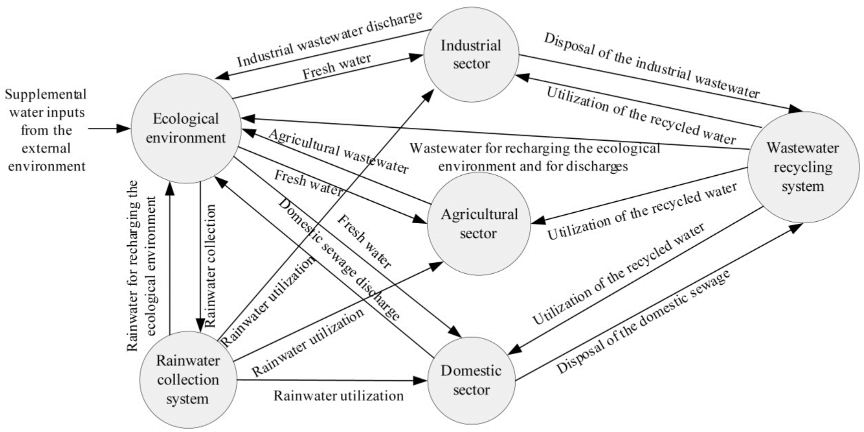

Fig. 3 A conceptual model of the water flows in the urban water metabolism.

3. Conclusion and Outlook

The emerging paradigm of sustainability in eco-cities planning worldwide is signaled by policies enacted by specific cities, counties, regions, and states. The sustainability paradigm is reflected in urban metabolic researches aimed at adapting to changing environmental, social, and economic conditions in the cities we study. Such eco-cities plans themselves have become part of the changing local and regional context, and like climate change, economic globalization, regional and international migration, and other large forcing functions, they must be taken into account in understanding eco-city plans. These cases studies will provide an overview of urban energy and water metabolic processes, and how to successfully accomplish the eco-city planning in face of the requirement of urban structure and efficiency. It will add a new dimension to the understanding and application of the concept of urban sustainability, based on hypotheses about the social and biogeophysical processes in several cities. These plans will employ methods like ecological network models. Ecological Network Models of feedback between social and biogeophysical processes linked through ecosystem services of ecological flows' quality and quantity, and storage identify variables and spatial patterns to be measured. The feedback models will also support the eco-cities' development of future scenarios. The ecological network models will draw on existing social, energy, ecohydrological, and ecosystem service modules but will be refined and operated for enhanced cross-disciplinary integration and prediction. These eco-city practices will enhance the understanding of eco-cities and eco-landscape as integrated, spatially extensive, complex adaptive systems and offer a sampling of planning practice common in this field.

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Photovoltaic electricity – promise, limits and potential for powering our cities

Marco Raugei

Department of Mechanical Engineering and Mathematical Sciences, Oxford Brookes University, UK

Corresponding Author e-mail: marco.raugei@brookes.ac.uk

Abstract

Since their first commercial introduction in the 1960s, photovoltaics (PVs) have been widely held and promoted as a quintessentially "green" technology that is flexible, easily scalable and which will soon allow us to tap into the limitless resource of sunlight energy and produce essentially zero-impact electricity at will. Fully realising such goal, however, has so far been elusive, because of a number of important caveats. Firstly, while the environmental impacts associated to the operation of PV systems are indeed negligible, on a full 'cradle-to-grave' life cycle scale PV electricity is still burdened by the energy, materials and emissions necessary for the production of the modules and balance-of-system components. Additionally, the inherently intermittent nature of solar irradiation means that PV power is only available during the daytime, and must be either supplemented by conventional (typically thermal) technologies, or complemented by often inefficient energy storage devices, in order to provide the end user with a dependable round-the-clock supply of electricity. Over the last couple of decades, however, significant advances have been made in reducing the material and energy inputs required for the production of the systems, while at the same time improving their energy conversion efficiency. This has resulted in striking reductions in the energy pay-back time and carbon intensity of PV electricity. If accompanied by not-yet-there but certainly achievable end-of-life recycling rates for the PV modules, and a reduced demand for energy storage due to optimal offsetting and integration with other renewable technologies such as wind power in 'smart grids', PVs are finally starting to look mature enough to be deployed on a grand scale – thereby fulfilling their long-standing promise as an optimal solution for powering our cities. Perhaps not coincidentally, in recent years there has been a surge of ambitious building-integrated PV installations in many major cities around the world. In London, for instance, a new "solar bridge" located across the River Thames and opened in January 2014 is expected to generate 50% of the energy requirements of the nearby Blackfriars railway station and to reduce its carbon dioxide emissions by 513t a year (vs. the average UK grid emission of 0.545 kgCO_2-eq per kWh). Also, a growing number of cooperatively owned solar projects at social housing sites, managed by Repowering London, have so far totalled 132 kWp of installed PV power.

AN ODYSSEY TO SUSTAINABILITY: THE URBAN ARCHIPELAGO OF INDIA

B.Sudhakara Reddy
Indira Gandhi Institute of Development Research.
Film City Road, Goregaon (E), Mumbai 400 065, India
Email:sreddy@igidr.ac.in

Abstract

The large urban agglomerates, often referred to as mega-cities, are increasingly a developing world phenomenon that will affect the prosperity and stability of the entire world in the future. The problems of mega cities include: (i) explosive population growth due to migration, (ii) alarming increases in the concentration of poor and jobless, (iii) massive infrastructure deficits in the delivery of services, (iv) pressure on land and housing, and (v) environmental concerns, such as contaminated water, air pollution, etc. Added to these is the impact of globalisation due to which, the role of cities as trading and distribution centres has increased as goods manufactured elsewhere needs to be moved effectively and efficiently to markets. Efficient utilization of natural resources and financing programs of maintenance and renewal of assets are challenges in themselves, and the strategies for such programmes need to be explored and developed. These issues are aggravated by serious deficits in the realm of knowledge and understanding on the dynamics of mega-cities, their problems and needs, and the policies required to make the cities sustainable[1]. The paradigm of sustainability has emerged as the key concern in regard to the future. Obviously, at the simplest level, sustainability is survival, but as human organizations and cities become more complicated, sustainability itself becomes more complex. For this we have to develop measures of sustainability using different indicators which help in simplifying complex information. These indicators play an important role in turning data into relevant information for policy makers and help in decision making. Indicators are now well established and are widely used in different fields and at various levels, viz., global, regional, national, and local levels. Examples of indicators include GDP (Gross Domestic Product) as a way of assessing economic development of city or a country, infant mortality rate (IMR) as an indicator of the health status of a community, or the rise in carbon emissions as a way of estimating the environmental conditions of a region. To be useful, indicators should be user-driven and depend on factors and the purpose for which they are used.

In the context of urban systems, the present study tries to investigate if the present pattern of development of megacities cities is sustainable. This is proposed to be done by performing an indicator-based evaluation of ten cities, viz., Mumbai, Delhi, Chennai, Kolkata, Bangalore, Hyderabad, Ahmedabad, Pune, Lucknow and Patna. In this context, the dimensions of economic, social, environmental and the governance of the urban systems are studied. The influence of various activities is analysed. The impacts will be measured in terms of various indicators such as growth, demographics, health, education, resource use, global climate change, urban design, etc. The comparison of the indicators of sustainability would enable us in identifying the positive and negative aspects prevailing in the system. This is expected to result in the development of a sustainable urban development index. The strategies adopted in achieving the positive dimensions will be studied, which will form the basis for suggesting alternative and workable model/approach to achieve the broad objective of making the megacities sustainable.

1 Sustainable urban development specifically means achieving a balance between the development of the urban areas and protection of the environment with an eye on equity in employment, shelter, basic services, social infrastructure and transportation in the urban areas.

Steps Toward a Working System for nZEB Concept - Ideas and Reality in Romanian Urban Area

Vasile Dogaru

West University of Timisoara, Nicholas Georgescu-Roegen Interdisciplinary Platform

E-mail: vasile.dogaru@e-uvt.ro

Abstract

The main pressures inside cities are generated by high energy consumption in buildings and density of population. The nZEB concept measures the net energy between the two parallel input flows, one from fossil fuels and one from renewable sources, in a dynamic optimization of its building parts (walls, roof, windows etc). The nZEB concept has not analytical explanations as closed working system. Some energy losses or discharges over system border are not explicitly (by definition) included and simultaneously correlated during the periodic yearly oscillations flows of recovered waste-energy: preheating or precooling of fresh air flows; partial recovery of heat from exhaust air polluted; partial energy recovery from fossil fuel burning for heating. The waste-energy flows and input energy flows are measured according to framework of Georgescu-Roegen matrix. The analysis considers two main cases in Romania of using energy from renewable for large buildings in Bucharest-Ilfov NUTS 2 region, helping us to understand analytically the new flows in a closed system. These flows can partially compensate in Romania the influence of temperature oscillations during the last and next decades. These measures can support the first stage implementation of nZEB systems in Romanian cities. The new design of the nZEB concept as closed system integrates and explains secondary energy flows for an improved human body comfort.

1. Introduction and methodology

The main pressures within cities are generated by high energy consumption in buildings and density of population (Bejan et all., 2011). Accordingly the new concept of nearly Zero Energy Buildings (nZEB) may serve as indicator of energy consumption in these buildings within urban areas. Discussions on the concept nZEB are focused on two main directions: the dynamic optimal cost that may be opposite to the static one (Dogaru, 2015), and the size of net flow/energy (European Commission, 2013; Georgescu-Roegen, 1971).

In terms of a common approach of nZEB general concept, the idea of studying one building with nearly zero energy consumption is similar to acknowledging an almost valid *perpetuum mobile* As a matter of fact more accurate determination of nZEB system borders – or at least of basic requirements – needs separate measurement for input flows of primary classical energy and renewable energy sources, and energy output flows. A closer analytical observation of measurement for energy flows inside of nZEB reveals that the calculus of net energy (Georgescu-Roegen, 1979), whatsoever source it may have been, is avoided or at least unexplained.

Conducting an appropriate analysis could partially prevent an initial misunderstanding on flow measurement[1]. Once defined the limits of nZEB closed system – it receives only energy, not matter –, we could be considered as observing more accurately the definition of nZEB concept. Certain countries, such as Belgium, in an attempt to measure normative levels required by European law (European Commission, 2010), identifies weakness in establishing analytical boundaries of the

[1] http://www.rehva.eu/publications-and-resources/hvac-journal/2014/022014/nzeb-definitions-in-europe/, last access on 24 March 2015. See also Annex Graph 1.1 in the present article.

concept. The purpose of the article is (1) to observe and to set some basic requirements to nZEB system borders, along with the renewable flows; (2) to analyze some issues of net energy measurement, inside nZEB system; (3) to discuss facts and ideas from Romania, starting from two energy-efficient buildings, that can stand for landmarks in establishing national standards for the nZEB concept.

The nZEB concept is hereby studied in relation to flows of thermal energy used for heating. This flow is considered necessary to individual satisfaction (basic necessity) and is significantly fluctuating compared to external environment of the system along one year (-15, +38) and along one day (+/- 20 degrees Celsius) in Romania. Within the research, these thermal energy flows include and analyze the ventilation ones and do not analyze the hot water and lighting ones. Thermal energy flows are defined at the same time with the determination of requirements for establishing more accurate spatial boundaries to nZEB system. In research are not noticed the time borders, analyzed in (Dogaru, 2015). The starting point of the present research is to minimize the consumption of nZEB system, through flows of classical and renewable energy. There are included new flows of capture and recovery of secondary sources of energy in the system or in its surroundings. The present analysis considered nZEB a closed system in weak sense, in terms of inventory through a more accurate measurement of input and output flows.

The analysis framework uses the matrix of flows-stocks of matter and energy for an economic process (Georgescu-Roegen, 1971). The matrix allows easier identification of flows, including the secondary ones for energy input and recovery of thermal energy necessary to heating. In summary nZEB system is analyzed for heating in two stages warm-cold air condition that reverses in terms of anthropomorphic utility along the three periods, within the action of entropy law.

2. Theory

The energy consumption is intensive spatially and anthropomorphically in cities (kWh / km2 and kWh / capita), rising the necessity of finding new integrated solutions for energy supply designed to buildings and facilities, in extreme conditions too. New nZEB systems could be aggregated through urban planning (Morar et al., 2014) and become an actual solution. Based on the precautionary principle, under these conditions a new macro-system nZEB city might provide separate operation. Total or partial temporary disconnection of such macro system from the electrical heating systems and national or regional gas supply can ensure city temporary operation during disasters or other extreme events in other regions (prolonged siege hypothesis).

According to the simple framework set by nZEB concept for the EU Member States, new buildings are supposed to comply with “nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby” (art. 2 Regulation 31/EC/2010). This definition includes two basic requirements: (1) “*nearly zero or very low amount of energy required*” for buildings. The first meaning of amount could be the total energy” and (2) this required low amount should be covered to "*a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby*”. The spatial area of the renewable sources is located inside of cities and, by definition in the sub-metropolitan or similar areas. As for the structure, “very significant” attribute can cover a majority of 60-80% in common terms, or over 30%, in statistical terms. From the point of view of statistical representativeness, unsustainable for nZEB concept, the samples it may be noticed only at few percent (3-5%). What such different percentage means for nZEB concept is not further explained in this research. By changing the ratio between two kinds of sources (classic and renewable) the nZEB system it is easy to notice the overlapping with other similar concepts: Net Zero Energy Buildings, Passive House or Plus Zero Energy Buildings.

The net energy flow noticed in nZEB system is a difference between the two flows, i.e. classic consumption of fossil fuels and renewable one. Although the main research directions are simultaneous approach of total consumption and of contribution from local renewable sources, maximum uplimits of these two usages are not sometime explicit and therefore treated apart. Thus only the difference seems to matter. Some countries adopted specified level of CO2 (United Kingdom), which limits the classic consumption. Under the nZEB concept umbrella in no circumstances is measured increase in CO2 emissions caused by device manufacturing for catchment renewable energy sources. So, the emissions are counted in r_1 or d_1 in table 2.1, which explains the relationship between the economic process and the environment.

Tabel 2.1 The Relationship Between the Economic Process and the Environment

Pr	(P_0)	(P_1)	(P_2)	(P_3)	(P_4)	(P_5)
Flow Coordinates						
CM	x_{00}	*	$-x_{02}$	$-x_{03}$	$-x_{04}$	*
CE	$-x_{10}$	x_{11}	$-x_{12}$	$-x_{13}$	$-x_{14}$	$-x_{15}$
K	$-x_{20}$	$-x_{21}$	x_{22}	$-x_{23}$	$-x_{24}$	$-x_{25}$
C	*	*	*	X_{33}	*	$-x_{35}$
RM	*	*	$-x_{42}$	$-x_{43}$	x_{44}	*
ES	*	$-e_1$	*	*	*	*
MS	$-m_0$	*	*	*	*	*
GJ	w_0	w_1	w_2	w_3	$-w_4$	w_5
DE	d_0	d_1	d_2	d_3	d_4	d_5
DM	s_0	s_1	s_2	s_3	s_4	s_5
R	r_0	r_1	r_2	r_3	r_4	r_5

Source: Georgescu-Roegen, 1979 and our note. *Note: where* P_i -Processes*:* P_0: transforms matter in situ, MS, into controlled matter, CM; P_1:produces „controlled" energy, CE, from energy in situ, ES; P_2: produces „capital" goods, K; P_3: produces „consumer" goods, C; P_4: recycles completely the material wastes, W, of all processes into recycled matter, RM; P_5: maintains the population, H. Pr- Products: CM- controlled matter; CE - controlled energy; K – capital; C- consumption goods; RM- recycled matter; ES- energy in situ ; MS- matter in situ; GJ- garbojunk (recyclable materials belong in garbage cans or in junk yards); DE- dissipated energy; DM- dissipated matter; R- "refuse" returned to the environment and consists in large part of available matter and available energy, but in a form that is not potentially useful to us at present;

The net energy in nZEB system has another starting point, according to Georgescu-Roegen (1979): "for the concept of net energy we do not have to distinguish between the various kinds of environmental energy, ES. In other words, it does not matter whether the net energy is derived from fossil fuels or from the wind, for example. Second, the dissipated heat must not be counted at all in computing net energy. That is, we must not add d_1 to the net output of energy x_{11}, or deduct d_i from the gross input x_{1i}". For the nZEB system are necessary to notice some special details: P_1 and P_3 are joining and P_5 works also inside of nZEB system. Georgescu-Roegen (1979) identifies from three directions to measure the net energy only viable one. The energetic analysis from this research does not follow subsequently the Georgescu Roegen scheme. This matrix is used to identify more accurate the new energy flows.

According to Regulations 31/EC/2010 and some report studies the CE product is simultaneously measured in processes P_1, P_3 partial and P_5 partial. The flows x_{11} and x_{13} are not noticed separate in the nZEB system. Also DE (d_i) has no distinct data/borders in nZEB. We will continue to notice the nZEB system having the unique purpose to clarify the concept definition. The nZEB system notices together the three processes from G-R matrix: P_1, P_3 and P_5. By joining the three processes, the analysis of the borders will hide the dissipated energy inside of system and, possible, do not notice some new sources.

Some EU countries have adopted air-conditioning as compulsory. Greece and Romania, by example, does not provide data in this regard. In a strong form, there is no explanation with respect to energy recovery from ventilated air, therefore the optimal cost can be calculated in a different way (by means of different elements) and the difference of 15% required by regulation between country measurement is not comparable. The study of an nZEB closed system using Georgescu-Roegen matrix-framework reveals that it is half-open through the window border (d_5), by example. When lacking energy recovery by ventilation, the system enables loss of thermal energy that is transferred slowly or fast through window or vent device open: d_5 is not transformed in x_{11}.

In chemistry systems, production of polyester copolymers, for example, there are similar issues, since energy recovery and efficiency are usually analyzed outside an integrated system. In addition the ones with chemical reaction are excluded from thermodynamic study, so that just the mixing ones still remain under the laws of thermodynamics. Analytical observation of chemical system efficiency can develop within the analytical framework provided by Roegenian matrix. Setting up an nZEB system by studying each input is a high necessity to chemical systems because they underlie, in one way or another, every item that nZEB systems will include.

The measurement of nZEB concept in the heating area could be modelled according to framework of Georgescu-Roegen matrix, by taken into consideration these secondary flows of input and output energy. The new energy flows observed at the borders of the nZEB system or in its immediate vicinity can be captured partially. They could be modelled in an integrated nZEB system: 1. Energy loss through natural or forced ventilation out of system should be minimized by partial recovery of energy from polluted air exhausted, according to Roegenian matrix. It is used an exchanger recovery heat. The basic requirement of energy output in the system nZEB is that energy have to be recovered at the maximum. 2. In the new system nZEB the heating produced by fossil fuel burning generates energy loss unrecovered simultaneously. A recovery device could provides a 40-55% recovery of heat, from 90-93 to 45-52 degrees Celsius in winter and also in intermediate season from October /November to March / April. 3. The energy input of air preheating by ground heat exchanger during at October/ November to March/April can increase the air temperature in the system with 3-12 degrees Celsius, between minus 6 and 10 degrees Celsius. The energy from air is taken directly from the atmosphere in September-October and April-May. The energy from air may be pre-cooled with 6-12 degrees Celsius starting to June until end of August, from 26-38 degrees Celsius to 20-28 degrees Celsius. Data from the experiment have a similar level with the some studies ones (Ivan Gabriel, et al, 2011). A mix of three flows assures at the system entrance an overall increase compared to the outside air temperature to 4-14 degrees Celsius, according to analytical observations (Borza, 2011; Nastase, 2009; Cotorbai at al, 2009; Polizu, Radu, 2013).

3. Some measurements, results and discussion

Some studies[2] of the EU countries show weakness in the setting of viable conditions for mixing the two types of energy sources. Other studies identify less effect on the partial implementation of some elements (Brata et al., 2012) of the system and lack of energy recovery in nZEB system in Romania.

The analyse of using energy from renewable sources (ground sources heat pump in a closed loop) for two large buildings in Bucharest-Ilfov NUTS 2 region, help us to explain the analytically integration of the secondary flows in closed nZEB system. In both cases the supplementary air conditioning-ventilation devices integrates the new energy flows. The results in the two cases could be noticed in table 3.1.

Table 3.1 The basic figures of two large buildings in Bucharest-Ilfov NUTS 2 region, 2007-2009

	Area (sqm)	Consumption from renewable source (%)	kW/sqmy-1	Unitary maintenance costs (UMC) Euros/sqm
PBV2	3507	79**	47.8	3.48
PBV1	*5231*	*28***	*260.1*	*10.46*
AMVIC Building	1905	60-90*	13.93	…
*AMVIC Building**	*1905*	-	*220**	…

Case 1 - PORSCHE Bucharest West 2 (PBV2). Reference case 1- PBV1 (classic energy source) Source of data: Polizu et al, 2007 (and Polizu, 2012**). Case 2- AMVIC Building. Reference case 2 *AMVIC Building**. Source of data: Ivan Gabriel, et al, 2011.*- our estimation; sqmy- square meters yearly; … – no data;

PBW1 has an HVAC system based on a classic natural gas central heating and Air-to-Air heat pump, multi VRV type. PBW2 has a geothermal HVAC system, based on Water-to-Water and Water-to-Air heat pumps (Automatic Changeover), connected to a ground heat exchanger, BHE type (Borehole Heat Exchanger). In terms of energy performance of the two buildings analyzed, only PBW2 meets the requirements imposed by Directive 2010/31/EC, meaning more than 50% of heat produced from RES and by Directive 2006/32/EC Recast energy to saving of over 20% in primary energy used for building (heating, cooling, ventilation and domestic hot water).

[2] http://ec.europa.eu/energy/en/topics/energy-efficiency , Belgian National Plan - Nearly Zero Energy Buildings - Implementation European Energy Performance of Building Directive, Brussels, September 2012 - Last access on 24 March 2015.

An air temperature increase by the contribution of these secondary flows in Romania inside of nZEB system indicate us an energy increment in the cold season and a reduction in the warm season. The differences could compensate partially in Romania the influence due to temperature oscillations during the last and next decades. By adding these flows at/to nZEB system, it is simultaneously possible to prevent heat loss from exhaust air polluted – 30-50% by windows or air vent input.

The nZEB system now includes secondary flows described, that have different efficiency in the three cyclical periods of the year: warm, cold and intermediate. In nZEB system are introduced some simple devices, as valves, heat recovery device for exhausted gas and device for polluted air. The nZEB system enables increased efficiency through the new secondary captured flows and generates along these periods different consumption and transfer efficiency. The results of studies about the use of classical and renewable sources in validating nZEB systems are significant for two types of buildings. Studies can be benchmarks in determining national levels (in Romania) of the nZEB figures about juridical rules.

4. Findings

In urban agglomeration the relation between energy and dense population (kWh / capita and kWh / capita) generates a specific design for nZEBs systems: the pressure requires the capture for each local renewable energy sources. The separate analysis flows (Georgescu-Roegen, 1979) become a goal in nZEB system by overcome the sharing between classical and renewable sources. Under these terms net energy calculus in nZEB system is a simple mathematical difference.

The analysis for determining a more accurate analytically borders of the concept nZEB, for P_1,P_3 and P_5 processes form G-R matrix, has identified new local sources of secondary renewable energy that were not explicit in Regulation 31/EC/2010. These sources were integrated together according to setting of appropriate parameters for the three periods in Romania, taking into account the temperature difference between the nZEB system one and the earth one (ground source). The combination of the three local sources could provides a constant minimum capture of energy. In weak way these sources are similar as renewable energy ones in Whole economic process (Georgescu-Roegen, 1971). They are in line with European innovation strategy: we do not reinvent the wheel. [We only do more efficient wheel in operation.]

The analysis of nZEB as system allows to fixing better its spatial boundaries to identify transfers into system to energy flows and energy-waste. Some evaluations regarding secondary captures of thermal energy that can be integrated in nZEB system could compensate the increased energy due to periodically extreme weather (temperatures, tornadoes) for Romania in the last 5-10 years. Energy waste of nZEB system can be recovered partially. The figures about the two buildings support the implementation first stage of nZEB systems in the Romanian cities to set the national laws. The two cases analyzed in Romania shows a large potential of increasing of energy consumption efficiency. The new design of the nZEB concept as closed system integrates and explains secondary energy flows for an improved comfort of human body.

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[3] http://rtsa.ro/tras/index.php/tras/article/download/94/90. - Last access on 24 March 2015.

[4] Also the study Polizu, Radu, 2012, *PORSCHE BUCHAREST WEST2 V.S. PORSCHE BUCHAREST WEST1 - INFLUNCES OF GEOTHERMAL HEAT PUMPS ON ENERGY PERFORMANCES OF BUILDINGS, ENVIRONMENT PROTECTION, INVESTMENT COSTS AND EXPLOITATION*, http://geoexchange-romania.ro/ORADEA%20PBW1%20VS%20PBW2%20EN-2012%20iunie%20ARTICOL.pdf, Last access on 24 March 2015.

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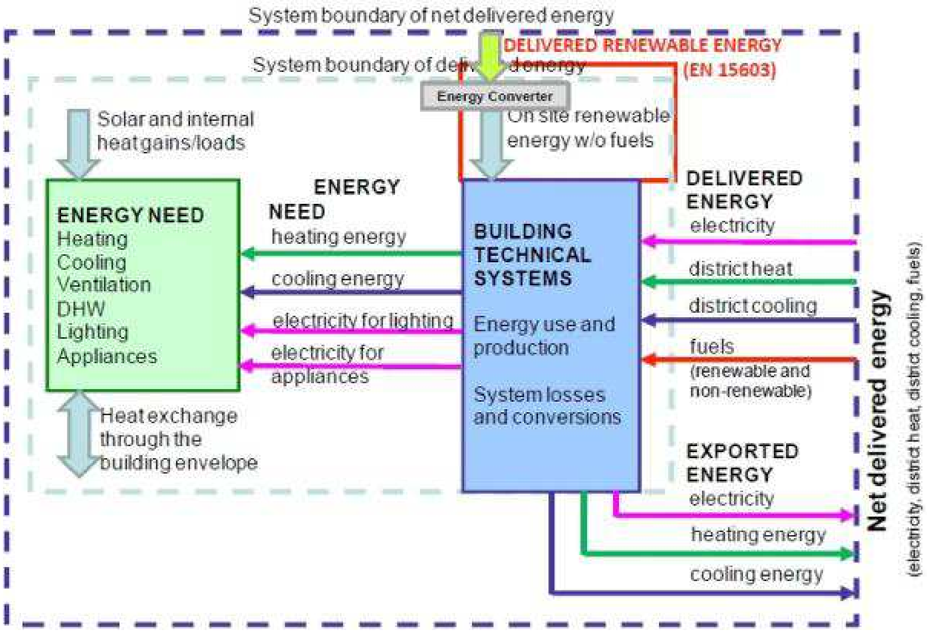
Annex graph 1.1 Detailed energy boundary of net delivered energy for nearly zero-energy buildings, in European Commission, 2013, initially source [REHVA, 2012]



Note. The box of "Energy need" refers to rooms in a building and both system boundary lines may be interpreted as the building site boundary. Source [REHVA 2012].

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The impacts of spatial organization and community based energy production on sustainable energy use

Petra Wächter

Institute of Technology Assessment of the Austrian Academy of Sciences

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Corresponding Author e-mail: petra.waechter@oeaw.ac.at

Abstract

Energy as the basis for daily activities on an individual level and for economic activities on a societal level gives fundamental importance to our lives. Therefore, individual decisions on the consumption of goods and services not only determine the energy use but also have impacts on the overall performance of economic structures. As economists point out that energy use and economic growth are mutually connected any change in energy consumption patterns influences the economic system of a society. The paper wants to draw the attention on individual innovations in the daily energy practice. More concrete, two examples of the field are further explored: one deals with energy demand related to space by analyzing possibilities that multifunctional settlements offer in the organization of less energy intensive practices such as food cooperatives etc. The other example focuses on the supply side of energy by analyzing the engagement of urban communities in providing sustainable energy. The paper aims to give an overview of these two examples by analyzing the most recent literature in the field and by critically reflecting their results.

Setting up more potential meeting places for citizens than in mono-structured settlements makes them a starting point for interaction and makes them a valuable basis for the creation of a sense of community. These kinds of activities can be organized in a self-esteemed and democratic way, so the citizens themselves can make decisions over resources and services. The objectives are to take some of the power from the markets and the state into the hands of people from the community and to increase the community‘s self-reliance. This practice also provides a step towards more societal cooperation instead of ongoing individualization and contributes to a rise of social capital. Moreover, multifunctional settlements provide a chance to increased self-sustaining economic networks reducing the social dependence on economic growth.

On the supply side, community based energy production has shown to be a valuable contribution to citizen participation in addressing sustainable energy issues. Decentralised energy models where energy is generated, stored and consumed locally provide a greater security and also quality of energy supply. Moreover, these energy projects are multi-faceted and they rarely address only one technology or one aspect of behaviour and rather combine behavioural initiatives with efficiency measures by micro-generation. One of the most important factors at this community level is that it brings together groups of people with a common purpose in which the engagement of people has a profound impact on the way energy is seen because it could be observed that there is less perceived separation between consumers and energy generation.

Improving recycling and reducing energy poverty by exchanging waste for electricity in Latin America

Angelo Facchini[1*], Renata Mele[1], Laura Montanari[2], Odailton Arruda[3]

[1] Enel Foundation, Rome, Italy

[2] Enel, Rome, Italy

[3] Coelce, Fortaleza, Brasil

Corresponding Author e-mail: angelo.facchini@enelfoundation.org

Abstract

Access to modern energy services and energy poverty are two important issues in informal settlements, where people in the lower income bracket live and spend a relevant percentage of their total income for energy-related services. Together with energy poverty, slums dwellers suffer from poor living conditions, and is not unusual finding large waste disposal areas near their settlements.
In this paper we describe and report the results of a series of initiatives developed by Enel in Brasil and Chile, that, in the last years, successfully represented a solution for both problems of waste disposal and energy poverty: the exchange of recyclable trash for electricity.
We focus on the direct implication that the initiatives have on the local populations in terms of billing reduction, and on the local utilities in terms of theft reduction. Finally, we also discuss the environmental benefits in terms of pollution and waste management, together with the improvement of the socio-economic structure of the settlements by looking at the inclusion of the people involved, and at the creation of new bottom-up economies based on waste recycling.

1. Introduction

The 21st century is the century of the city. Since 2007, more than half of the world's total population lives in cities, and this share is expected to increase to 60% or more by 2050. Meanwhile, the urban population is expected to increase from 3.5 billion in 2010 to 6.5 billion in 2050. During this period, cities in developed countries will host only 160 million more people, while cities in developing countries will absorb close to 2.5 billion people, almost doubling their global urban population (Angel, 2012).

This impressive urban growth is essential for our future development. Cities are one of the main engines of development, concentrating in a relatively small area minds, cultures, innovation, economies, and network of relationships. On the other side, cities also concentrate some of the worst characteristics of urbanization, such as inequalities and very poor living conditions in large peri-urban areas, where people laying in the low and very low income bracket live. These areas are usually known as 'slums', or 'informal settlements', and include a wide variety of highly populated areas characterized by substandard living conditions and squalor. Slums are usually found in peripheral areas of large cities of developing countries, where large cities in Africa, Latin America and Asia are usually surrounded by an informal area of settlements in which dwellings may vary from simple shacks to more permanent structures, mostly characterized by limited (or sometimes missing) access to basic services such as clean water, energy, education, and sanitation.

According to recent data from UN-Habitat, informal settlements dwellers around the world, are estimated to be about 863 million, slightly less than one third of total urban population (UN-Habitat, 2013).

Urban population living in slums is also unevenly distributed. By example, UN-Habitat estimates that in Africa about 70% of urban population lives in slums, while in

Asia and Latin America the figures are different (30% in Asia and 24% in Latin America)[1].
Slum eradication and improvement is also crucial topic in the Sustainable Development Goals, and the evolution of slums towards formal settlements is a key topic that can be also achieved by ensuring the access to modern energy services to slum dwellers. In fact, together with energy access, energy poverty, defined as the “inability to cook with modern cooking fuels and the lack of a bare minimum of electric lighting to read or for other household and productive activities at sunset” (Sovacool, 2012)[2], is one of the relevant barriers in slums.

It is straightforward that availability of electricity connection, together with efficient and clean cooking systems, are key elements for socio-economic slum development. Focusing on electricity, access to affordable sources is still an issue because of barriers that constitute a sort of ‘vicious circle’ that prevents a fruitful cooperation between utilities, slum dwellers, and local authorities (Schnitzer et Al., 2014; Mimmi, 2014; Butera, 2015).

Among the barriers, the two most relevant of them are the connection fee and the inability to pay regularly. Both barriers are direct consequence of the informal nature of the settlements: people in the low income bracket cannot enter in formal agreements, and, because of their occasional income, cannot pay a regular bill. As a consequence of this, many families opt to pay a neighbor to share a meter or turn to unlicensed electricians and even local cartels that can provide the service illegally (common forms of stealing electricity include tapping electricity directly from the distribution feeder and tampering with the energy meter). For further information on these topics the reader is referred to (Depuru, 2010; Mimmi, 2010; Smith, 2004).

In this paper we present the initiatives and report the main results of a series of initiatives developed by Enel in Brasil and Chile, that, in the last years, successfully challenged the topic of energy poverty in informal settlements of Fortaleza, Rio de Janeiro, and Santiago de Chile. Section 2 provides a focus on Brazil and Chile, describing the socio-economic context, the main aspects of the initiatives Ecoelce, Ecoampla, and Ecochilectra, providing the main results achieved. Finally, in section 3 we state our conclusions.

2. Reducing energy poverty by exchanging waste for electricity

Focusing on Latin America, Figure 1 shows that the percentage of slum dwellers varies in a wide bracket, ranging from 70% of Haiti to 9% in Chile and 4% in Suriname.

In Latin America, the physical access to electricity is generally available at high percentages (as shown in table 1), and access to modern electricity service is a matter of affordability and still a challenge for slum inhabitants, that usually rely on low quality energy sources, on electricity theft, or to informal service providers for their needs. In particular, relying on poor energy sources for cooking has direct impact on the health of the dwellers (WHO, 2004), while relying on electricity theft affects the utility company and then its customers, being them both informal and formal.

[1] http://unhabitat.org/wp-content/uploads/2014/07/WHD-2014-Background-Paper.pdf
[2] Conventionally, energy poverty starts when the fraction of income used for energy related services (e.g. cooking, lighting, etc.) is above 10%.

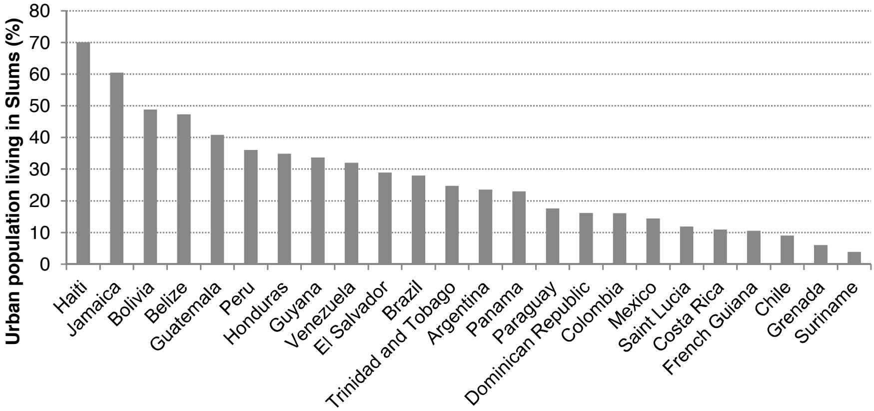

Figure 1 Percentage of urban population living in slums in the Latin America and Caribbean Region (Source: EF elaboration based on UN-Habitat Urban-Info Data – Data are from 2005 excluding Haiti, Bolivia, Guatemala, Peru, Brazil, Argentina, Dominican Republic, Colombia, Mexico, provided for 2007)

Table 1 Percentage of population with access to electricity in LAC (2012 - EF elaboration based on WB data)

Country	Electricity access (%)	Country	Electricity access (%)
Argentina	96,28%	Honduras	85,57%
Bolivia	88,19%	Mexico	99,2
Brazil	99,49%	Nicaragua	72,52%
Chile	99,6	Panama	89,12%
Colombia	96,99%	Paraguay	98,45%
Costa Rica	99,0	Peru	90,77%
Ecuador	94,00%	Uruguay	99,1
El Salvador	91,96%	Venezuela	99,66%
Guatemala	84,66%	Average	93.39%

In fact, electricity theft overloads the generation unit, and, in addition, adversely affects the quality of the supplied electricity, as the utility company has no estimate about the quantity of electricity to be supplied to genuine customers as well as to illegal consumers. This overload might result in over voltage affecting the performance and even damaging appliances of customers. In extreme cases, the amount of non technical losses might trip the generation unit, which interrupts power supply to all customers (Sullivan, 2002).

Escaping from this situation is a complex process that involves a wide spectrum of actors (especially utilities, informal settlements dwellers, private firms, and local authorities). In Brasil, a contribution to overcome this situation has been implemented by one of Enel local electricity distribution companies, Coelce (Companhia Energética do Ceará), that in 2007 launched the initiative 'Ecoelce', a

program that allows the exchange of recycled solid residues for a bonus in the electricity bill.
Access to electricity in Brasil is among the highest in Latin America, and major issues come from the high rates of insolvency and electricity thefts. Furthermore, under the environmental point of view, slums often lay near large landfills, and dwellers suffer from diseased derived from residues not properly collected. Despite federal laws for the correct and environmentally sound waste disposal[3], solid waste management in Brazil still shows a deficit, as also stated by the Panorama of Solid Waste in Brazil in 2013 (ABRELPE, 2013), reporting that the country registers the presence of dumps in all states, and that about 60% of Brazilian municipalities still send their waste to inappropriate areas. It addition, only 58.3% of the collected municipal waste are disposed of properly. It is also stated that, for the correct operation of a waste management system, together with a suitable disposal system, some preliminary actions are required for an appropriate disposal of solid waste. Among these activities, the separation of waste and the selective collection of the same are important steps that facilitate the recycling processes.
The program Ecoelce[4] works exactly in the direction of separating residuals, and represents a new socio-environmental paradigm, resulting both in the preservation of natural resources and in a new form of treatment and payment of electricity bills for the low income population.

To participate in the program, the customer is directed to a Collection Point to the receive the ECOELCE card which has the identification of the Consumer Unit that will receive the bonus.

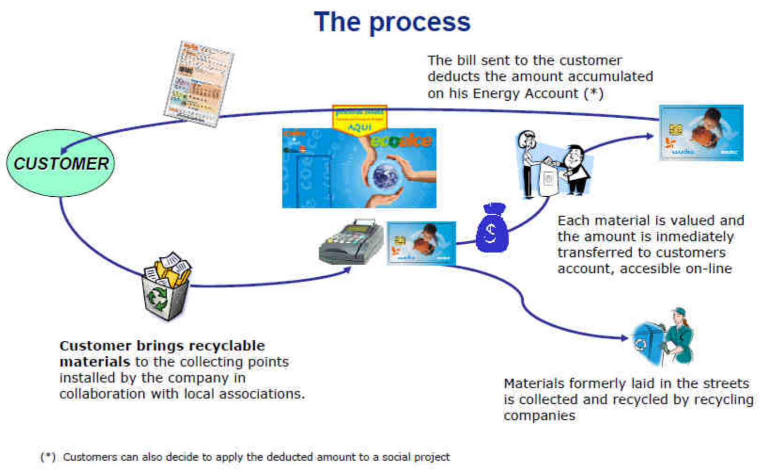

Figure 2 Working scheme of Ecoelce

Figure 2 shows how the system is organized: a number of collecting stations (mobile or fixed) are distributed on the territory and in permanent communication with a central server. A client of the company can join the initiative and an electronic card, like a POS, is assigned to him. People then collects recyclable waste bringing it to the collecting station, where it is weighted and automatically transformed into points.

[3] Federal Law 12,305 / 2010, which established the National Policy on Solid Waste (PNRS).
[4] https://www.coelce.com.br/coelcesociedade/programas-e-projetos/ecoelce.aspx

Points are then directly transferred to an electronic card as credit, which is used to calculate the discount on the client's energy bill. The collection sites are fully automatic, the interaction is very intuitive and, more relevantly for the security of the user, does not involve the exchange of money.

Materials collected are paper, glass, iron, plastic, and car batteries. Each garbage has a specific rewards computed according to the typology of the collected waste. In particular, material such as aluminum and copper are paid more with respect to plastic and paper. Table 2 reports the remuneration for the above mentioned materials.

Table 2 Payback for type of residual collected

WASTE	TYPE	UNIT	PRICE R$	WASTE	TYPE	UNIT	PRICE R$
BRONZE	METAL	KG	2,70	WHITE PAPER	PAPER	KG	0,12
BRASS	METAL	KG	2,50	NEWSPAPER	PAPER	KG	0,07
COOKER	METAL	KG	1,70	CARDBOARD	PAPER	KG	0,07
ST. STEEL 304	METAL	KG	1,50	MIXED PAPER	PAPER	KG	0,06
ALUMINUM CAN	METAL	KG	1,50	PVC	PLASTIC	KG	0,40
BATTERY	METAL	KG	1,00	HOSE	PLASTIC	KG	0,30
CAST ALUMINUM	METAL	KG	0,90	PET	PLASTIC	KG	0,25
ANTIMONY	METAL	KG	0,75	PLASTIC FILM	PLASTIC	KG	0,20
LEAD	METAL	KG	0,70	TETRA PAK	TETRAPAK	KG	0,04
CAN STEEL	METAL	KG	0,35	COCA LITER	GLASS	UN	0,50
ST. STEEL 430	METAL	KG	0,30	BEER	GLASS	UN	0,40
CAST IRON	METAL	KG	0,20	WHITE LITER	GLASS	UN	0,20
BEATEN IRON	METAL	KG	0,10	LITER BLACK	GLASS	UN	0,20
OIL	OTHER	LT	0,30	BOTTLE POT	GLASS	UN	0,05

Nowadays, there are about 30 collection points in Fortaleza, and more than 100 in the whole state of Ceará, distributed in more than 29 municipalities. Since 2007, the program accounts for over 18,500 tons of trash properly disposed, over 430,000 families benefiting from the project, and about 800.000 Euros of bonuses granted in the electricity bill (equivalent to 70.000 MWh of Energy).

2.1 Replication in Rio de Janeiro and Santiago de Chile

The initiative has been replicated in Rio de Janeiro and Santiago de Chile. 'Ecoampla'[5] is the name of the initiative developed by Ampla, Enel company in Rio de Janeiro. As of today, the program, started in 2008 and present with 25 collection point, accounts for more than 4,800 tons of waste collected and more than US$ 300,000 in energy bonuses accounted. Residues that are more collected in Ecoampla are: paper, cardboard and paper with 51%, then 14% glass, Pet 8%, plastic 4%, and aluminum 2%.

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[5] https://www.ampla.com/ampla-e-a-sociedade/programas-e-projetos/consci%C3%AAncia-ampla/consci%C3%AAncia-ecoampla.aspx

'Ecochilectra'[6], developed by Chilectra, the Enel company in Santiago de Chile is started in 2010 through an Environmental Education Center located in Peñalolén. During these years a model of mobile operation has been developed, involving about 24 stations distributed in the municipalities of Santiago, Recoleta, Quilicura, Peñalolén, Providencia, and La Florida. Ecochilectra collected over 600 tons of recyclable material and awarded more than US$ 15,000 in energy bill savings. Families participating delivered on average 16 kg of recyclable material per month, and more than 21% of them donated to one of the foundations participating in the program their discount.

3. Conclusions

In this paper we described relevant initiatives that companies of Enel Group are developing in low-income urban areas in Latin American cities. Affordable access to modern energy and electrification is a key topic for developing poor areas, and benefits for the low income population are straightforward: exchanging waste for electricity contributes to the generation of income and liquidity, as well as contributing to reducing the electric clandestine connections and the diseases caused by the pollution of the solid residues exposed to the environment.
More specifically, the initiative contributed to:

1. Improve the quality of life of slum dwellers, enabling their access to affordable electricity and providing profitable occupation in areas of risk (more than 200 working placed generated, together with the formation of a bottom-up economy based on recycling);
2. improve the quality of services by reducing the power outages, increasing the payment rate by 60%, and reducing by 30% the electricity theft;
3. guarantee the citizenship, thinking which counts of energy and of other public utilities indicate and confirm the dwelling.
4. reduce the environmental impact provoked by the solid residues, lifting up his rate of recycling and economy of energy.

Furthermore, the companies also benefit from the recognition for their social and environmental responsibility, as well as from improving the quality of life of its customers and the sustainable development of the region. On the customer side, the initiative provides a cultural change in the population, allowing for the knowledge of the use and reuse of the natural resources and for the real contribution of his acts for the life of the new generations.
Finally Ecoelce has received awards by Brazilian and international institutions, and has been elected by the UN Global Compact as one of the most important projects of the Latin American area. Its replication potential and its ability to solve at the same time more issues related to the 'vicious circle', make the exchange of recyclable waste for electricity a paradigmatic business model for utilities operating in poor urban areas.

[6] http://www.chilectra.cl/wps/wcm/connect/ngchl/ChilectraCl/Hogar/TrabajandoComu/ecochilectra

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Size and the City – The potential of downsizing in reducing energy demand and increasing quality of life

Gesche M. Huebner*[1], David Shipworth[1]

[1] Energy Institute, University College London

Corresponding Author e-mail: g.huebner@ucl.ac.uk

Abstract

Recent decades have seen a tremendous growth in the population, particularly in cities. London, for example, has increased from about 6.8 million to 8.2 million over 20 years from 1991 to 2011. Additionally, we have seen substantial demographic change, with an increasing life expectancy and other factors resulting in a larger number of households with only one or two people. One consequence of this is that older people can end up living in inappropriate housing being too large for their needs, with high heating bills and stairs restricting mobility. In addition, this also contributes to the decreasing availability of housing for the growing population. Ultimately, this can lead to unnecessary use of energy and carbon emissions.

One potential approach would be to promote downsizing amongst those who live in larger-than-needed properties (defined in relationship to a standard). Some people might desire to live in large properties – for those the question might be how downsizing could be rendered an attractive option. For those keen on downsizing, the question is more how it can be realized, i.e. what barriers need to be removed and what help given. In any case, for those who downsize, this could result in significant release of equity (for home owners) or reduced rent, in addition to lower bills and potentially more suitable accommodation in terms of access and mobility. Potential benefits for the wider population would be greater availability of housing stock.

This paper will address this issue in different ways. Firstly, empirical data will be presented on the effect of housing size on energy consumption. A sample of N = 991 households, approximately representative for the English population, is analysed with regard to the impact of housing size and housing type on energy consumption. Results show that those two predictors are of greatest importance, and together explain about 29% of the variability in the log-transformed annual energy consumption, surpassing all other variables. In addition, the analysis calculates the amount of under- and overpopulation of housing to give an estimate of the distribution of living space. Secondly, the paper will discuss the benefits of downsizing for the population. A detailed literature review is performed. The results address the benefits of downsizing and highlight which factors would promote downsizing. One issue that has been shown previously, was that those who could downsize felt that little adequate alternative housing was available. Also, general potential effects are discussed, such as freed up living space, and issues of intergenerational justice. Thirdly, the paper will look beyond downsizing at other options such as co-housing, creating multiple-generation homes, or taking a lodger. The prevalence of these schemes will be discussed, and their potential highlighted.

1. Background

Energy use in buildings is one of the largest contributors to global and local energy consumption. In the UK, domestic buildings are estimated to be responsible for 26% of total carbon emissions (Palmer & Cooper, 2012). The UK Government established the goal of reducing emissions from homes by 29% by 2020 (DECC, 2009). Energy efficiency improvements in UK homes form a central part of the decarbonisation plans, with millions of retrofits of domestic homes planned over the next decades (UK CCC, 2010). However, a potential driver of domestic energy consumption not covered by Government policy is under-occupancy, i.e. when a household has more space / rooms than it would need. This paper shows the impact of building size on domestic energy consumption, exemplifies the differences in energy consumption for single-person households with varying numbers of rooms, shows the extent over under-occupying, and discusses benefits, challenges and alternatives to downsizing.

2. Empirical findings

We present data on the importance of building size vs. household size on domestic energy consumption. We then show the amount of over- und under-occupying in the UK, before exemplifying how energy consumption could change if occupants had fewer rooms. We used nationally representative samples from England for data analysis; the Energy Follow-Up Survey (EFUS) and the English Housing Survey (EHS). They collected data about the dwelling and household characteristics and behavior. Gas and electricity meter readings were obtained to estimate annual energy consumption. N = 991 households were analyzed. Correlational analysis was used to understand the relationship between energy consumption, dwelling size, and occupancy. Regression analysis tested the impact of the different predictors on (log-transformed) annual energy consumption. Selecting subsamples of the data set, we showed the impact of living in a larger then needed property.

2.1.1. The effect of building size

The correlation between building size, measured in m^2, and energy consumption (kWh) was $r = .49$. The correlation between household size and energy consumption was $r = .34$. Only a weak correlation existed between household size and building size of $r = .27$. Then, linear regression was carried out. For a model only encompassing dwelling size, the $R^2 = 25\%$; i.e. 25% of the variability in energy consumption is explained by building size. Adding dwelling type, increased the amount of explained variability to adjusted $R^2 = 29\%$; $F(5, 985) = 84.34$, $p < .001$. A model only using household size as a predictor explained 11% of the variability in energy consumption. A combined model using house size, dwelling type, and household size showed an adjusted $R^2 = 33\%$; $F(6, 984) = 82{,}86$, $p < .001$. Table 1 shows unstandardized coefficients and their standard error (B, SE) and standardized (β) regression coefficients. Note that despite the moderate correlation between household size and floor area, there was no issue of multicollinearity (all VIF < 1.6).

Table 1. Regression coefficients and standard errors (B, SE, β). *** indicates significance at <.001

Predictor	B (SE)	β
Dwelling size (m2)***	0.005 (< 0.000)	0.357
Dwtype (Ref= Detached): Flats***	-0.351 (0.057)	-0.223
Dwtype: EndTerrace	0.029 (0.055)	0.016
Dwtype: MidTerrace	-0.067 (0.050)	-0.046
Dwtype: Semi-detached	0.026 (0.043)	0.021
Household size***	0.089 (0.012)	0.199

Hence, the analysis as above clearly shows that dwelling size has by far the largest impact on domestic energy consumption, with a standardized coefficient being about 70% higher than that of household size. Flats use significantly less energy than detached houses. A full regression – for brevity not included in this paper (see Huebner et al., forthcoming) – shows that when controlling for a range of other building-related variables, the basic finding stays the same: Dwelling size trumps all other factors.

2.1.2. Over- and under-occupying

The correlation between how many bedrooms a household has and how many it needs to meet its minimum requirements was only $r = .33$, indicating that a large share of households have more or fewer rooms than defined under the bedroom standard (ONS, 2014) as actually being needed. The DCLG (2013) reports that the overall rate of overcrowding in England in 2011-12 was 3%. Overcrowding rates differed considerably by tenure: 1% of owner occupiers, 7% of social renters, and 6% of private renters were overcrowded. Around 8.0 million households were estimated to be under-occupying their accommodation in 2011-12, i.e., they had at least two bedrooms more than they needed according to the bedroom standard. Around half (49%) of owner occupiers were under-occupying compared with 16% of private renters and 10% of social renters. A further 7.7 million households had one bedroom more than they needed under the bedroom standard. It is noteworthy that the bedroom standard sets out minimum criteria: A separate bedroom is allowed for each married or cohabiting couple, any other person aged 21 or over, each pair of adolescents aged 10-20 of the same sex and each pair of children under 10. However, even if ‘granting’ one spare bedroom, then still 8.0 million households, 36% of the population would be under-occupying.

2.1.3. Example of potential for downsizing

For ease of communication, we exemplify the effect in terms of number of bedrooms in the subsample of all homes with a single occupier. Figure 1 shows how average annual energy consumption varies with the numbers of bedrooms, calculated with the EHS data. Data show an approximately linear relationship; for each additional bedroom, energy consumption increases by roughly 3750 kWh.

Figure 1. Annual energy consumption per number of bedrooms in a single-person household.

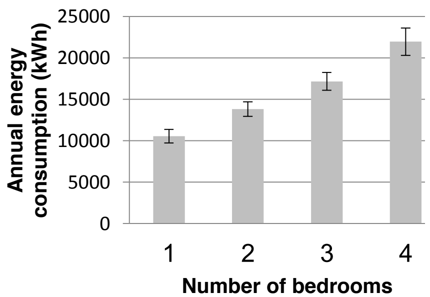


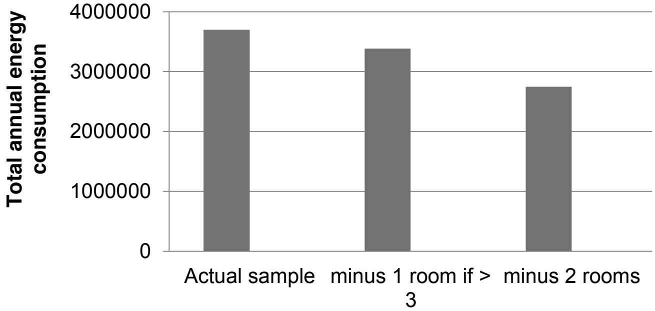
Table 2 shows how what share of single-households have how many bedrooms, in the actual sample, and in two downsizing criteria.

Table 2. Prevalence of number of bedrooms in sample and scenarios.

No bedrooms	Energy consumption (kwH) p.a.	% in sample	% if those with 3 or more rooms downsized by one room	% if all downsized by two
1	10548	24.12	24.12	95.72
2	13809	41.25	71.6	4.28
3	17159	30.35	4.28	
4	21947	4.28		

Figure 2 shows the changes in the sum of annual energy consumption for all single-person households in the actual sample and the two downsizing scenarios.

Figure 2. Total annual energy consumption in the different cases.



Hence, even a very lenient downsizing would result in an energy reduction of 8%, and reducing by two rooms to a reduction of about 25% in energy consumption in the sample of single-occupancy households. Of course, this analysis has limitations; it does not account for differences in, for example, building quality, and is based on a sample with only with a limited number of cases (N = 257 single-person households). But even assuming a wide error margin, this would still be a significant reduction, and illustrates the potential for energy savings through downsizing.

3. Issues around downsizing
    3.1. Benefits of downsizing

Given the national targets of reducing energy consumption, one obvious benefit would be lower energy consumption if downsizing were to be realized. A complete and detailed analysis of the energy saving potential is beyond the scope of this paper; however, the example as above illustrates the potential for significant reductions in energy consumption. If underoccupying and overcrowding balanced each other, redistribution of housing would not result in energy savings; however, given that under-occupying is so much more prevalent than overcrowding, there is presumably a huge potential for energy savings if alternative, smaller housing was available. Other benefits include a greater availability of housing stock for the younger population, i.e. larger properties for families and more properties if existing large dwellings were converted into multiple living units. Whilst, as evidenced above, the overall amount of overcrowding is currently limited in the UK; this is not true for cities such as London where overcrowding is a significant issue; in particular in families with children. Estimates vary, but it is estimated that around a quarter of families in London experience overcrowding[1], and 11% of all households (ONS, 2014). The housing crisis, i.e. a lack of available, appropriate properties, and high housing costs, is often seen as a core issue of intergenerational justice (Morton, 2013). A redistribution of housing would be a huge step forward; given that the majority of households are under-occupying, in the case of London roughly 50% (ONS, 2014). A further benefit for those downsizing is the possibility of moving to more age-appropriate housing, e.g. without stairs, with wide doors, and in close proximity to amenities or public transport. In fact, research showed that bungalows are the preferred housing option (Ipsos Mori, 2002). Also, a smaller property with a smaller or no garden allows for easier maintenance. Downsizing could also significantly increase the disposable income of householders, through lower rent and/or lower bills and by freeing up substantial capital[2] for home owners.

3.2. Challenges of downsizing

One challenge relates to the non-availability of appropriate housing: Whilst bungalows were the preferred choice, only very few of them are currently built. New flats that dominate the new-builds are only popular with 1% of the elderly population. In general, there are too few one or two-bedroom properties. In recognition of the problem of under-occupying, Government had introduced the “under-occupancy charge”, better known as bedroom tax in the UK, to penalize social housings tenants who have more bedrooms than needed. Occupants lose a share of their entitled benefits for occupying more space than deemed necessary. However, this scheme has been highly criticized because of the lack of alternative housing to which tenants could move in order to avoid the penalty. Research has also shown that people are concerned what to do with their possessions when moving to a smaller home and have expressed the need to have spared bedrooms for visiting children and grandchildren (Leach, 2012). Possible other factors are the considerable inconvenience and the costs of moving, and – if deciding to downsize to a rented accommodation – the loss of ownership.

4. Alternatives to downsizing

Taking a lodger would be an alternative; and indeed, schemes that exist that bring benefits beyond monetary gains such as promoting intergenerational justice and easier maintenance. Germany, for example, has a scheme called “Wohnen fuer Hilfe”[3] (“Living for help”) where students or apprentices live (almost) free of charge in a household of an elderly person but provide other support in exchange, such as shopping, household chores, and companionship. The UK and other countries have similar schemes. Also, a pilot scheme was designed in London, the Redbridge “Free Space” project in which property owners leave their house to move to a smaller, more appropriate housing, but retain ownership of their house. The dwelling is rented out by the Council who takes care of all landlord responsibilities.[4]

5. Implications

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[1] http://england.shelter.org.uk/news/previous_years/2011/july_2011/1_in_4_london_children_overcrowded
[2] http://www.moneywise.co.uk/news/2015-01-23/downsizing-to-semi-detached-could-free-120k
[3] http://www.hf.uni-koeln.de/wfh.php?id=30203
[4] http://www.ilfordrecorder.co.uk/news/redbridge_scheme_for_older_homeowners_hailed_by_housing_minister_1_1180475

Data clearly show how building size dominates domestic energy consumption and that a large number of English households are under-occupying. If more householders would downsize, significant energy savings could be achieved, contributing to the national goal of carbon emission reduction. Other benefits would include freeing up living space for the younger generation, creating more disposable income and more age-appropriate living conditions. Existing policy interventions targeting the social housing sector simply don't work because of the lack of alternative accommodation. In particular in large cities, the lack of availability of housing is significant problem. However, given the much higher prevalence of under-occupying than overcrowding, redistribution of housing together with converting existing housing into smaller living units could have a huge impact. Apart from logistic issues, a pure redistribution might not cover other issues, such as allowing living in a bungalow or the desire to have space for visitors. Developing buildings solutions that turn large properties into smaller desired living units that are then designed to e.g. have wide doors and mobility aids at stairs are an idea. Additionally, it might be an incentive to have a shared space for visitors, i.e. a "guest house" for those living in a community. Also, the idea of home share could be promoted much more.

Finally, more rigorous research is needed to understand what incentives and hinders downsizing, and ideally use a stringently designed randomized control trial to test actual downsizing rates.

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Energy, Emergy and the City

Erik Grönlund*[1], Morgan Fröling[1], Torbjörn Skytt[1]

[1] Ecotechnology and Sustainable Building Engineering, Mid Sweden University, 83125 Östersund

Corresponding Author e-mail: erik.gronlund@miun.se

Abstract

In his book *Environment, Power, and Society* (1971) H.T. Odum introduced a picture of the energy metabolism of a city based on Wolman's paper from 1965 (Sci. Am., 213: 179-190). With the development of the emergy concept--a branch of energy systems accounting--several authors have contributed to develop a quantitative view of HT Odum's picture, which from many aspect are diverging from the traditional energy accounting picture. In this paper the emergy view of the city is reviewed. The research on emergy and cities had its focus in United States during the period 1975-1995 with investigations of cities like Miami, Jacksonville, San Francisco and Chicago. The main research during 1995-2010 took place almost only in Taipei. From approximately 2006 up today the main research takes place in Chinese cities; Macao, Beijing and 30 other Chinese cities have been investigated the last 6 years. Newer investigations have also been done on Rome (Italy) and Montreal (Canada). The main interest in the research up to 2007/2008 was on the spatial aspect of the city. After that new focuses have emerged, with sustainability as a main question.

1. Introduction

A central research theme for the famous systems ecologist H.T. Odum was how ecosystems and general systems can be described from an energetic perspective or with an energetic backbone. This was the approach in his seminal research on food webs in Silver Springs, Florida – a cornerstone in many textbooks – and the work with his brother, E.P. Odum, at the coral reefs of the Eniwetok Atoll (Cleveland, 2008). In his first book "*Environment, Power, and Society"* (Odum, 1971) he continued applying the energy hierarchy of food webs to systems also including humans. In this approach it became clear there were systems properties in energy hierarchies that were difficult to deal with, within the traditional thermodynamic concepts of energy developed for describing heat engines and later chemical processes. He started to develop new energy related concepts, that would later be grouped under the heading Emergy.

1.2 Objectives

This paper aims to give an overview of how the emergy concept has been used in the context of cities. The paper is based on literature search in the databases ScienceDirect and Link Springer, and the publication lists available at the web site Emergy Systems[1]. The space available does not allow for a thorough review; rather the general picture will be elucidated.

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[1] www.emergysystems.org

2. Energy and emergy

Emergy is a bit of an unusual type of energy measure. It has some features that differ from the traditional use in physics and thermodynamics. The inventor of the concept, H.T. Odum (even though he did not coin the specific term emergy on his own (Scienceman, 1987)), used to say that he "… didn't like to add up energies of different kinds" (pers.comm. June 2000, Copenhagen[2]). In his life time studies of natural and human ecosystems he had found that the traditional way of adding up energy heat values did not make sense in the energy hierarchies of the old nutrient webs in the long run. He therefore started to express energy units in terms of the type of energy that produced it. What is said to be the first step was to express coal power plant electricity in terms of how much coal energy was needed to produce it. On average for the existing technology it took 4 joules of coal to produce 1 joule of electricity. The electricity from the coal could then be expressed as 4 coal emergy joules (cej). The coal in turn could then be expressed in how many joules of solar energy it took to produce it, solar emergy joules (sej). Solar emergy joules is today the dominating unit to express emergy, but in principle any type of energy can be chosen. H.T. Odum himself used to describe emergy as the previous energy it took to produce the actual type of joule, and all of them expressed in one type of energy, almost always solar energy, giving the sej unit (for example Odum (1996). This gives the impression of a historical energy, and emergy is often said to be an abbreviation of energy memory. This is true for most cases, but sometimes it can be useful also to view the concept as a steady state equilibrium measure where everything is produced in average amounts within the time frame chosen (Grönlund, 2009). In modeling terms this means that no storage is changed. This is of course almost never the real situation, where storage of for example wood, or body fat, are used in cyclic or fluctuating ways, sometimes built up, sometimes used up. However, the simplified situation of no storage changed, can be a helpful picture to grasp the concept, since it diverts to some extent to most of our everyday use of the energy concept (where we happily add up different kinds of energies).

3. Emergy and the city

Regarding emergy and the city it was addressed already in H.T. Odum's book "*Environment, Power, and Society*" from 1971. In a picture (Figure 1-3 in that book, based on Wolman's paper from 1965 (Sci. Am., 213: 179-190)) the similarities of the energy metabolism of an oyster reef and a city were pointed out. No more explicit discussion about cities was presented in that book, other than that cities was natural centers higher up in the energy hierarchies of the world. This had not changed in his second book, 1976: the more popular written "*Energy basis for man and nature*" (co-authored with Elisabeth C. Odum). The city still had the same position, even though internal structure of the city was sketched in Figure 10-2 in that book.

However, during these years several references reveal that cities were in focus in H.T. Odum's research. A young Mark Brown – Odum's long time coworker for the coming 30 years - wrote a Master's thesis on the subject 1973 (Brown, 1973), and James Zucchetto was also already working on the subject, since his dissertation with an urban focus was presented in 1975 (Zucchetto, 1975). Mark Brown, during the second half of the 1970s, wrote his thesis about "*Energy hierarchies in urban and regional landscapes*", presented 1980 (Brown, 1980).

[2] The graduate student course "Ecosystem theories – a pattern?" organized by Sven Erik Jørgensen.

At some point during this period H.T. Odum also introduced a course - Ecological and General Systems - that was taught during one semester (Odum, 1983, foreword), and later published in an extended version: "*Systems ecology: An introduction*" (Odum, 1983). A separate chapter in this book was assigned to the city presenting many models from the works of for example James Zucchetto (1975) Mark Brown (1980).

During the 1990s the focus on the city was continued with works by Whitfield (1995), Lopez and Brown (1995), Woithe (1995a, b) and Doherty (1995). All summarized in the 1995 project "*Zonal Organization of Cities and Environment - A Study of Energy Systems Basis for Urban Society*" (Odum et al., 1995). This project also included an important international cooperation with Dr. Shu-Li Huang, who brought the urban focus in emergy research to East Asia.

3.1 Status in the mid 1990s

The report "*Zonal Organization of Cities and Environment - A Study of Energy Systems Basis for Urban Society*" (Odum et al., 1995) was, as said in the previous section, the result of a new cooperation around the fast growing cities in Asia, but also summing up the research on emergy and cities so far. The latter were found in the report as hypotheses around city organization. In Fig. 1 is the older agrarian city represented with most people living outside the town, but anyway centered around it. To the right in Fig. 1 is the new town developed in parallel with the increased use of fossil fuels. A theory of emergy and landscape hierarchy was presented, some of the hyptethical outcomes are presented in Fig. 2.

In the report above the city is viewed as a natural concentration of information and people in the energy hierarchy of landscapes. There are similarities between cities and ecosystems, Lopez and Brown (1995) mentioned succession and metabolism. As in natural ecosystems there are succession phases as of growth, homeostasis, regression, renewal and oscillation (Odum, 1983). The metabolism of the city is also similar to natural system as the city takes up resources from vast areas, transforms them to city structure, and releases wastes to the surrounding areas. .

Lopez and Brown (1995) investigated Miami with seven transects and found a clear zonation in the city from the center to the periphery 25 km out. The highest Empower was found 5-15 km from the center. Whitfield (1995) investigated Jacksonville, Florida, and also found structure in the organization. However, here the center of the city had very high Empower, decreasing fast at first and then slower out to east en west. Woithe (1995b) investigated zones of empower density in Chicago and San Francisco and found gradients in all of them.

3.2 Development after the millennium shift

Taiwan

As said earlier the work on cites published in 1995 (Odum et al., 1995), was a co-project with Taiwan. Already in 1991 Huang and Odum (1991) published a plan for the project and with start from 1995 up to 2011 Huang and co-workers published many papers on the investigation of Taipei and its hierarchical position in relation to the full island of Taiwan (Chen and Huang, 1998; Huang, 1996, 1998, 2003; Huang and Chen, 2005; Huang et al., 2011; Huang and Hsu, 2003; Huang et al., 2007; Huang et al., 2001; Huang et al., 2006; Huang et al., 1998; Huang et al., 1995; Huang et al., 2010; Lee et al., 2008, 2009).

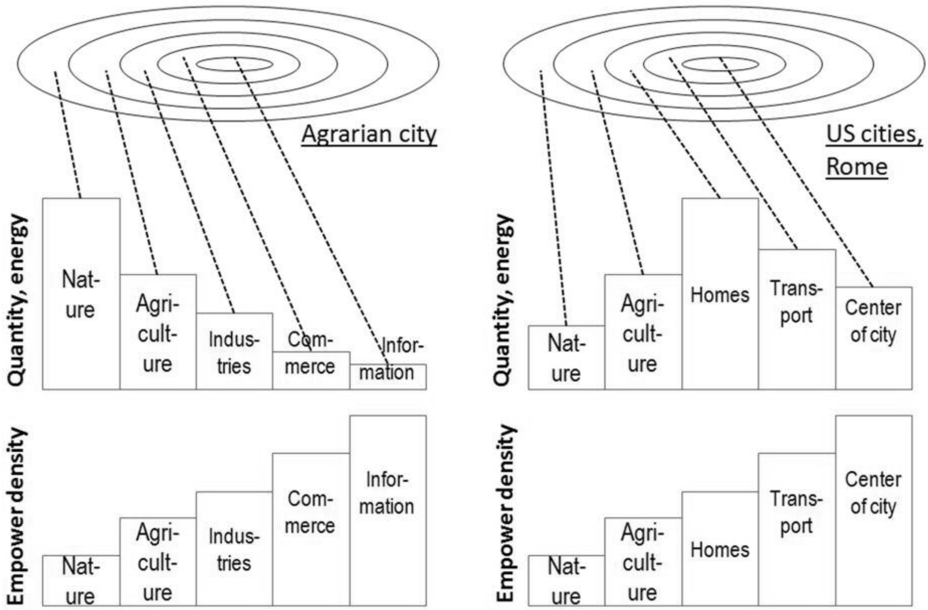

Fig.1: Model of zones of a city in an agrarian landscape and in a city in a fuel-based urban landscape, both with hypothetical distribution of energy and empower. (Redrawn from Figure 1 and 2 in Odum et al. (1995)

In Huang and Chen (2005) was repeated the distribution picture from Odum et al. (1995). Huang et al. (2006) published the time frame from 1936-98 where Taipei showed the same urbanization pattern as other cities studied, and Huang et al. (2007) could verify the spatial picture from the American cities regarding Empower density adding also the diversity of emergy use.

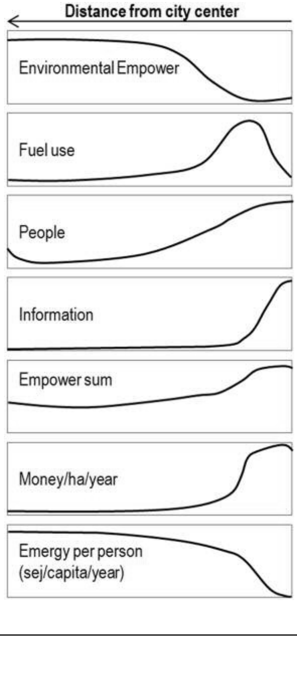

Fig.2: Hypothetical gradients in zonal properties around a city. (Redrawn from Figure 3 and 4 in Odum et al. (1995)

Macao

From 2008 a series of emergy papers was published by Kampeng Lei and coworkers (Lei et al., 2012; Lei and Wang, 2008a, b, c; Lei et al., 2008; Lei et al., 2011; Lei et al., 2010). In 2014 the research were summarized in a book: *Ecological Emergy Accounting for a Limited System: General Principles and a Case Study of Macao* (Lei et al., 2014). A major outcome were the positive Net Emergy Ratio that Macao experiences, since the vast amount of tourists entering the town spends more emergy than they take with them leaving the town. The net emergy has sustained Macao's socioeconomic development for many decades.

Beijing

During the last years most international journal publications regarding emergy and cities has had their focus on Beijing. There seems to be two major groups, one around Yan Zhang (Zhang et al., 2010a; Zhang et al., 2010b; Zhang et al., 2011; Zhang et al., 2006, 2009a, b; Zhang et al., 2009c), and one around Gengyuan Liu and co-workers (Liu et al., 2011a, b, c, d; Liu et al., 2011e, 2014a; Liu et al., 2014b; Liu et al., 2013; Liu et al., 2012; Liu et al., 2009a; Liu et al., 2009b). Other journal articles on Beijing have been published by Hu et al. (2010); Cai et al. (2009); Chen and Chen (2011); Li and Wang (2009); Song et al. (2014); Song et al. (2015). Several time scenarios have been published and the emergy data amount seem to grow fast around Beijing.

Other Chinese cities

Other Chinese cities have also been investigated: Yangzhzou city in East China by Hu et al. (2009). Liu et al. (2009a) evaluated 31 Chinese cities and found a pattern where they divided the cities into six groups and proposed a new urban ecosystem health evaluation framework including efficiency, structure, impact and flux with an emergy-based index. In another paper (Liu et al., 2011d; Liu et al., 2013) they proposed an urban emergy loss evaluation framework including human-made and natural capital loss. Liu et al. (2009b) also made a separate ecosystem health evaluation of Baotou City, located in the west of the Inner Mongolia Autonomous Region. Su (2010) investigated the Yangtze river delta urban cluster, Su et al. (2011) the Pearl river delta, and Su and Fath (2012) investigated Guangzhou.

Rome and Montreal

A few western cities have also been investigated in recent years. Rome by Ascione et al. (2009), and Montreal by Vega-Azamar et al. (2013).

4. Discussion

HT Odum and coworkers put up many hypotheses regarding the emergy view on cities during the period 1975-1995. Many of these hypotheses had a spatial focus from city center to the periphery. After that many emergy evaluations have been performed on cities, mainly in East Asia. The works by Shu-Li Huang maintained to spatial focus and could to a large extent confirm the hypotheses and findings from the cities in United States during 1975-95. However, the later studies in East Asia have not had a spatial focus in the same way as the Odum and Huang groups. Instead the focus has been on evaluation the cities from a sustainability view. This has been especially prominent in the works of Kampeng Lei and his group addressing Macao. It seems like H.T. Odum's wish (Odum 1995) to develop predicting models for spatial organization of cities is still yet to be proved. It is interesting that the new investigation for Rome (Ascione et al., 2009) did not address the spatial prediction made by Odum et al. (1995) in Fig.1.

The research groups in Beijing around Yan Zhang and Gengyuan Lei seem to have taken the emergy research on cities in new innovative ways, suggesting many new indices for evaluation of for example urban ecosystem health. The Gengyuan Lei group has also increased the volume of investigated cities substantially. The increasing piles of data from these cities are promising for future new knowledge and hypotheses.

However, even though many new indices are developed a problem seem to be the interpretation of them. What do they actually say us? This seems also for long times have been the case for the old indices: they give an almost macroeconomic view of the city or a country from a more complete perspective, including also the work and flows from the ecosystems. However, the question of what are “good” or “bad” values often remains unanswered, or answered in an inconsistent way compared with other investigations.

One of the key skills in emergy calculations is to choose the appropriate transformity to convert the joule, kg or $ to an emergy value in sej. This is often not explicitly addressed in the paper currently. There is today a situation of uncertainty regarding the quality of the transformities used. Some papers do not even give which annual emergy baseline they have used as calculation base. Using transformities from different emergy baselines can give an uncertainty in the order of 50-70%. Therefore there is a need to be precautious still when comparing studies. Sensitivity in data is discussed by for example Ascione et al. (2009).

Regarding the choice of using energy or emergy as a measure no one seem to have discussed this in depth yet. Using the traditional energy measure instead of energy would probably to a large extent give a similar picture as the use of emergy, for example in Fig. 1.

An attempt was made in the process of this paper to verify the energy diagrams in Fig.1. Two conclusions came out of this attempt: First, data are not available for different zones. Second, the mechanism in emergy accounting to transform material and monetary values by using the sej/g and sej/$ ratios make it possible to include many more categories in the evaluations. Just taking the joule values from emergy investigations will give a much less interesting outcome, not at all comparable to macroeconomic calculations.

5. Conclusions

The research on emergy and cities took place in United States during the period 1975-1995. The main research during 1995-2010 took place almost only in Taipei. From approximately 2006 up today the main research takes place in Chinese cities, so far many papers on Macao and Beijing but also 30 other Chinese cities have been investigated initially. Newer investigations have also been done on Rome (Italy) and Montreal (Canada).

The main interest up to 2007/2008 was on the spatial aspect of the city. After that new focuses have emerged, with sustainability as a main question.

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Analysis and Simulation of Emergy Flows of Urban Eco-economic Systems: Taking Beijing as a Case

Wei Fang[1,2] , Haizhong An[1,2]* , Huajiao Li[1,2] , Weiqiong Zhong[1,2] , Xiaoqi Sun[1,2]

[1] School of Humanities and Economic Management, China University of Geosciences, Beijing 100083, China;

[2] Key Laboratory of Carrying Capacity Assessment for Resource and Environment, Ministry of Land and Resources, Beijing 100083, China;

Corresponding Author e-mail: ahz369@163.com

Abstract

Due to the large population and rapid economic development, the resources consumption and environmental pollution exceeds the maximum carrying capacity of urban resources and environment. Smog, water shortage and other problems become especially common problems of urban metropolis. A city is a completely open ecological-economic system, which has a close emergy exchange with the surrounding areas. Most of the resources needed for the city's development are from the outside. This paper first defines the ecological-economic system boundaries, and then divided the whole system into 6 sections based on emergy analysis, namely renewable emergy, local renewable emergy, local nonrenewable emergy, import emergy, export emergy, and waste emergy. The emergy indicator system of Beijing is thus established. Then, the whole city is divided into economic subsystem, population subsystem and environmental subsystem and the economic subsystem is subdivided into agriculture, industry and tertiary industries. We analyze the urban emergy of different types of flow and conversion between different industries.Third, the system dynamics method is used to simulate the urban emergy flow and the conversion process. The system dynamics model of urban ecological-economic system driven by economic development and population growth. And finally, we design three scenarios of economic development, and analyze the level of dependence on importing emergy , nonrenewable emergy. some suggestions are brought forward to improve the urban carrying capacity.

Keywords: emergy flows, urban eco-economic systems, system dynamic, carrying capability

1. Introduction

A city is a widely open system with exchange of materials, energy and information with the outside to support the population of the city(Chen and Chen, 2006). Emergy analysis set up a bridge between urban ecosystems and economic systems(Odum, 1983; Odum et al., 1987). It treats the entire economic, social and ecological environment of the city as a whole(Hardin, 1986; Daily and Ehrlich, 1992; Meyer and Ausubel, 1999). Emergy flow analysis can study the flows of resources and goods between the various sectors of the city, as well as the exchange between humans and ecological environment, which is a quantitative assessment of environmental carrying capacity of urban resources(Odum et al.,2000; Chen and Chen, 2009). Emergy flow analysis methods can be mainly focused on the analysis of internal and external emergy flow in the urban systems(Brown, M. T., & Ulgiati, S., 2001); it is difficult to study the city's feedback system and the dynamic analysis on future trends. System dynamics model can be a good method to analyze and simulate the interaction between various resources, population and development, as well as the causal relationship between the factors. By computer simulations it can show development and trends of the related factors in the systems. It has significant advantages in terms of dealing with complex systemic problems(Berling-Wolff and Wu, 2004;Arquitt and Johnstone, 2008). This paper will use system dynamics method to simulate the emergy flow in urban ecological-economic system, and construct an system dynamics model of urban ecological-economic system. With this model, we will analyze how much emergy comes from outside of the city, how much belong to non-renewable emergy, and the future trends. The innovation of this paper is using the system dynamics model to simulate urban emergy flow system, and a emergy-flow dynamics model of the ecological-economic system is established.

2. Data and Method

2.1 Study Area and Data

Beijing is an international metropolis with large population, high population density and rapid economic development. Common problems of the city, such as the population concentration, air pollution and other problems exist in Beijing. At the end of 2013, the city's resident population is 21.6 million and migrant population is 8.027 million. In the recent 10 years, GDP growth rate of Beijing is over 6%, but the environmental problems it generates has become increasingly serious, especially serious smog attracting worldwide attention. Data sources: *Beijing statistical yearbook (1998-2013)(Beijing Statistical Office,1998-2013)*, *China statistical yearbook (1998-2013) (National Bureau of Statistics,1998-2013)*, *China environment statistical yearbook (1998-2013) (National Bureau of Statistics, Ministry of Environmental Protection, 1998-2013)*.

2.2 Emergy flows

Emergy is a method to transform various material, energy, currency with different units to unified unit, also called the "emergy synthesis" (Brown and Ulgiati, 2004; Chen and Chen, 2009a). So it is a bridge linking ecology with economy in a city. Firstly, based on the theory of emergy analysis, the flowing of emergy in Beijing city is analyzed to draw the emergy-flow diagram inside or outside of Beijing, as shown in figure 2.1. In the figure, the whole city is divided into four parts, including primary industry, secondary industry, tertiary industry and resident consumption. The emergy to be needed for the development of a city is provided in part from outside it, the other part by three industries in the city. The emergy of ecological economic system in Beijing include six parts(as shown in Table 2.1): (1) renewable emergy; (2) Local renewable emergy; (3) Local nonrenewable emergy;(4) import renewable emergy; (5) import nonrenewable energy; (6) Export emergy; (7) Waste emergy.

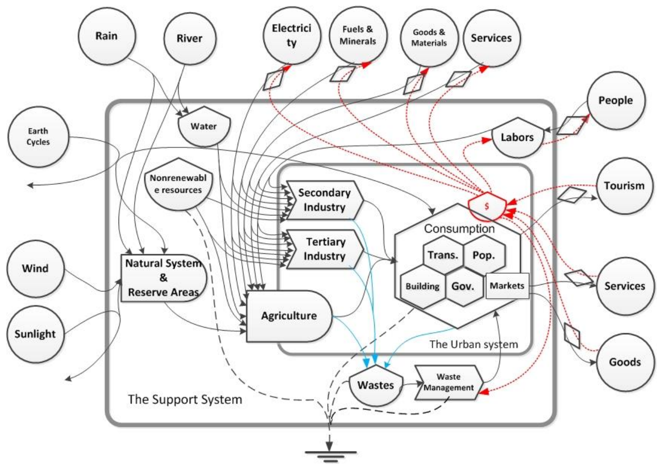


Figure 2.1: emergy flow diagram of urban eco-economic system

Table 2.1: Matter, energy and emergy flows supporting the urban system of Beijing

Emergy components	Items	Unit	Transformity (seJ/unit)	Reference for transformity
Renewable resources	1. sunlight	J/year	1	Odum et al. (2000)
	2. Wind, kinetic	J/year	2.45×10^{3}	Odum et al. (2000)
	3. Rain, geopotential	J/year	4.70×10^{4}	Odum et al. (2000)
	4. Rain, chemcal	J/year	3.05×10^{4}	Odum et al. (2000)
	5. Earth cycles	J/year	5.80×10^{4}	Odum et al. (2000)
Local renewable resources	6. Agriculture product			
	6a. Grain	g/year	9.82×10^{8}	Odum et al. (2000)
	6b. Vegetable	g/year	5.96×10^{9}	Odum et al. (2000)
	6c. Fruit	g/year	1.23×10^{9}	Odum et al. (2000)
	7. Livestock product			
	7a. Meat	g/year	3.17×10^{10}	Odum et al. (2000)
	7b. Milk	g/year	2.41×10^{10}	Odum et al. (2000)
	7c. Eggs	g/year	1.07×10^{11}	Brandt-Williams (2001)
	8. Fisheries product	g/year	2.0×10^{6}	Lan et al. (2002)
	9. Wood	g/year	6.48×10^{8}	Campbell et al. (2005)
	10. Water	g/year	3.05×10^{4}	Odum et al. (2000)
local nonrenewable emergy	11. Topsoil loss	g/year	2.87×10^{9}	Odum et al. (2000)
	12. Electricity	J/year	1.59×10^{5}	Brown and Bardi (2001)
	13. Fuels			
	13a. Gasoline	g/year	2.92×10^{9}	Bastianoni et al. (2009)
	13b. Fuel oil	g/year	2.66×10^{9}	Bastianoni et al. (2009)
	13c. Diesel oil	g/year	2.83×10^{9}	Bastianoni et al. (2009)
	13d. Liquid petroleum gas	g/year	3.11×10^{9}	Bastianoni et al. (2009)
	13e. Coal	J/year	4.0×10^{4}	Odum et al. (2000)
	14. Cement	g/year	2.56×10^{9}	Brown and Buranakarn (2003)
	15. Iron & steel	g/year	3.27×10^{9}	Ascione et al. (2009)
import renewable emergy	16. Agriculture product			
	16a. Grain	g/year	9.82×10^{8}	Odum et al. (2000)
	16b. Vegetable	g/year	5.96×10^{9}	Odum et al. (2000)
	16c. Fruit	g/year	1.23×10^{9}	Odum et al. (2000)
	17. Livestock product			
	17a. Meat	g/year	3.17×10^{10}	Odum et al. (2000)
	17b. Milk	g/year	2.41×10^{10}	Odum et al. (2000)
	17c. Eggs	g/year	1.07×10^{11}	Brandt-Williams (2001)
	18. Fisheries product	g/year	2.0×10^{6}	Lan et al. (2002)
	19. Wood	g/year	6.48×10^{8}	Campbell et al. (2005)
	20. Tourism	$/year	1.66×10^{12}	Brown and Ulgiati (2002)
Import nonrenewable emergy	21. Electricity	J/year	1.59×10^{5}	Brown and Bardi (2001)
	22. Fuels			
	22a. Gasoline	g/year	2.92×10^{9}	Bastianoni et al. (2009)
	22b. Natural gas	J/year	4.8×10^{4}	Odum et al. (2000)
	22c. Coal	J/year	4.0×10^{4}	Odum et al. (2000)
	23d. Crude oil	J/year	5.4×10^{4}	Odum et al. (2000)
	24e. Fuel oil	g/year	2.66×10^{9}	Bastianoni et al. (2009)
	25f. Liquid petroleum gas	g/year	3.11×10^{9}	Bastianoni et al. (2009)
	23. Cement	g/year	2.56×10^{9}	Brown and Buranakarn (2003)
	24. Iron & steel	g/year	3.27×10^{9}	Campbell et al. (2005) and Ascione et al. (2009)
	25. Fertilizer	g/year	3.99×10^{9}	Brandt-Williams (2001)

Table 2.1(Continued)

Emergy components	Items	Unit	Transformity (seJ/unit)	Reference for transformity
Export emergy	26. Goods	$/year	6.34×10^{12}	Jiang et al. (2007)
	27. Services	$/year	1.21×10^{13}	Jiang et al. (2008)
Waste emergy	28. Solid waste	g/year	1.8×10^{6}	Odum et al. (2000)
	29. waste water	g/year	8.6×10^{5}	Odum et al. (2000)
	30. Emission	g/year	4.8×10^{4}	Lan et al. (2002)

2.3 System Dynamics

Due to the city's emergy flow is drove by its economic development and human life needs. Therefore, the GDP development and resident consumption is the core of the system dynamics model. According to the analysis of chapter 2.2, the system dynamics model includes 2 subsystems or 4 modules: economic development subsystem and population growth subsystem. The four modules are consisted of primary industry's production & consumption module, secondary industry's production & consumption module, tertiary industry's production & consumption module, resident consumption module.

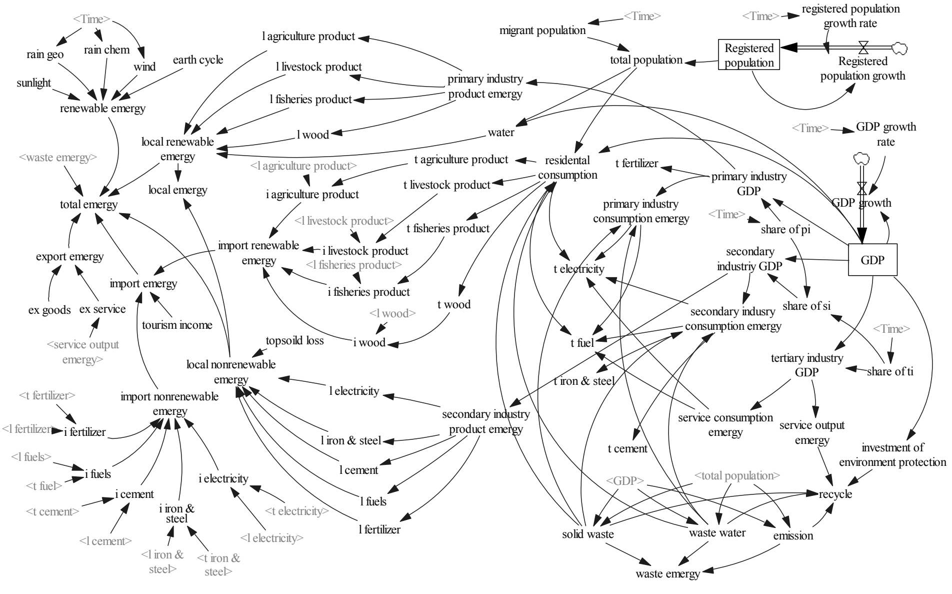


Figure 2.2: emergy-flow SD model of urban eco-economic system

Population in the population subsystem model is the key. The population pushes the emergy flow by resources consumption, and put impact on the environment. Economic development subsystem is based on GDP and GDP growth, which consume all kinds of resources and discharge various wastes. According to the interaction mechanism among subsystems and the elements of them, an emergy-flow SD model is established by using the Vensim PLE of version 6.3 (as shown in Figure 2.2). The functions of factors in the emergy-flow SD model are built by SPSS with the historical data of 1998-2013 in Beijing.

In order to verify the validity of the model, the Beijing's historical data of 1998-2012 is put into the model to predict the 2013 data. the error between the simulation value and the actual is less than 5%, which indicates the emergy-flow SD is valid. The results of validation are shown on table 2.2.

Table 2.2 Validation of the SD model in 2013

Items	Simulation result	Reference data	Relative error(%)
GDP(Yuan)	1.09E+12	1.14E+12	-4.19
Total population(person)	2.16E+07	2.11E+07	2.38
renewable emergy(seJ)	2.61E+21	2.60E+21	0.38
local renewable emergy(seJ)	1.72E+23	1.65E+23	4.24
local nonrenewable emergy(seJ)	3.72E+23	3.90E+23	-4.62
import renewable emergy(seJ)	1.23E+24	1.19E+24	3.36
import nonrenewable emergy(seJ)	3.22E+24	3.31E+24	-2.72
export emergy(seJ)	6.44E+23	6.24E+23	3.21
waste emergy(seJ)	1.33E+22	1.28E+22	3.91

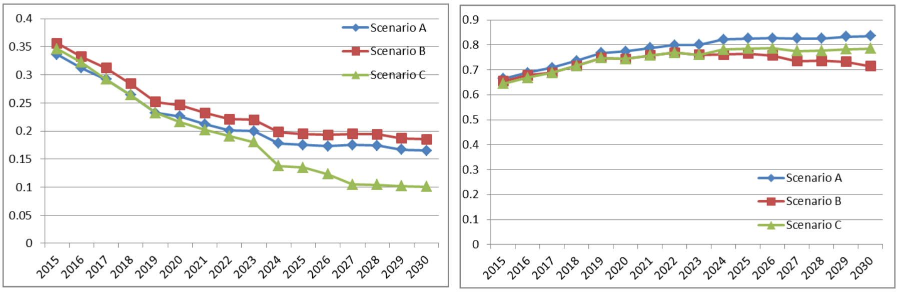
3 Results

3.1 Setting scenario

From 2015 to 2030, a total of 15 years of Beijing energy changes is simulated by the emergy-flow SD model. On this basis, the economic development and ecological environment will be predicted and analyzed. In order to make the comparative analysis of different levels of economic development, growth rate of economic growth will be changed. At the same time, also the investment of environment protection is considered. So three scenarios is set:(1)Scenario A: to maintain the current level of economic development and population growth level unchanged, as a reference to the other two scenarios.(2) Scenario B: environmental protection. GDP growth rate of 2015-2030 is set to 5%. At the same time, Investment of environment protection is increased to 10% of GDP. (3)Scenario C: economic development. It is considered to improve the economic development and increasing the environmental protection investment in this scenario. The economic growth rate of 2015-2030 is set to 8%, and the investment of environment protection will be increased to 15% of GDP..

3.2 Comparison of three scenario

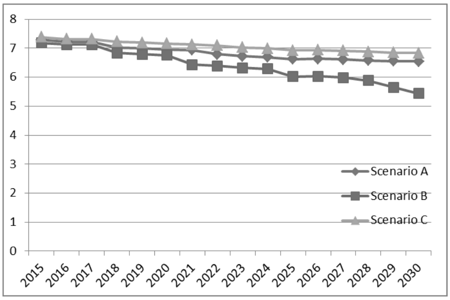
Figure 3.1 (a) reflects the degree of dependence on external resources of Beijing city in the future, it can be seen from the figure, the self-sufficiency ratio of local emergy obviously deline from 2015 to 2030. In Scenario C, the degree of external resource dependence reached 90% in 2030. Therefore, with the development of economy, the environment of the city will be more and more overwhelmed.



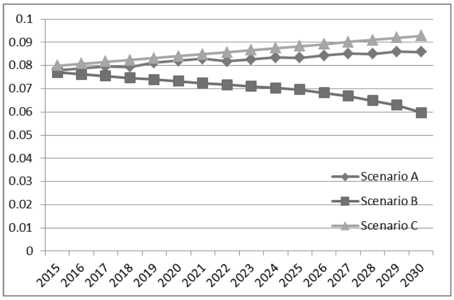
(a) ratio of local emergy to total emergy (b) ratio of nonrenewable emergy to total emergy

Figure 3.1 results of local emergy, nonrenewable emergy and total emergy

Figure 3.1 (b) is reflected the consumption of the whole nonrenewable resources in the process of development of the city. As can be seen from the figure, the proportion of nonrenewable resources in the total resource consumption remain extreme high, close to 90% in 2030 in original scenerio A. Scenario B show a decline at the rear of curve, that means the mothods in scenario is effective.



(a) ratio of import emergy to export emergy



(b) ratio of waste emergy to total emergy

Figure 3.2 the efficiency of using emergy

Figure 3.2 (a) shows that, Beijing investment and the consumption are at a high level, indicating that Beijing's development is still high-input and high-consumption mode of economic development. The decline is more obvious in Scenario B, which means slowdown of the speed of economic development will be helpful to raise the input-output ratio of whole emergy in an urban system.

Figure 3.2 (b) reflects the utilization of waste. On the whole, Beijing's waste rate is relatively low; indicating Beijing's recycling rate of waste is high. But with the development of economy, the waste emergy proportion in scenario A and B continues to grow, while the one in Scenario C has a significant decreasement. That indicate increasing the investment in environmental protection will have a direct role in waste recovery and utilization.

4. Conclusion

Through the emergy analysis method, urban external and internal emergy flows are analyzed, and a emergy-flow system dynamics model for dynamic analysis of ecological carrying capacity is built, which is also good at analyze the relationship between the urban ecological environment and economic development. Those provide new methods and ideas for the dynamical research of urban carrying capacity of resources and environment. And some interested conclusions have been obtained by using this method:

(1) Beijing will more and more seriously depend on extenal resources. If government do not take any measures, in 2030, Beijing's ratio of external resources to total resources will reach 90%; the proportion of nonrenewable resources keeps extreme high in Beijing city. In all of its consumption of resources, the proportion of nonrenewable resources has reached 67%, will reach more than 80%. Depressing the speed of economic development and increasing investment of environmental protection will effectively reduce the proportion of nonrenewable resources.(2) Beijing is still in the high input and high consumption growth pattern. Although input-output ratio will decline year by year, but the decline is very slight. To creasing the investment of environmental protection will put more impact on the reducing discharge of waste, by improving the utilization and recycling of wastes.

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Natural Energy Basis and Urban Development in Dourados County, Mato Grosso do Sul, Brazil.

Vito Comar[1]*, Jose-Luis Izursa[2], David Tilley[2]

[1] Universidade Federal da Grande Dourados, Dourados-MS, Brazil.

[2] Environmental Science and Technology Dept., University of Maryland. USA.

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*Corresponding Author e-mail: vitocomar@gmail.com

Abstract

The role of natural energies in fostering urban economic development was evaluated for Dourados, a town of around two hundred thousand people in the southern region of the State of Mato Grosso do Sul. System analysis concepts, energy principles and computer simulations were used to understand the character, quality and quantity of resources and energy flows interacting within the urban system and with the natural environment. The Energy Memory, or emergy approach, together with model simulations help identify trends and evaluate different urban development alternatives. Dourados' simulation model explores the relationship between natural energy sources, grain production and cattle breeding, industrially processed products, economics and human population dynamics. Imported electrical energy could be substituted by a local gas-fueled thermo-electric plant, turning Dourados into an energy exporter. The model identifies the main functional components of this system and their relationships and interprets the results in terms of the system behaviour as a whole. It thus hopes to offer elements for a sustainable use of natural resources, within a participatory decision-making process, for different development scenarios with or without endogenous energy production. The paper analyses these questions in the light of the challenge of climate change in urban planning restructuring and management, aiming for greater sustainability, including clean air, water resource use, green urban areas design and solid waste management within a watershed perspective, greater urban soil permeability and non-fueled vehicular mobility in more autonomous city nuclei, connected by a rapid public transport network. The main aim is to discuss and propose an integrated planning system and participatory public policy decision making tools for sustainable urban design, linking sustainable construction and mobility and disaster prevention planning.

1. Introduction

Natural resource management is one of today's most critical issues. Integrated studies of social and natural resource use - and the development of management strategies that recognize and promote the vital connections between the two - need to be seen within the context of resiliency (Simonsen et al. 2014). Present trends in large-scale transformations in information technology, biotechnology and energy systems can improve our lives in a sustainable way. There is, however, a need to incorporate knowledge of social-ecological systems and planetary boundaries in risk assessments and development strategies and build capacity to deal with unexpected change. Cities are part of, interact with, and change the biosphere, use ecosystem services and products, water, soil for crops, alter climate and partake of spiritual or cultural connections to ecosystems. A resilience thinking approach tries to investigate how these interacting systems of people and nature – or social-ecological systems – can best be managed to ensure a sustainable and resilient supply of the essential ecosystem services on which we depend. In the same way as distinct economies of individual nation states are being woven together within a world economic system, it is becoming clear that economic well-being and ecological stability depend on the establishment of an interface between ecology and economy.

The formulation of short and long-term economic policies that disrespect the planet's contribution to our well-being, aggravated the biological and human situation as they return nothing to a natural system that has its limits (Odum, 1983). These considerations have impelled new directions both in the conception of new values and in a more audacious and creative scientific approach with practical applications. Solutions will be found within a holistic approach that integrates man and nature in symbiotic and sustainable patterns for their common future (Capra, 1982).

An evaluation of the Emergy, written with M, in the various components and processes of ecosystems (Odum, 1983; Odum and Odum, 1983) clarifies the interdependence between human economy and natural systems, where energy is used as a common denominator to measure activities in both types of systems. Sometimes it is convenient to think of Emergy as energy memory.

The evaluation of the main Emergy flows provides quantitative measures of the ecologic and economic system of the area under study. Decisions on the usage of natural resources cannot be correctly taken using money, as money is just paid for services provided, inasmuch as a comparison amongst environmental alternatives can be made using Emergy as a metric. The global scheme in this economic view includes the economy of nature and its inputs.

Lack of theoretical knowledge and reliable data is an aggravating factor to the constant drain of natural resources of Dourados's County, in the Brazilian State of Mato Grosso do Sul, which leaves it with less emergy without attracting added value. This is especially so with its massive exports of soybean production and cattle, in standing stock.

1.1 Dourados: agricultural production and urban growth

The present study evaluates the role of natural energies in stimulating economic development with respect to Dourados' urban growth. The basic presumption is that the economic vitality of a region is determined by the density of the urban structure and the natural energies which it can draw upon.

Trends observed in previous studies (Regan, 1977) indicate that, depending upon the natural energy of a region, there is an optimal density of urban structure after which the rate of urban growth declines. The logistic nature of the model which describes this behaviour conforms to the parabolic energy corollary which states that maximum power occurs at 50% efficiency (Odum, 1996). In the case of Regan's Florida Counties study, mineral and soil energies declined in importance through time in some of the models, and wave and sunlight energies dominated the later period's timeframes. As Florida moved from a strong agricultural base to a recreational economy, with high emphasis and investments in infrastructure, the productive significance of these energies may indicate the decreasing importance of agriculture to the system in lieu of recreational pursuits. In Florida's case, this change might suffer a future reversal as fossil fuel energies external to the system decline, but cultural lags may impose economic hardships on a system excessively dependent on exogenous energy for recreational pursuits.

Dourados' simulation model explores the relationship between natural energies, grain production and cattle breeding, industrially processed products, economics and human population dynamics. Within the next 10 years, imported electrical energy may be substituted by a gas-fueled thermo-electric plant, making Dourados an energy exporter. The model identifies the main functional components of this system and their relationships, and interprets results in terms of the system behavior as a whole. It thus hopes to offer elements for a sustainable use of natural resources for different development scenarios with or without endogenous energy production.

1.2 Urban systems and natural resources

The investigation of the impact of urban systems on the environment, related to the use of energy and natural resources in the productive, commercial and subsistence processes is of great interest today, since historical processes are forcing human populations to constitute larger urban settlements (Bunker, 1982; Sachs, 1986). The maximization of the usage of resources or the waste of natural and produced energy sources, the integration of the components of the urban system in this equation, the spatial pattern of development of the town due to these relationships are critical factors to be analyzed.

Through the structuring, diagramming and monitoring of urban energy systems their behavior with time can be observed. The process of evaluation for public decision making should be based on the weighing of benefits and/or losses resulting from the use of resources (Postel, 1990).

The evolution of models that represent realistically the complexity of different urban systems is a constant challenge for urban designers and planners. Urban systems are not evaluated through a common indexing measure applied both to the internal processes within a city and to the energy contributions from the natural environment. The impact on ecosystems are also unrelated to the real energy costs that produced them. Studying the energy resource flows that connect urban activities to their natural environment, on the basis of a common indexing measure, can help define present distortions in urban systems.

System analysis concepts, energetic principles and computer simulations are here used to understand the character, quality and quantity of resource and energy flows which interact within the urban system and between it and the natural environment. Model simulation offers a dynamic instrument capable of identifying trends and helping in the evaluation of different alternatives of urban development.

This new conception defines the formulation of policies for development which take into consideration the environmental impacts derived through their application. It also defines administrative efficiency as the optimization between income, more humane working relationships, quality of the finished product and low environmental impact. *Ecodevelopment* is defined as a "development which is socially desirable, economically viable and ecologically prudent." (Sachs, 1986). The 'quality of life' is now a multidimensional and dynamic phenomenon which includes growth, rationality, spatial allocation and social and environmental impacts (Oliveira, 1993).

Present economic indicators require these new variables for the evaluation and measurement of regional, national and international economic activities.

2. Methods

The system under study is put into perspective by initially drawing a system diagram 'overview' using energy language symbols. It combines information about the system from various sources and organizes the efforts in collecting data. The process of diagramming an overview of the system of interest ensures that all driving energies and interactions are included. The diagram includes both the economy and the environment of the system and shows all relevant interactions.

An aggregated, or simplified, diagram is then drawn retaining the essence of the more complex version. This final, aggregated diagram is used to construct a model for the simulation. After defining the system boundaries, all pathways crossing them are evaluated. The generation of a family of curves of system storages helps to understand the system's behaviour in time, helping to evaluate the relative importance of the system's forcing functions.

2.1 Macroscopic minimodels

Macroscopic minimodels are a family of models that can help construct a large scale overview of the ecological and economic components of a specific system under investigation (Odum and Odum, 1989). They are macroscopic in that they represent a broad overview of the main determining components and the forcing functions within a system, its inputs and outputs and its workings within a larger system. They are also minimodels in that they aggregate various factors and simplify the general picture to quickly identify certain basic questions and define possible tendencies of that system with changes in the prevailing conditions. The integration of monetary flows within these models allow them to explore fundamental relationships between prices of production sold and goods acquired, between population and crop or animal production, in our case, between resources extraction rate, such as topsoil and soil fertility and environmental impacts.

2.2 Model conception

A model, as a summary of the important components of a system, represents a decision as to what activities are essential in that system. The relationships between sources, parts, storages and products are graphically defined in a diagram. System behavior results from these relationships. The system diagram is not just an important visual tool that establishes components functions and connections, but a mechanical statement that defines mathematical relationships, produces a set of related equations, written from the relationships shown, and integrates them into a computer program. These equations represent changes of each stored quantity. Simulating this program with available or made-up data will show what the system does over a period of time.

The integration of monetary flows within the model explores relationships between sold production prices and goods acquired, between population and crop or animal production, in our case, between resources extraction rate, such as topsoil and soil fertility and environmental impacts.

2.2.1 Calibration

Once data is available for most of the components in the model coefficients for the different pathways are calculated. Coefficients indicate flow rates along pathways and their values can be either observed data measured from real situations or made-up numbers to test model response.

2.2.2 Dourados' Production and Population Model

This macroscopic minimodel represents the impact of agricultural and industrial production on natural resources, according to increased or diminished industrial gains and assets, oil, natural gas and labor prices, as well as the relationships between industrial success or failure, population growth and immigration, and Dourados' assets.

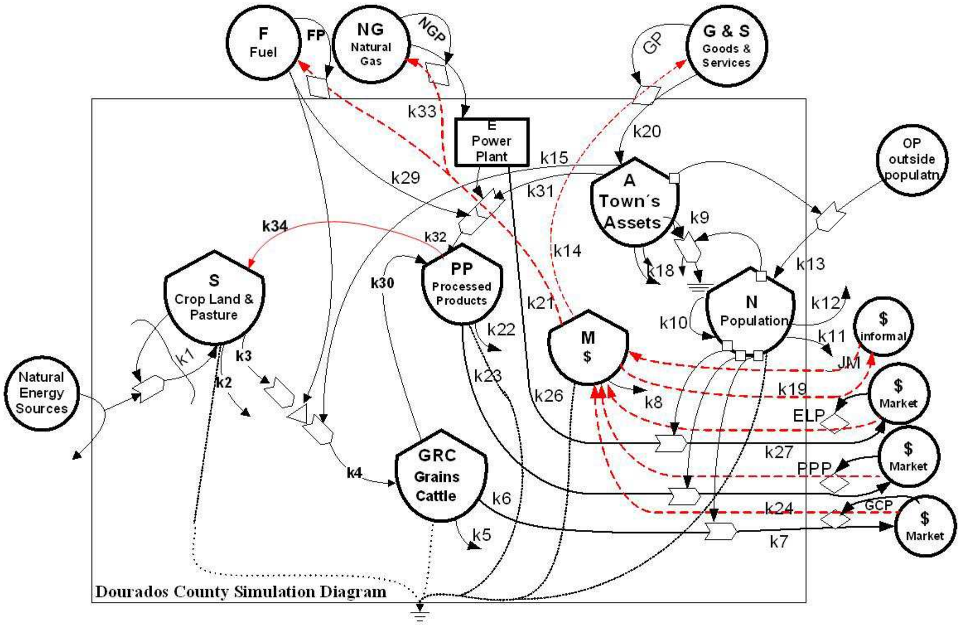

Figure 1: Dourados County simulation Diagram. Soil stock (S); Grains and cattle (GRC); Assets (A); Money stock (M); Processed products (PP); Population (N).

The model uses environmental energy inflows to soil stock (S) for crop land and pasture, purchased inputs and available labor of people who immigrate to generate useful products for exports. According to the model's diagram (Figure 1), natural resources on the left provide energy (I) which interacts with soil stock for crop land and pasture (S). Grains and cattle are harvested (GRC) from the stocked agricultural soil (S), at the rate dictated by assets (A).

All cattle and most grains go to outside markets. Rates of harvesting and cattle export also depend on market prices (GCP) for the finished product, on prices of goods and services (GP), fuel (FP), and natural gas import, having a certain effect on population numbers (N). Part of grains goes to processing products (PP), also dependent on their own market prices (PPP). Outside population (OP) is attracted to the town by increase in assets (A), dependent on money invested by industry (JM) and money from product sales. In Dourados' case some money received from export sales exits the system and what stays within it maintains industrial assets with technological additions to industrial efficiency. A natural gas-fueled electric power plant, E, might shortly transform Dourados from an energy buying to an energy exporting county. It would then sell the extra energy produced (240MW produced as against the actual 20MW peak demand) to the national network at a stipulated price (ELP).

The model is then based on rates of flow into and from six (6) stocking components: soil stock for grain crops and pasture (S), grains and standing cattle stocks (GRC), processed products stock (PP), Dourados' population numbers (N), its assets (A), and its money (M).

3. Simulation Results

Assuming available data for system components (IBGE, 2012)[i] and present flow rates correct, the model describes a peak situation with within the first three years (see Figure 2), where grain and cattle production (GRC) reach a maximum – from 450,000 tons/year actual production to 560,000 tons, but the money stock (M) plummets from a 900 million/year stock to around 50 million/year within 19 years, together with assets (A), after the first year of heavy investment in urban infrastructure (A). This cuts investments in farming and grains and cattle production also reach a very low level (50 tons/year) within the same period. Rapidly rising population (N) within the first 5 years, mostly due to immigration, stabilizes quickly around the 500,000 people mark.

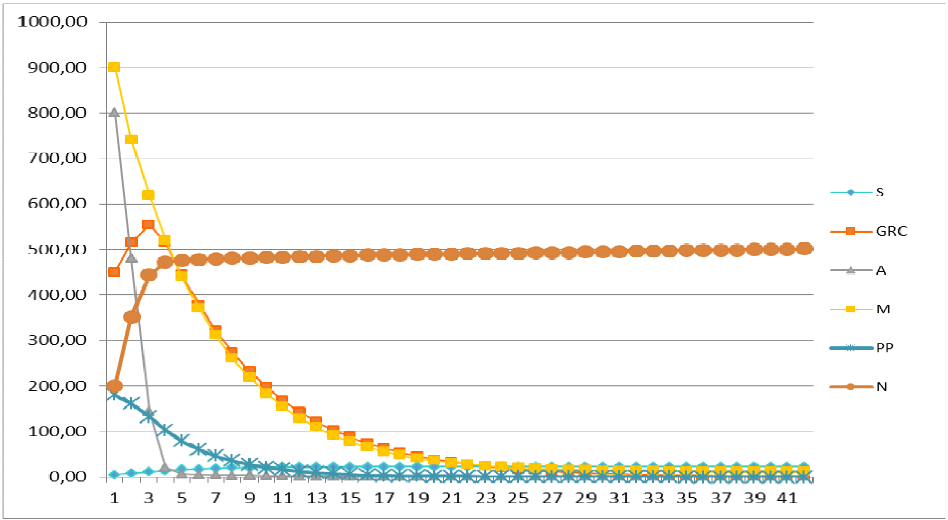

Figure 2: Model simulation output up to year 41. Soil stock (S); Grains and cattle (GRC); Assets (A); Money stock (M); Processed products (PP); Population (N).

Due to investment of organic manure from processed products (PP), soil resources (S, soil stock) slowly rise from an initial 5,000 tons/ha to around 30,000 tons/ha. Processed products rapidly dwindle to very low levels, characterizing the economy as a “boom and bust” one. Although soil is kept fertile by responsible farming techniques, it seems that the economy is in for a major crash, mainly due to a vertiginous increase in population numbers and investments in public social (schools, hospitals, recreation areas and security services) and technical infrastructure (road, water, electricity and communication networks).

How could the situation be reverted? Recently, Dourados artificially inflated its urban territory by a 265% increase in its land area. This was mainly due to manipulative and forceful speculation of land corporations and estate agencies. It is now forcing local municipal administration to invest heavily in infrastructure and, for this purpose, it has doubled the urban land taxes. Neither crops and cattle production, together with added value produced by processed products, are going to meet the challenge.

It is a very simple, deterministic model, but can help predict trends by altering flow rates, initial conditions and external contingencies, such as greater or lesser investment from the outside, changes in fuel, natural gas and market prices for goods and services, amongst others.

Investments in urban infrastructure must be viewed within the challenge of climate change in urban planning restructuring and management, aiming for greater sustainability. Clean air, water use, green urban areas and solid waste management within a watershed perspective, should be accounted for designing for greater urban soil permeability. The development of more autonomous city nuclei, interconnected by a rapid public transport network, should include a bicycle mobility plan. An integrated planning system and participatory public policy decision making tools for more sustainable urban design should include more environmentally friendly construction and disaster prevention planning.

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How to improve the energy-saving effect of China's urbanization?

Xi Ji[a, *]

[a]School of Economics, Peking University, Beijing 100871, China

Abstract

The rapid urbanization process has posed great challenges to China's energy system. This paper uses the Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model to evaluate the energy-saving effect of China's urbanization based on provincial panel data. The results suggest that: 1) The urbanization induces the energy consumption with a notable negative energy-saving effect; 2) The heterogeneity of urbanization impact on energy consumption is analyzed in different stages of urbanization, showing that the energy-saving effect of urbanization follows a U-shaped path; 3) Considering the heterogeneity of the energy-saving effect of urbanization at different income levels, the energy-saving effect increases with income level. The outcome may draw a causation picture on the relationship between energy consumption and urbanization. In addition, an in-depth causation analysis on energy inefficiency of China's urbanization is carried out and accordingly policy recommendations are put forward.

Keywords

Intensive urbanization; Energy-saving effect; Incremental reform; Market mechanism

1. Introduction

China's urbanization process gains its momentum in reshaping the global economic structure in this century. The average annual growth rate of China's urbanization maintains at about 1.37% during the past 10 years, meaning every year 10 million people at least changed their life style

*Corresponding author. Tel.: +86 10 62755283; fax: +86 10 62754237.
E-mail addresses: jixi@pku.edu.cn (Xi Ji)

from rural to urban, which has posed a great challenge to China's economic and energy system.

The possible improving living standard of the immigrants may increase the demand for energy. Fig.1 illustrates the comparison between per capita residential energy use of urban residents and rural residents in 5 regions including Jiangsu, Qinghai, Guangdong, Tianjin, and Henan to respectively represent cities in East, West, South, North and Central China over recent years. As the figure indicates, urban residential energy use per capita is indeed higher than rural use. The multi-year average shows that in Tianjin, the residential energy use per capita of urban residents is 4.1 times rural use and this figure in Jiangsu, Qinghai, Guangdong and Henan 2.3, 3.1, 1.3 and 2.7. Most rural residents have changed their lifestyles in certain ways and improved their living standards during the urbanization process. In pace with the improvement of living conditions and income levels, the consumption levels of urban residents also continue to increase, and their consumption patterns gradually shift from 'survival mode' to 'development mode', and even to 'enjoyment mode', which may directly or indirectly push up urban energy use.

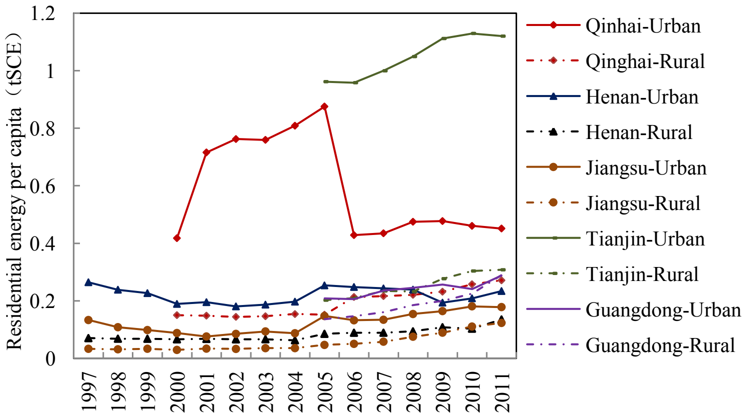

Fig.1. Comparison between residential energy use per capita of urban and rural residents in China's representative cities and provinces.

(Data Sources: Urban and Rural living energy consumption data of Tianjin, Jiangsu and Guangdong is collected from China Energy Statistical Yearbook; Data of Qinghai is from Statistical Yearbook of Qinghai 2001-2012; Data of Henan is from Statistical Yearbook of Henan 2001-2012. All energy data are unified into the unit of SCE referring to General Principles for Calculation of Total Production Energy Consumption（GB/T 2589-2008）. The population data of these provinces uses permanent population figure)

Urbanization process also means the concomitant production mode change of the immigrants and accordingly the industrial structure adjustment of the whole economy. Two streams of thought on cities' merits and demerits have been formed during the course of human's addressing energy and environmental crisis. One believes that the city is to blame for the emerging energy and environmental crisis. This view takes city as the main carrier of industrialization where fossil fuels are most intensively used, and urban production thus become the major human factor for energy scarcity (UN-Habitat, 2011; Chen and Chen, 2011; Chen and Chen, 2013). On the other hand, some scholars believe that with the agglomeration economy[1] and scale economy[2] taking shape in the urbanization process, the city is not only the driving force for economic growth, but can also play the role as an engine to tackle the energy and environmental problems (Wu and Wu, 2008; White, 1994; Romero-Lankao and Doman, 2011).

The recognition of the engine power of urbanization in promoting economic growth has approached a consensus, while will it be possible to safeguard a reliable energy delivery with the ongoing advance of urbanization in China? China is now standing at a new historical juncture when the new Chinese leadership is pinning their expectations on a new intensive, energy-saving and green urbanization strategy. So a sound understanding of the relationship between urbanization and energy consumption will offer an insightful perception into the sustainable development in China.

Some scholars have already conducted research on the relationship between urbanization and energy consumption. Jones (1991) explored the impact of urbanization on energy consumption with a regression analysis on the data of 59 developing countries in 1980, illustrating that although urbanization can benefit urban production through economies of scale, it stimulated traffic, and pushed up the modern energy consumption. Parikh and Shukla (1995) also carried out a regression analysis on 83 developed and developing countries in 1986, concluding that urbanization accelerates energy consumption and the concomitant carbon emission. York et al. (2003) assessed the STIRPAT, IPAT and ImPACT models for unraveling the driving forces of environmental impacts, and uncovered that urbanization has a promoting effect on both CO_2 emissions and energy footprint. A further work of York indicated that urbanization precipitates energy consumption even in some most modernized countries (York, 2007). Hossain (2011) analyzed the data of 9 emerging economies (i.e., Brazil, China, India, Malaysia, Mexico, Philippines, South

1 Agglomeration economy here refers to the economic benefit brought by the clustering of industries and economic activities.
2 Scale economy here indicates to the economic benefit from improved efficiency due to larger scale.

Africa, Thailand and Turkey) during the period 1971-2007, and observed that every 1% of urbanization rate growth leads to a 0.6% reduction of CO_2 emission. These studies demonstrate the simple relationship between urbanization and energy consumption, namely urbanization either pushes up or reduces energy use.

However, the impact of urbanization on energy varies at different stages of urbanization and economic development. That is to say, the effect of urbanization on energy is heterogeneous for the same country in different stages, and therefore, there is possibly not a simple relationship between urbanization and energy consumption. This conclusion has also been confirmed by some other studies. Poumanyvong and Kaneko (2010) offered an insightful view that some previous researches on the relationship between energy and urbanization were based on a hypothesis that the effect of urbanization on energy consumption was homogeneous for all countries; however, this hypothesis can not be justified, because countries on different levels of affluence are characterized with different features. They further effectively consolidated their research by discussing the effect of urbanization on energy consumption at different income levels, and the result showed that urbanization does generate more energy consumption overall, however, this effect turns out to be most significant among middle-income countries. Ji (2010) also supported a more comprehensive analysis on the relationship between urbanization and energy consumption against a rigidly uniform conclusion. Liddle and his colleagues' related study went to long lengths discussing the heterogeneity in the effect of urbanization on energy consumption of different countries, particularly on electricity consumption, private traffic energy consumption, and other environmental problems (Liddle, 2013a, b; Liddle and Lung, 2014).

Similarly, plenty of studies have concentrated on the relationship between China's urbanization and energy consumption. Wei et al. (2006) applied an input-output model to a scenario analysis of possible impact factors on China's energy consumption. The result reflected that urbanization will generally lead to an increase in energy consumption, and the impact of urbanization on the total energy requirements of the primary industry was obviously weaker than that of the secondary and the tertiary industry. In addition, Consumer Lifestyle Approach (CLA) (Wei et al., 2007) and Grey Model (Feng, et al., 2011) were employed for quantitative analysis on the respective effects of urban and rural lifestyles on China's energy use and CO2 emission, proving that the difference between urban and rural lifestyles directly influences the impact of urbanization on energy use and CO_2 emission, as the energy consumption structure of urban residents was more complicated, with both direct and indirect urban energy use larger than rural use. Zhang and Lin (2012) discovered a positive correlation between China's urbanization, energy consumption and CO_2 emission based on the data for 1995-2010. Wang (2014) found that despite urbanization could lower the growth rate of per capita energy consumption compared to rural areas, the total urban residential and production energy consumption was still larger than the rural, in other words, urbanization in general raised energy consumption in China.

Some scholars have now detected a possible more complicated relationship between China's urbanization and energy consumption, a typical example of which is the findings of research group headed by Liu. Liu employed ARDL (autoregressive distributed lag) and FDM (factor decomposition model) to prove a non-linear relation between China's urbanization and energy consumption over the period 1978-2008. The result manifested distinct long-term and short-term relationship between urbanization and energy, and a weaker impact of urbanization on energy consumption in the present stage than in the past (Liu, 2009). Liu and his research team then further demonstrated the non-linear and asymmetric relationship between urbanization and energy intensity, respectively taking the whole country of China and 7 regions in China as examples. Their research revealed a structural variable threshold effect in the relationship between China's regional urbanization and energy intensity. Before reaching the threshold value, the change of energy intensity is much faster than the change of urbanization rate; and after crossing the threshold, China's urbanization exerts an asymmetric effect on energy consumption (Liu and Xie, 2013).

Despite of the broad interest in the relationship between urbanization and energy consumption with various methods and approaches, few researchers have put their emphasis on quantitative analysis on the energy-saving effect of China's urbanization in different urbanization stages and at different income levels. This paper aims to fill this blank by giving a comprehensive analysis of the effect of China's urbanization on energy consumption during different urbanization stages (measured by urbanization rate) and at different income levels (measured by per capita income). In addition, this paper seeks to complement the existing research, by presenting an in-depth analysis of the impact factors on the energy-saving effect of China's urbanization, and moreover by putting forward targeted policy proposals to improve the energy-saving effect of

China's urbanization.

2. Material and Methods

2.1 Model

For convenience, the effect of urbanization on energy consumption is defined in this paper as the energy-saving effect of urbanization: when urbanization leads to the decrease of energy consumption, it has a positive energy-saving effect, and if conversely, it has a negative energy-saving effect. The less positive effect urbanization exerts upon energy consumption, the stronger energy-saving effect it has, and if conversely, the weaker energy-saving effect it has.

To evaluate the energy saving effect of China's urbanization, this paper employs the STIRPAT model which is reformulated by Dietz and Rosa (1994, 1997) on the basis of the IPAT model proposed by Ehrlich and Holdren (1971) as the basic calculation and analytical tool. The following regression equation is set up on the basis of STIRPAT model:

$$\ln I = a_0 + a_1 \ln P + a_2 \ln A + a_3 \ln T + e, \quad (1)$$

where, a_0 is the constant term of the equation; a_1, a_2, a_3 are coefficients; e is stochastic error; ln means taking natural logarithms of variables. In this equation, *I* represents environmental impact, namely the energy consumption in this research (denoted by '*energy*' in the model); *P* is population factor, here represented by total population (denoted by '*pop*') and urbanization rate (denoted by '*urban*'); *A* refers to affluence, here represented by GDP per capita (denoted by '*growth*'); *T* is technology factor, represented by industrialization rate (denoted by '*industry*'). Then, Eq. (1) can be further described as:

$$\ln energy = a_0 + a_{11} \ln pop + a_{12} \ln urban + + a_{21} \ln growth + a_{31} \ln industry + e, \quad (2)$$

where, a_{11}, a_{12}, a_{21}, a_{31} are the coefficients of variables of 'ln*pop*', 'ln*urban*', 'ln*growth*', and 'ln*industry*', respectively. On basis of Eq. (2), and referring to the result of Hausman Test, this paper employs heteroskedasticity-robust Fixed Effect model for regression.

2.2 Data

The panel data of 29 cities, provinces and autonomous regions in China over 1998-2010 are selected for regression analysis, excluding the Tibet and Xinjiang autonomous regions (due to missing data for these regions) and such special regions as Taiwan, Hong Kong and Macau (statistical methodology inconsistent with mainland provinces).

Total energy consumption ('*energy*') is calculated by summing the regional energy use in the

China Energy Statistical Yearbook, after energy unit conversion. Data for total population ('*pop*') is directly from the China Statistical Yearbook.

Data for urbanization rate ('*urban*') is calculated according to the basic data of the China Population Statistics Yearbook. As statistical methodology of China's urban population changed in 2000[3], the urban population proportion data released in the China Population Statistics Yearbook lacks consistency. With full consideration of this, the consistent data of urban non-agricultural population is used to make an update. China's non-agricultural population refers to people who live and work in cities with their household registered as urban, whereas the calculation of urbanization rate also includes people who live and work in cities for over 6 months, whose household is registered as rural. Therefore, the size of urban population is larger than that of the non-agricultural population, and it is necessary to make an update to the non-agricultural population data for the calculation of urbanization rate. This paper uses the following method to make this update: taking average ratios of urban population to non-agricultural population over 2000-2010 as the estimated proportion, multiplying non-agricultural population over 1998-1999 by this proportion to get continuous and comparable data of urban population; then calculating the urbanization rate according to the urban population to total population ratio.

The data of GDP per capita ('*growth*') is collected from the China Statistical Yearbook. Industrialization rate ('*industry*') is collected from the China Statistical Yearbook.

3. Calculation and Results

3.1 Considering the heterogeneity due to different urbanization stages

According to the 'S-shaped curve' which is the stylized version of 'urbanization curve' first suggested by Northam (1975), urbanization process can be divided into several stages. This paper divides the urbanization process in China into three identifiable stages: initial stage (urbanization rate <30%), acceleration stage (urbanization rate between 30%-70%), and terminal stage (urbanization rate >70%). Each stage has its own characteristics of economic scale, industry layout and energy structure, with a distinct energy-saving effect as well. Therefore, according to this three-stage theory, this study divides the panel data of 29 Chinese cities and provinces for

[3] Compared with the statistical methodology of urban population in 1990, the statistical scope in 2000 excluded populations in villages and townships administrated by municipal districts with population density less than 1500 persons/km^2, but included the population of outlying villages and townships within urban construction coverage, bringing the population of invisible urbanized areas into the urban population.

1998-2010 into three groups for respective regression, in order to present the relationship between energy consumption and urbanization in different urbanization stages.

Table 1 shows the results of the calculation considering the heterogeneity due to different urbanization stages: the coefficient of 'ln*urban*' is 1.105 in the initial stage, and increases to 1.620 in the acceleration stage, then drops to 0.615 in the terminal stage, with similarly first increasing then decreasing significance level. This result reveals that China's urbanization increases energy consumption most significantly in the acceleration stage, while the positive effect is the weakest in terminal stage. Urbanization's impetus to energy consumption follows an inverted-U shaped curve, that is, the energy-saving effect of urbanization shows a U-shaped path.

Table 1
Energy-saving effect of urbanization: considering different urbanization stages.

	Initial Stage	Acceleration Stage	Terminal Stage
Variable	Lnenergy	Lnenergy	Lnenergy
Lnurban	1.105*	1.620***	0.615
	(0.507)	(0.241)	(2.253)
Lnpop	2.504	0.204	1.742
	(1.665)	(0.691)	(0.749)
Lngrowth	4.088	5.042***	4.351
	(3.445)	(1.658)	(2.142)
Lnindustry	-0.060	1.374***	0.712
	(0.577)	(0.465)	(0.312)
Constant	-35.400*	-28.066***	-29.976*
	(16.119)	(7.567)	(9.687)
Observations	53	281	39
R-squared	0.768	0.801	0.878

***P<0.01
**P<0.05
*P<0.1

3.2 Considering the heterogeneity due to different income levels

A high urbanization level does not necessarily correspond to a high income level, and vice versa. Under different income levels, the energy-saving effect of urbanization might also differ, on which we need to do further investigation. This paper divides the panel data of 29 cities and provinces for 1998-2010 into 3 groups according to the income level classification standard proposed by World Bank in 2009[4]. These are low income, lower-middle income and upper-middle income. The high income group is excluded since only Shanghai (in 2010) among the panel data reached this level.

The results of the calculation allowing for the heterogeneity of different income levels are shown in Table 2: regression results for low income group show the coefficient of 'ln*urban*' is 1.620 and becomes significant at the 0.01 level; for lower-middle income group, the coefficient is slightly smaller than that of low income group, also significant at the 0.01 level; and for upper-middle group, not only the coefficient but also the significance level obviously declines/slide, declaring that the energy-saving effect of China's urbanization strengthens along with the lifting income level, that is, the energy-saving effect of urbanization is weakest at low income level, and strongest at upper-middle income level.

Table 2
Energy-saving effect of urbanization: considering different income levels.

	Low Income	Lower-middle Income	Upper-middle Income
Variable	lnenergy	Lnenergy	lnenergy
Lnurban	1.620***	1.489***	0.183
	(0.216)	(0.222)	(1.711)
Lnpop	0.463	-1.019	2.194**
	(0.526)	(0.725)	(0.850)
Lngrowth	5.747***	5.767***	4.005
	(1.881)	(1.586)	(4.081)
Lnindustry	1.074**	1.601***	0.312
	(0.442)	(0.510)	(0.323)
Constant	-32.435***	-21.821***	-28.829
	(7.712)	(7.587)	(15.498)
Observations	76	220	76
R-squared	0.771	0.764	0.875

***P<0.01
** P<0.05
*P<0.1

4. Discussion

4.1 Heterogeneity for urbanization stages

Taking into account the heterogeneity of urbanization's impact on energy consumption at different urbanization stages, it is found that the energy-saving effect of China's urbanization

4 Countries with annual gross national income per person less than USD 1005 are low income countries; USD 1006-3975 are lower-middle income countries; USD 3976-12275 are upper-middle income countries; above USD 12276 are high income countries.

comes in a U-shaped curve. There are possibly three main factors exerting influence on energy-saving effect of urbanization: the scale effect, technological effect and structural effect.

Scale effect refers to the causal relationship between expanding economic scale and growing energy consumption, which is different from the scale economy mentioned in section 1.1. In 2011, China's urbanization rate doubled that in 1997, and GDP per capita soared/leaped fivefold. According to the data released in the China City Yearbook 2011, the average GDP of the 10 largest cities accounted for 43.2% of the total cities, and the share of the largest city was 7.66%.

Whether in its initial, acceleration or terminal stage, urbanization has a long-term scale effect on energy consumption. In the initial stage, economic scale expands at a relatively low rate, and the scale effect is not very obvious; in the acceleration stage, when economic scale expands at the fastest pace, the scale effect is also most evident; when stepping into the terminal stage, the economic scale almost reaches the peak, and the expansion slows down, with insignificant scale effect once more in this period.

Technological effect here refers to the causal relationship between technological advance and the reduction of energy use. Generally, technological effect leads to a positive energy-saving effect of urbanization (Ji, 2010). Cities are the direct and largest beneficiaries of technology innovation. Although rural areas might suffer from the possible shift of resource waste and environment pollution (Chen and Chen, 2007; Chen and Chen, 2007), it cannot be denied that technology innovation lifts the urban production efficiency and progressively lowers the energy use per unit of GDP. Technology can enhance the positive energy-saving effect of urbanization to some extent, especially during the terminal stage of urbanization: the experience accumulated through the early and middle stages can help improve functions and the forming of new technology and ideology in the terminal stage, so that the technological effect will become stronger along with the advance of urbanization.

Structural effect refers to the causal relationship between the change of economic structure and the change of energy consumption. The economic structural adjustment is a variation on the theme of urbanization: in the initial stage, agriculture usually takes predominant position; and then agriculture-oriented structure shifts to an industry-oriented structure during the urbanization progress. Many countries at this stage including China, experience a transition from heavy to light industry. When urbanization steps into the acceleration and the terminal stages, the economy will gradually shift to a service-based structure.

Fig.2 shows China's energy use per unit of GDP by different sectors in 2007. This figure suggests that energy use per unit of GDP for heavy chemical industries, including Smelting and Pressing of Ferrous and Nonferrous Metals, Nonmetal Mineral Products, Coal Mining and Dressing, Petroleum Processing and Coking, Gas Production and Supply, Chemical Products Related Industry, was far larger than for the agricultural industry, as well as most light industries and service industries[5](Ji, et al., 2014).

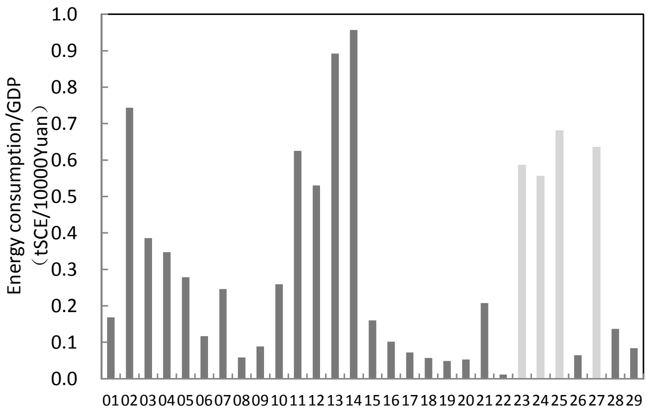

Fig.2. China's energy use per unit of GDP in different sectors in 2007.

(Data Source: energy consumption of different sectors and GDP data are collected from China Statistical Yearbook; The serial numbers in the x-axis correspond to the sectors as shown in Table 4)

Table 3

The corresponding sectors of the serial numbers in the x-axis in Fig.2.

Code	Sector
1	Farming, Forestry, Animal Husbandry, Fishery and Water Conservancy (Agriculture)
2	Coal Mining and Dressing
3	Petroleum and Natural Gas Extraction
4	Ferrous and Nonferrous Metals Mining and Dressing
5	Nonmetal and Other Minerals Mining and Dressing
6	Food Processing, Food Production, Beverage Production, Tobacco Processing
7	Textile Industry
8	Garments and Other Fiber Products, Leather, Furs, Down and Related Products

5 Some service industries including Electric Power/Steam and Hot Water Production and Supply, Gas Production and Supply Industry, Transport, Storage and Post, have the nature of public welfare dating back to the planned economy, therefore the cheap heating, water and electricity supply with municipal subsidies actually causes large energy use per unit of GDP. These sectors, which are different from those participating in market competition, are atypical for discussion and thus de-emphasized in the chart.

Code	Sector
9	Timber Processing, Bamboo, Cane, Palm and Straw Products, Furniture Manufacturing
10	Papermaking and Paper Products, Printing and Record Medium Reproduction, Cultural, Educational and Sports Articles
11	Petroleum Processing and Coking, Gas Production and Supply
12	Raw Chemical Materials and Chemical Products, Medical and Pharmaceutical Products, Chemical Fiber, Rubber Products, Plastic Products (Chemical Products Related Industry)
13	Nonmetal Mineral Products
14	Smelting and Pressing of Ferrous and Nonferrous Metals
15	Metal Products
16	Ordinary Machinery, Equipment for Special Purpose
17	Transportation Equipment
18	Electric Equipment and Machinery
19	Electronic and Telecommunications Equipment
20	Instruments, Meters Cultural and Office Machinery
21	Manufacture of Artwork and Other Manufactures
22	Waste
23	Electric Power/Steam and Hot Water Production and Supply
24	Gas Production and Supply Industry
25	Water Production and Supply Industry
26	Construction Industry
27	Transport, Storage and Post
28	Wholesale, Retail Trade and Hotels, Catering Service
29	Other service industries

In summary, the existence of the structural effect generally leads to a negative energy-saving effect from urbanization at first, which gradually turns to a positive energy-saving effect in pace with structural upgrading.

Looking at the scale effect, technological effect and structural effect, it is not hard to find that in the initial stage of urbanization, the technological effect and structural effect seem to be inappreciable, while the scale effect, although also insignificant, is comparatively the main factor influencing energy consumption. Hence urbanization takes on negative energy-saving effect in this period. When urbanization steps into the acceleration stage, the scale effect becomes the most significant, while the technological effect is only just emerging, and the structural effect has not yet turned from negative to positive. In this regard urbanization still has a negative energy-saving effect. In the terminal stage however, the scale effect begins to shrink, and the technological effect and positive structural effect can offset the scale effect. Urbanization does not necessarily initiates\

increased energy use any more, and instead it can reduce energy consumption, leading to a positive energy-saving effect. This can clearly explain the inverted-U curve in the relationship between China's urbanization and energy consumption. In China, although there is still a negative energy-saving effect in the terminal stage of urbanization, it appears not to be that significant anymore.

4.2 Heterogeneity for income levels

Considering the heterogeneity of the energy-saving effect of urbanization caused by varied income levels, the energy-saving effect of China's urbanization rises with the improving income level. A high urbanization rate does not always yield a high income level. Some differences of the energy-saving effect of China's urbanization exist at varied income levels and in different urbanization stages. In China, the energy-saving effect of urbanization in the initial urbanization stage is stronger than that in the acceleration urbanization stage, while that at a low income level is weaker than that at a lower-middle income level.

By comparing the samples of the low income level group with the samples in the initial urbanization stage, it can be recognized that most samples in the initial urbanization stage belong to the low income level group, however, many of the low income level samples do not belong to the initial stage group, but are in the acceleration stage instead. For instance, data of Shanxi, Inner Mongolia, Jilin, Anhui, Hubei, Hunan, Hainan, Chongqing, Qinghai, Ningxia and some other provinces in several years are classified as low income level samples, but these provinces and regions are all in the acceleration stage of urbanization. The follow-up comparison suggests that many of the lower-middle income level samples are in the terminal stage of urbanization. In section 3.1, this paper analyzes the reasons why energy-saving effect of urbanization is relatively weaker in the initial stage of urbanization, weakest in the acceleration stage and strongest in the terminal stage from the perspectives of scale effect, technological effect and structural effect. Therefore, it is easy to understand that the energy-saving effect of urbanization for low income samples should be weaker than that of lower-middle income level and upper-middle income level samples.

The low-income sample regions in China are equipped with more extensive development mode, more inefficient industrial structure, a lower technological level, and consequently lower energy efficiency. This low energy efficiency is partially determined by China's development stage and the structure of international labor division, and partially results from China's history giving priority to heavy industries. Among the original sample data in this analysis, the cities and provinces in the center, west and north of China including Sichuan, Chongqing, Guizhou, Hunan, Hubei, Henan, Inner Mongolia, Shaanxi, Shanxi, Jilin before 2006 are classified as in the 'low income' group. These cities and regions depend on heavy industry and resource industries with larger energy use and lower energy efficiency. Therefore, it is not surprising that the elasticity of energy use relative to urbanization in these regions is higher.

The elasticity of energy use relative to urbanization at the upper-middle income level is neither very high nor significant, which, similar to the condition in the terminal urbanization stage, is also mainly triggered by technology upgrading or structural optimization.

5. In-depth cause analysis on the negative energy-saving effect of China's urbanization

Cities facilitate the formation of scale economy, agglomeration economy and specialization economy better than other human inhabitation modes; therefore urbanization provides opportunities for efficient and intensive utilization of energy. However, as the results of this study suggest, urbanization does not always improve energy efficiency, and its energy-saving effect is actually subject to multiple factors. This study reveals the following underlying reasons for the low energy efficiency at China's present urbanization stage.

5.1 Development stage

China is in the middle stage of industrialization and the acceleration stage of urbanization. Mass industrial production, accelerating urban construction and the improving living standard of city residents all add to the demand for energy. This is the rigid demand at the current economic development stage in China. Whether for China or other countries at such a stage, the negative energy-saving effect of urbanization is invariably and partly caused by rigid demand of energy.

5.2 Problems rooted in history

China's urbanization has long been controlled and dominated by the government. Historical problems, including the planned economy before the reform and opening up, the 'catching-up' strategy for heavy industry, the establishment of the household registration system, and the reform of townships into municipal districts, paved the path for China's urbanization with a strong characteristic of passive advance pushed by the government. This has influenced the energy-saving effect of China's urbanization in two main aspects:

1) The urbanization path dominated by the government deviates from the universal rule of market-lead urbanization, thus it curbs the energy-saving effect of urbanization.

China's special political system and strategies make it difficult to push an active bottom-up urbanization path. The government-lead urbanization is greatly influenced by political factors, and easily deviates from the universal urbanization rules dominated by the market. Urbanization is a process of re-allocating and integrating resources. In the market-oriented urbanization process, the market commands and controls resources allocation, while urbanization follows market rules and obeys market selection, and the law of 'survival of the fittest in the market' generally applies to population mobility, capital accumulation and industry evolution. In the urbanization process driven by industry upgrading and economic development, the agglomeration economy, scale economy and specialization economy due to urbanization could give full play in raising the efficiency of resource allocation and utilization, and facilitating the intensive and effective use of energy. In the urbanization process driven by administrative power, however, the role of the market is weakened, while government directs the allocation of most resources. The rise and fall of China's heavy-industry oriented cities and resource-based cities, the crisis of land-based finance, and the local government debt problems, are all inseparable from the government-lead urbanization process, where the strength of cities in resource utilization is suppressed, and the energy-saving effect is consequently curbed as well.

2) The city planning pattern that attaches more importance to the function for production than that for life cannot be adapted to fast-paced urbanization.

Since the first five-year plan period, China has followed the 'catching-up' industry strategy, giving priority to heavy industry and pushing the rapid development of many heavy industry-oriented cities. During the urbanization process which was mainly driven by heavy industry, the city planning was biased towards production function, and neglected the living function. Although China has advocated multiple paths of urbanization since 1982, the old city layout still hinders many cities from fitting the rapid urbanization process. The update of infrastructure cannot keep up with the growth of urban population, leading to city congestion and low efficiency in production and life. Under the approach of stimulating economic growth by increasing infrastructure investment, the urban sprawl or city reconstruction is not only unhelpful for the improvement of energy efficiency of old cities, but also boosts energy demand, especially the non-rigid demand.

5.3 Development mode

China's urban and economic development is comparatively extensive at the current stage, which is mainly reflected in the following two aspects:

1) Structural extensiveness

China's industrial structure is composed of bloated energy-based industries and few labor, technology and capital intensive industries. The data of the year 2007 suggests, the sectors with large energy use per unit GDP also had the largest production scale, such as Iron and Steel, non-Ferrous Metals, and Chemical industry, while the development of some high-efficiency, labor intensive and high-capacity industries was still urgent.

2) Technological extensiveness

The backward technological level has been one of the major reasons for the low overall efficiency of China's economy. In 2007, for instance, China's energy consumption of primary products in many sectors including Iron and Steel, non-Ferrous Metals, Petrochemical, Electric Power, Building Materials, Chemical, Textile, was on average about 40% higher than international advanced level. Moreover, both the economic efficiency and the emission standard of China's vehicle fuel were much lower than the European levels. China's energy equipment manufacturing still lags far behind the most advanced international levels, with core technology and advanced large equipment highly dependent on importation.

5.4 Unsound mechanism of energy and resource system

China is still in an economic transition period, when the market is taking the place of central planning as the key decision maker in resource allocation. However, China's market mechanism still needs improvement, especially in the energy and resource field. Taking heating, water and electricity supply as an example, at present these sectors are still featured by public welfare, and the low price of the products and services with government subsidies neither reflects the scarcity of energy and water resources, nor covers the real cost of the supply (making matters worse, the low-priced resource benefits the middle-high class, while the low-income and poverty populations can hardly enjoy the social welfare because their residences are usually beyond the cover of public facilities, thus urban energy poverty is very common in China). In addition, for resource and environment issues, the obscure definition of property rights works against the intensive use of energy resources. In some important energy resource fields, significant administrative monopoly, market monopoly and ineffective competition left over from planned economy era, all result in the waste of energy resources in the production and utilization process.

6. Conclusions and policy implications

6.1 Conclusions

Based on China's provincial panel data, this paper evaluates the energy-saving effect of China's urbanization by employing the STIRPAT model. The main conclusions are as follows:

1) Considering the heterogeneity of the impact of urbanization on energy consumption in different urbanization stages, the energy-saving effect of China's urbanization follows a U-shaped path. Although a negative energy-saving effect can be observed across all stages of urbanization, it is particularly significant in the initial and acceleration stages and intensifies with the urbanization advance, yet when moving into the terminal stage, this negative energy-saving effect obviously declines, and is no longer as significant as in the previous stages.

2) When the heterogeneity of the energy-saving effect of urbanization at different income levels is involved, although China's urbanization still shows a negative energy-saving effect throughout all income levels, it can be observed an increase of the energy-saving effect as the income level increases. For the low income level, urbanization obviously increases energy consumption, while for the lower-middle income level, the increase in energy use gradually reduced, and for the upper-middle income level, this increase becomes insignificant.

Compared with the related research on the relationship between urbanization and energy consumption in China, this paper further underlines the heterogeneity of the energy-saving effect of urbanization in varied urbanization stages and income levels. In addition, this paper gives an in-depth discussion of the factors that cause the low energy efficiency of China's urbanization, including urbanization stage, problems rooted in history, development mode, and management mechanism, providing some unique perspectives lacking in most existing research.

6.2 Policy implications

China's economic development is facing mounting energy challenges. Whether the advance of urbanization can goes smoothly depends on whether the predicament of resource and environmental limitations can be overcome. In order to achieve the energy-saving potential of urbanization, China should confront its development stage and problems rooted in history, encourage reform of the system, structure and technology, and increase the urbanization rate without compromising on urbanization quality. To promote intensive, energy-saving and green urbanization, the following policy proposals are suggested:

1) Focus on the 'incremental reform', supplemented by the improvement of current 'stock'

China's urbanization rate barely exceeds 50%, that is to say, only half of the Chinese population are urban residents. For China's urbanization path, both 'stock-based reform' and 'incremental reform' are worth considering.

'Stock-based reform' refers to the reform of old cities (that is, the current 'stock') based on long-standing unreasonable planning. Many local governments desire reconstruction of old cities' infrastructures, but on the one hand the bulldozing and rebuilding may cause new chaos and congestion, and on the other hand the stereotyped planning may not help to solve the fundamental problems, and may also cause new energy and resource waste. As 'stock-based reform' is concerned, this paper suggests making more effort in mechanism innovation first, such as rationalizing the price mechanism, optimizing the tax rules, building the credit system, and strengthening public supervision, so as to internalize the environmental and social external cost for both industrial and residential users efficiently. Secondly, a healthier urban consumption ideology should be advocated including guiding rational consumption, spending wisely and saving diligently, resisting extravagance and waste, and reasonably controlling the excess capacity consumption. In summary, 'stock-based reform' should place more emphasis on improving mechanisms, supplemented by rebuilding facilities.

'Incremental reform' targets newly designed municipal districts or newly rising towns and cities. 'Incremental reform' must conduct overall planning in combination with the needs of production and livelihood, and organically integrate the principle of intensive, energy-saving and green development into urban planning, so as to increase the urban productivity and improve the convenience of urban life. The new industrial planning should avoid further redundancy in excess capacity industries and eradicate high energy consumption and high emission industries. It is suggested to encourage reasonable layouts for residence and industrial parks and enhance the job-housing balance so as to reduce daily commuting time and lower the cost of congestion. Public services including medical care, traffic and education facilities also require rational layout to increase the energy efficiency of urban life and cut down the cost of urban residential energy. Urban construction must be conducted on the basis of actual demand, and the feasibility of large-scale infrastructure has to withstand strict verification to eradicate blind competition or vain pomp leading to redundant projects.

2) Advocate the 'active' bottom-up urbanization instead of the 'passive' government-lead and top-down urbanization

There are four main driving forces for urbanization. The first is the cities' own pulling force due to the sound public infrastructure including education and health services, as well as employment opportunities. The second is the spontaneous lifting force during transition due to regional economic growth and industrial upgrades. The third is the pushing force from rural areas, mainly caused by the underdeveloped rural economy and unsound rural infrastructure. The fourth is the administrative force which directs the population and resource flow by administrative allocation. Urbanization mainly driven by cities' pulling force or regions' lifting force is obviously different from that driven by rural areas' pushing force or the government administrative force. The former is defined as the 'active' urbanization in this study, while the latter is the 'passive' urbanization. In the active urbanization process, urban economic level, industrial structure and infrastructure are ready to accommodate new population and resources, and the cities can maximize the potential in resource utilization, so that urbanization quality can be guaranteed. Urbanization driven by rural pushing force easily results in 'excessive urbanization', represented by unemployment and urban slums. Urbanization driven by administrative power, similarly, will possibly lead to 'semi-urbanization', which cannot fully attain urban potential or guarantee urbanization quality.

In brief, to improve urbanization quality, it is necessary to insist on a market-oriented 'active' urbanization path from the bottom up, driven by economic development and industrial upgrades. For one thing, urban and regional infrastructure and public services including health care, education and energy facilities should be encouraged and improved, and urban-rural connecting infrastructure should be promoted to expand the scope of the benefits from the growing urban economy and to avoid the passive flow and migration of population. For another thing, the government should reduce administrative intervention, and allow the market mechanism to determine resource allocation, and abandon the mode of guiding urbanization by land confiscation or administrative division. Most importantly, it is suggested to actively develop the urban economy, upgrade the urban industrial structure, improve the urban infrastructure and urban management system, so as to effectively guarantee the ‘active’ advance of urbanization.

3) Increase the efficiency of rigid demand and eradicate the non-rigid demand

Compared with other countries at a similar urbanization stage and economic development level, there is still large potential for improvement in the efficiency of China’s rigid energy consumption. Firstly, China should review the relationship between the industrial evolution and urbanization. Compared to developed countries in the early and middle stages, the historical heavy industry-based strategy dramatically pushed the rigid energy demand and has made energy problem a barrier for urbanization progress given today’s increasingly scarce energy resources. To rectify this long-standing problem, the relationship between China’s industrial evolution and urbanization should be determined to further stress the role of light industry and the service industry in promoting urbanization progress. In addition, China’s industrial layout should be reviewed in order to lower the energy cost by spatial optimization. Currently, China is vigorously promoting the national main function zoning strategy, designing the industrial layout in accordance with national main function zones, comprehensively allocating factors such as resources, environment, and logistics, and giving priority to the central and western regions with rich energy for energy-intensive industry layout, in order to slash the cost of energy resource transportation.

Moreover, non-rigid demand for energy is very high in China’s urbanization process. For instance, the high urban production energy due to the irrational expansion of production scale in defiance of the excess capacity; the redundant urban construction and the vain comparison game; and the unnecessary production caused by obsessive pursuit of GDP. Another example is, the high urban residential energy use due to the extravagant and irrational urban consumer culture. On the one hand, investment in industries with excess capacity should be limited to reduce surplus capacity. On the other hand, reform should proceed on the existing financial and taxation system, as well as the political targeting of economic achievements. A comprehensive and diversified political achievement evaluation system should be built that suits local conditions, supplemented with a supervision mechanism. At the same time, an incentive mechanism to eradicate urban redundant construction and irrational production should be introduced. The improvement of high urban residential energy consumption requires further advances in energy mechanism reform. To eliminate over-consumption without compromising on people's wellbeing, it is urgent to adjust the urban energy pricing system. For one thing, China should accelerate the urban energy livelihood projects to ensure that the municipal heating and electricity supply network cover the urban poverty population, set up a minimum living standard price for heating and electricity supply, and eliminate the urban energy poverty. For another thing, for consumption beyond the minimum living standard, it is necessary to build a pricing system that reflects the scarcity of energy, and to push forward tiered energy pricing. For industrial users, it is recommended to set differentiated price according to the industrial property, and set punitive high price for excessive energy use. For residential users, it is recommended to implement and improve multistep electricity pricing system.

It can be recognized that many of above policy proposals are concerned with the relationship between market and government. Indeed, to increase the energy-saving effect of China's urbanization, it is essential to clarify the relationship between market and government. The market mechanism should be respected, allowing the market to play the role as the major decider of the allocation of population, resource and environment during the urbanization process. Meanwhile, the role of the market mechanism in environment governance should be underlined. Due to the deficient or unsound price mechanism and property rights mechanism for resource and environment management, the 'market failure' in respect to resource and environment problems actually reflects the 'government failure'. Therefore, it is necessary to establish a sound price and property rights mechanism to exert incentive effect on individuals, enterprises and the whole society, in order to realize the internalization of social and environmental external costs in the most efficient way. The government, on the other hand, should provide stronger supervision mechanism and fairer public services. In summary, allowing the market to maximize efficiency, while the government guaranteeing fairness, so as to truly ensure the implementation of the intensive, energy-saving and green urbanization strategy in China.

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[1]Exergy Assessment for Energy Efficiency in Qinghai, China

Rui Kong, Fangfang Xue*

School of Humanities & Economic Management

China University of Geosciences (Beijing), Beijing 100083, China

1. Introduction

The purpose of this study is to clarify the link between energy consumption and economy and environment pollution in Qinghai Province. It is aimed at providing an effective basis for decision making in terms of economic development, environmental protection, and urbanization and so on in Qinghai. Qinghai is located in the northeast of Qinghai-Tibet plateau, covering an area of 72.23 x 10^4 km^2 (data from Qinghai Province Government, 2013), which is an important ecological source and cushion area in western China. It's an integral part of the national strategy “One Belt and One Road". The study in Qinghai has a practical significance.

1.1. Overseas and Domestic Research Status

Energy exploration and consumption has derived economic growth while consuming natural resources reserve. Therefore, studying energy safety and sustainable development is crucial. Looking back, energy study is mainly divided into three parts. Firstly, It is natural to pay attention to all parts of the value chain of economically use and better management of energy including ways of exploration, development, production, supply, reserve and consumption (Andrea Trianni, 2014; Massimo Filippini, 2014; Huifeng Pan, 2013; Hong Li, 2014). Secondly, lay emphasis on the role play by energy on social activities, such as national strategy, defense and environment protection (Rui Kong, 2014; Gong - Bing Bi, 2013). Thirdly, focus on economic and sustainable development. Economic benefits of a country or region based on energy resources have been analyzed by using economic principles, such as unit energy efficiency analysis (Dan Shi, 2002; Dong Wang, 2014). Management knowledge has been used to analyze for energy efficiency in an enterprise or a country, such as economic evaluation on energy use (Rui Kong, 2011; Hailin Shi, 2011; Shixiang Li, 2008). Analyze energy consumption by using thermodynamic principle and its impact on surrounding environment and related sectors (Hongtao Duan, 2012; Mert Gurturk, 2014)

Pressure on ecological degradation from energy use has become a hot topic in recent years. Lots of evaluation criteria could be used for the issue, such as conventional energy efficiency, energy consumption per unit output value, the output value of unit energy consumption, energy consumption per unit services, unit energy consumption and so on (Wang, 2003; Bo Zhang, 2012).

1.2. The Economic Development Status of Qinghai Province

According to data from the statistic bureau, the GDP of Qinghai is recorded as 210.105 billion Yuan, ranking 29th of 31 provinces in China in 2013. But annual growth rate is increased by

[1] Project supported by the development strategy of important mineral resources in Qinghai Province (China Geological Survey, Grant NO.03128031).

10.97% from a year ago, ranking 7th. And over the past decade, growth rate of GDP on monthly basis has been higher than the national average.

Along development, much attention has been paid on resources depletion and environmental pollution. Over the past 20 years, the power consumption has been huge in Qinghai, 50.19% (1994), 42.58% (2004)46.88% (2013). Coal consumption rate has also been high, 40.27% (1994), 27.56% (2004)31.24% (2013).Energy has made a great contribution to local economic development. Coal, oil and natural gas production accounted for 66.35% of the total mineral resources production in Qinghai , and 49.48% of the total industrial revenue in 2011(China's mining industry yearbook, 2012). Therefore, studying connections between energy structure and economy is very meaningful.

1.3. Raising Questions

From statistics, Qinghai’s hasn’t made big contribution to China's overall economy. But its development speed and industrial structure should be noted. With increasing energy consumption, energy structure becomes more prominent as it is bearing on local development environment fortune. So the research of Qinghai is critical.

In addition, literatures show that many studies are focusing on a country or a region rather than in specific areas by using thermodynamic theory. Using the theory could better reflect relations between energy consumption and environment in different industries.

2. Ideas and Solutions of Researching

The data is from statistics released by the central and local government in 2014. Thermodynamic theory of exergy is chosen as the analysis means. So assume that Ⅰ: the data is credible, and meets all conditions of using exergy theory; Ⅱ: environmental condition such as temperature changing has no impact on the study. Ⅲ: energy consumption and output of unit energy consumption in Qinghai are increasing; Ⅳ: its emissions and emissions of unit energy consumption continue to grow.

Economy related thermodynamic theory is measured through two indicators, energy consumption per unit of output value and output of unit energy consumption. Energy consumption per unit of output is equal to the ratio of energy used for output to GDP of a country (or region, department, industry) in a certain period of time (Hongfei Zheng, 2004). Output of unit energy consumption equals to the ratio of GDP of a certain country (or region, department, industry) to energy consumed for the output. Exergy equals to certain energy consumed for the output multiplied by the coefficient of the energy in a country (or region, department, industry) (Hailin Shi, 2011) (table 2.1). Electricity has 100% of the work ability, so its exergy equals to its power (Hongfei Zheng, 2004).

Table 2.1: conventional energy exergy coefficient

Name	coal	Crude oil	Petrol	Diesel oil	Coal oil	Natural gas
[1]LHV(kJ/kg)	20908	41816	43070	42652	43070	55448
[2] exergy coefficient	1.08	1.08	1.06	1.07	1.07	0.93

Data sources: 1 national standard of the People's Republic of China general principles of the comprehensive energy consumption calculation (2008).2 zafer Utlu b. (2007), Chen, G.Q. Chen (2006).

Energy efficiency also depends on the impact on other systems. The environment related thermodynamics could be indicated by emission of unit energy consumption. It means the ratio of pollution emissions to energy consumption in a system in a certain time (Hailin Shi, 2011).

This research analyzes the energy consumption and pollutant emissions both generally and individually before studying structure of the energies and emissions.

3. The analysis of the energy input in Qinghai Province

3.1. The exergy of energy investment

In this study, energy consumption equals to energy inputs. The total energy structural data, according to GB/T2589-2008, is converted into energy consumption. Then calculation results show that exergy value of the total energy input is 190.23 x 10^{12}kJ in 1994 and jumped to 1144.09 x 10^{12} kJ in 2013. The monthly growth speed is in the same trajectory as economic growth, which shows local economic development consumed more energy. But the energy efficiency is not high. The energy consumption per unit of output in Qinghai is declining from 1.32 x 10^4 kJ/Yuan in 1994 to 0.53 x 10^4 kJ/ Yuan in 2013. Output of unit energy consumption is improved from 0.73 Yuan/10^4 kJ in 1994 to 1.84 Yuan / 10^4 kJ in 2013. It proves energy efficiency is on a rising trend.

3.2.The analysis of industrial energy exergy

Data shows that contributions by industries to the economic development have been different in the last ten years. Secondary industry is the biggest contributor and it is developing faster. The energy consumption also grows rapidly from 105.50 x 10^{12} kJ in 2004 to 315.50 x 10^{12} kJ in 2013. Due to increasing GDP growth rate, energy consumption per unit output value is dropping from0.69 x 10^4 kJ/Yuan in 2004 to 0.33 x 10^4 kJ/Yuan in 2013.

According to energy consumption and the exergy coefficient table 2.1, exergy of various energies are got. It shows that the total energy exergy has been increasing in recent years, with increasing total input energy and continuous economic growth. From the varieties of energy consumption, it's clear that coal consumption exergy is on the decline while power consumption increased rapidly. In 2013, the latter exergy is 217.92 x 10^{12} kJ, the former is 104.34 x 10^{12} kJ, 200% of difference.

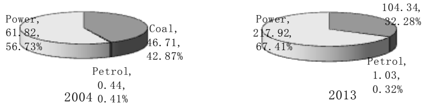

Fig.1: Industry main input energy exergy values

The output of unit energy consumption is also constantly improved, from 1.41 Yuan / 10^4 kJ in 2004 to 2.98 Yuan / 10^4 kJ in 2013. It's obvious to see that Qinghai's output of unit energy consumption is on the rise. Compared with the data at provincial level, output of unit energy consumption in industry is higher. It shows that enhancement of energy efficiency in industry improves the whole energy efficiency in Qinghai.

3.3.The Analysis of Non-industrial Energy Exergy

Similarly, according to government's data, energy efficiency in the non-industrial (other than

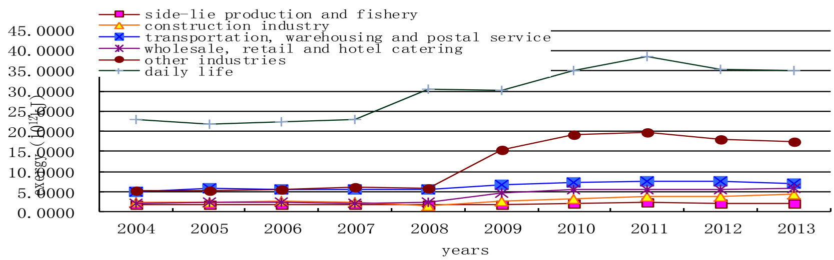

Fig.2: Non-industrial sectors input major energy exergy values

manufacturing) sectors is different from each other (figure 2). The highest is in domestic life, the lowest is in construction. Other sectors (except transportation, logistics, and postal service, wholesale and retail and catering) jumps to the second highest in 2008. And output of unit energy consumption in the first industry ranks top in a fast growing pace (figure 3). The lowest energy consumption is in wholesale, retail, catering industry and daily life, not much change for many years. And total output of unit energy consumption of non-industrial sectors is increasing from 7.91 Yuan / 10^4kJ in 2004 to 15.81 Yuan / 10^4kJ in 2013.

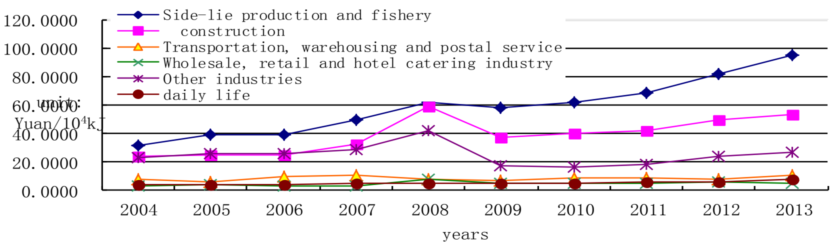

Fig.3: Non-industrial industry unit available output changing trend

In comparison, exergy of industry sectors is more than that of non-industrial sectors combined. Then the highest energy consumption is from industry. Between 2004 and 2013, non-industrial output of unit energy consumption is fifth more than that of the industry. So, non-industrial sectors have higher unit energy consumption value than that of the industry.

4. The Analysis of Environmental impact in Qinghai Province

Energy consumption brings economic benefits and environmental impacts. Emissions, the major source of ingredient of PM2.5, SO_2, soot, and particles, come mainly from industry and daily activities. In 2012, waste water discharge is 21994 x 10^4 t, 40.54% from industry, 59.42% from daily activities; Chemical oxygen demand (COD) is 103756 t, 41846 t from industry, 37477 t from daily life; SO_2 emissions is 153853 t, 129094 t from industry, 24758 t from daily life; Soot (dust) emissions from industry is 133698 t, 19615 t is from daily life; industrial solid waste discharge is 12301 x 10^4 t (Qinghai statistical yearbook, 2013).

4.1. The Exergy Analysis of Industry

The secondary industry development is in high level. All industries consumed about 70% of the total energy in Qinghai. Therefore, the industry is the key. Data shows that the gas emission in unit energy consumption is much higher than that of waste water and solid, but the latter two are growing fast. Calculation shows that the solid waste of unit energy consumption is growing the fastest, and gas emission is the slowest. Exhaust gas is 2232.71 $m^3/10^{12}$ kJ·min in 2004, 3656.92 $m^3/10^{12}$ kJ·min in 2012; and general industrial solid waste is 0.09 t / 10^{12} kJ·min and 0.75 t / 10^{12} kJ·min respectively. According to all kinds of exergy coefficient (table 4.1), exergy of industrial iste can be calculated. The results show that solid waste exergy is higher than that of other emissions, with soot the lowest. Solid waste discharge ratio rose from 84% in 2010 to 98% in 2011, and stayed there. Energy type is linked with the products of company. Although exergy of SO_2 is in the second position, much lower than that of solid waste, it should not be ignored.

Table 4.1: Exergy coefficient of waste discharge

Index	[1]COD	[2]SO_2	[3]Soot	[3]Dust	[3]Solid waste
kJ/g	13.6	4.9	3.5	1.5	0.5

Data source：1Hellst Örm (1997, 2003) ，2Szargut (2005) ，3Bo Zhang (2012)

4.2. The Exergy Analysis of Non-industrial Impact

Domestic waste discharge is the highest impact on environment in Qinghai. In comparison with the industry, it has higher amount of waste water and COD, ammonia nitrogen, SO_2 and dust. Growth rate of its emissions of unit energy consumption grew by 15% from 2012 to 2013. It's important to note that SO_2 and soot emissions of unit energy consumption in 2012 and 2013 increased over 14%. It is something to do with the local resident’s coal burning.

According to the calculation, it is clear that COD volume is much higher than amount of SO_2 and soot. It is 0.49 x 10^{12} kJ, 0.040 x10^{12} kJ, and 0.040 x 10^{12} kJ, increasing from 2004, and then returning back to 2004 level. Therefore, COD improvement in waste water should be paid more attention. It is different to the industrial emissions data distribution. Measures to tack the problem should be also different.

5. Conclusions and Recommendations

As the economic benefits relying on energy consumption is increasing, and the emissions increased simultaneously, especially solid waste and waste water.

The output of unit energy consumption (namely exergy) is improving and exergy and monthly growth rate of total energy input is consistent with the economic growth trend, then the third assumption is verified. To promote sustainable development, Chinese governments should consider updating workmanship and equipments by using high-techs. It could also improve the energy efficiency and level of local residents.

Although the exergy of industrial is higher than that of the whole province, the local government shouldn’t slack monitoring to energy efficiency. At the same time, incentive measures should be taken to encourage innovation and technology development to improve energy efficiency.

The exergy of non-industrial sectors showed that energy utilization varied widely accordingly. Exergy of residents' living energy consumption is the highest. Despite the whole industry's exergy value exceeds the exergy sum of non-industries; output of unit energy consumption of the latter outnumbered the former. Therefore, Qinghai should pay more attention to encourage non-industrial industry in innovation, technology, and energy efficiency.

Overall emissions and unit energy consumption emissions in Qinghai changed little, so the fourth hypothesis is not true. But different industries have different emissions. Main emission is from industry and daily life. Among them, amount of the unit energy consumption gas emission is much higher than waste water and residue and exergy of general industrial solid waste is much higher than that of other emissions. Therefore, local government and corporate should work together in environmental protection. For example, waste water reuse projects in the mining tailings of the western Xitieshan subsidiaries, abandoned boric acid liquor recovery project and comprehensive Utilization in the transit lithium boron Mining Company of Qinghai projects. Adding more flotation tail slag recovery and coal gangue processing projects and reducing the amount of general industrial solid waste are necessary.

The waste discharge is mainly water with higher COD, together with fast growing emissions of SO_2 and soot. Though local government has begun to solve this problem, for example the newly added 16 sewage plants in yellow river valley in 2011, the data show that the strength is not enough. In order to better protect China's "Three Rivers", the local government should pay more attention to the domestic waste water COD optimization, increasing the waste water treatment capacity, improving water use efficiency. The market should be wide open to introduce private capital and foreign investment for more waste water treatment plant in the region.

Vigorous developing clean energy can reduce emissions and promote high-tech industries as Qinghai has abundant solar, wind and hydro power resources. Thanks to national policy and current technology, using solar and wind energy to meet local demand in daily life, service and other industries is possible. Although there have been many new energy companies in the region, such as photovoltaic power plant project of Xitieshan CGNPC and CECEP, etc, the speed and scale of them cannot meet the current demand. Therefore, the government should establish China's "solar poared city" and "wind poared city" to bring together all related advantages to speed up development of clean energy. More preferential policies should be provided to the clean energy markets including photovoltaic industry such as tax relief; reduce capital investment and other restrictions to offer access of new companies. In addition, Qinghai is conducting the “coal changed into gas” project to extend clean energy into households, reducing coal consumption, replacing or partially replacing fossil energy consumption, optimizing energy structure. In short, you can implement the above strategies to establish an effective environmental protection system and reduce the impact from personal activities.

The result of the analysis has certain defects due to data limitations. Energy classification is different from the sub-industry statistics in the table of the total energy consumption, leading to the statistical data limit. In the measurement consistency process, due to lack of data of accurate input of each kinds of energy, we could only use the lower thermodynamic value, leading to the lower calculation results. It has limited us to do the overall amount consumption among all sectors and industries.

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Sustainability Scenarios between Rural Farms and Urban communities: A dynamic Societal Metabolism Analysis.

Vanessa Armendariz[1], Alberto Atzori[2], Stefano Armenia[3]

[1,3] Centre of Cyber Intelligence and Information Security, Dipartimento di Ingegneria

[2] Informatica, Automatica e Gestionale "Antonio Ruberti" from Sapienza University of Rome
Dipartimento di Agraria, Sezione di Scienze Zootecniche of University of Sassari

Problem

The challenges to feed cities in the future times, the energy demand growth, availability of key resources for industrial production and households consumption are creating different levels initiatives across the globe to find new ways of re-organizing processes towards the sustainability and resilience of the current system. Examples of this are the FAO's search for new ways of analyzing the nexus between Energy, Water, Land and Population[1], or the Meeting Urban Food Needs project[2], the European Union legislations dated since 2012 on agriculture changes and the Horizon 2020 on societal challenges. In this spirit, at local levels, there is a bloom of grass-root projects aiming for resource autonomy and which are trying to implement closed production and consumption cycles, for example in food, within their daily lives. These last kinds of projects are not new, in fact, the experience of similar projects since decades ago have demonstrated the lack of capacity to maintain those over the time. The reasons, among others, respond to internal deficiencies such as financing, resources, commercial spaces, people participation, distance, or to the lack of conditions and directions on the shared processes with urban centers, which dynamics tend to be corruptive.

Objective

In this work we explore sustainability scenarios based on a societal metabolism approach of one rural and one urban community sharing food production and consumption processes. Two modalities are used to characterize the food production and consumption processes a) A business as usual (BAU) mode or b) A collaborative (C) mode seeking the organic farm maintenance by directing processes on the food production and consumption activities. System Dynamics (SD) is the methodology used to conceptualize the system interactions and run a simulation model. The model will make use of real data of a rural and an urban connected areas of a developing country. Bio-economic indicators are established to monitor what happens with the population, human activity allocation, energy use and food availability in the defined territorial over a period

[1] Information on the Water-Energy-Food Nexus Approach to Inform Policy-Making by FAO http://www.fao.org/energy/81320/en/

[2] Information available: http://www.fao.org/ag/ags/newsandevents/news/en/c/231954/

of 10 years. The sustainability assessment will be based on the viability of the system in both cases.

Method of analysis

Exploring sustainability scenarios is possible when clarifying the analysis mode to make the assessment. In this case, the acknowledgement of dwelling in socio-ecological systems provides a framework from which the traditional analysis of sustainability is improved (Constanza, et al., 1993). Material issues as resource availability, people or energy use are studied in an integrative way rather than partial observations on economic, social or administrative issues. This last is an often perspective held where interventions are planned (Folke, et al., 2002). A societal metabolism approach considers the society as a complex system with a structure driving energy and material use and the human activity allocation -in paid work or households- required by that system to fulfill its functions (Giampietro et. al, 2000, 2013, 2014). The system counts with limited amount of resources changing over time due to its organization characteristics. A drastic change in these resources could affect the system functioning, stability and properties conservation (Greer, 2005). A societal metabolism perspective for a sustainability analysis, following Daly's sustainability principles (1990), allow us to identify which are the relevant material issues a society needs to maintain in order to fulfill its functions. In the other hand, SD, as methodology, provides a framework capable of keeping track of the dynamic change of those material issues on which a society depends. In coherence with this biophysical perspective, the geographical and economic boundaries have to be considered simultaneously and in an integrated way in a determined territory. In this sense, urban and rural systems have dependent processes that should be managed jointly for the sustainability of the system as a whole. Literature in SD has stated better indicators are needed for sustainability assessments and those should be about time, thresholds, efficiency, sufficiency, equity and quality of life and should respond to coherent information systems in order to support decision-making processes and improve learning (Meadows, 1998).

Expected results

The outcome of this work will be a formal SD model capturing the necessary variables to explain interaction between human activity allocation, energy use, food production, and consumption in a given territory. Finally, we will use this model to simulate scenarios under different assumptions (BAU or C modalities). The purpose of this exercise is to make a contribution in the discussion on collaboration dynamics between rural and urban communities towards sustainability transitions.

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Energy efficiency and environmental sustainability of urban systems within the constraints placed by resource availability. The case of Napoli and Roma, Italy.

Dario Felice Civitillo, Silvio Viglia*, Sergio Ulgiati

Department of Science and Technology, "Parthenope" University of Naples, Italy.

*Corresponding Author: silvio.viglia@uniparthenope.it

Abstract

More than 50% of world population live in urban areas. The role of cities as engine of economic development and human wellbeing becomes increasingly crucial with special reference to their metabolism. An assessment of the environmental sustainability of the city of Napoli was conducted, with reference to the years 2000, 2005, 2011, by means of the Cumulative Energy Demand and Emergy Synthesis methods.

Cumulative energy demand allowed an assessment of the commercial energy consumption required on large scale to support the city, expressed as fossil energy equivalents. Energy consumption was then converted into global and local scale atmospheric emissions (CO_2, CO, SO_2, etc.).

Emergy Synthesis method was used to estimate the environmental support required for the urban metabolism from a biophysical point of view, providing a measure of sustainability of the urban system expressed as solar energy equivalents.

In the year 2011, the city of Napoli required 106 million GJ of fossil energy, the equivalent of 2.54 million ton of oil, translating into 7.63 million ton of CO_2 released into the atmosphere. The calculated emergy-based Environmental Loading Ratio showed a slightly decreasing trend, but the urban system still resulted to be far from a desirable level of sustainability. Results obtained for Napoli are compared to a previous study related to the city of Roma, and are used as the basis to suggest sustainability indicators and resource use criteria at urban level. A new measure of sustainability is provided, based on the emergy required to both dilute and uptake emissions. A city's support area to buffer upstream and downstream environmental loading is also calculated.

Finally, virtuous practices are suggested to be adopted as exit strategy from the present intensive fossil powered economy and to reach a higher level of sustainability.

Keywords: Energy efficiency, urban systems, sustainability, emergy accounting.

1. Introduction

Recent demographic studies indicate a steady increase in the rate of urbanization in the world (UN, 2013). Cities play a vital role in the economy of a country because they represent its cultural, financial, governmental and administrative core; every day thousands of people reach the city to work and study. These urban areas require an increasing amount of energy and material resources to support its development and activities (Holmes and Pincetl, 2012). A city can be compared to an organism that requires resources to live (support and develop) and release wastes of its metabolic activities (Samaniego and Moses, 2008). In the last decades, Environmental sustainability of urban areas has been a topic of discussion both in the scientific world (Satterthwaite, 1997; Newman and Kenworthy, 1999; Decker et al., 2000; Liu et al., 2009; Schremmer et al., 2011) and in policy debates (UN, 2013) for the crucial link with the exploitation of natural resources, the use of non-renewable energy and the consequences on the state of the environment. Worldwide the metabolism of urban systems is increasingly investigated using different approaches: Macao and Beijing in China (Zhang et al., 2011; Liu et al., 2011), Montreal in Canada (Vega-

Azamar et al., 2013), Uppsala in Sweden (Russo et al., 2014) and Rome in Italy (Zucaro et al., 2014) among others.

2. Materials and Methods

2.1 The investigated urban systems

Naples, located in southern Italy, is the regional capital of Campania Region. The urban area covers approximately 120 km^2 and has an average altitude of about 20 m. The territory is predominantly hilly. Although the city has a very limited surface extension, it has a significant value of population density (about 8,000 inhabitants / km^2), the highest among the major Italian cities. The city has a developed tertiary sector (administrative structures, local and regional government, schools and universities, accommodation and commercial activities) and poor primary and secondary sectors.

Rome, located in central Italy, is the capital of Italy. Its population is about 2.7 million people. With a surface area of about 1,500 km^2, Rome is the country's largest and the fourth-most populous city in the European Union by population within city limits. The economy of Rome is characterized by the absence of heavy industry, it is largely dominated by services, high technology companies (information technology, aerospace, defense, telecommunications), research, construction and commercial activities (especially banking), and it has a very dynamic and economically relevant tourist sector. Data and results about the urban system of Roma were taken from Ascione et al (2008, 2009, 2011) as well as from Ulgiati et al (2011).

Figure 1 shows the population and GDP at current prices in the selected years: 2001, 2005 and 2011 for Naples and 1992, 2002 and 2008 for Rome. Data used to implement the analysis were mainly taken from the official statistical offices of the municipality and from the statistical databases produced by Eurostat (Camera di commercio di Napoli, 2013; Comune di Napoli, 2012, 2013; Eurostat, 2010, 2013).

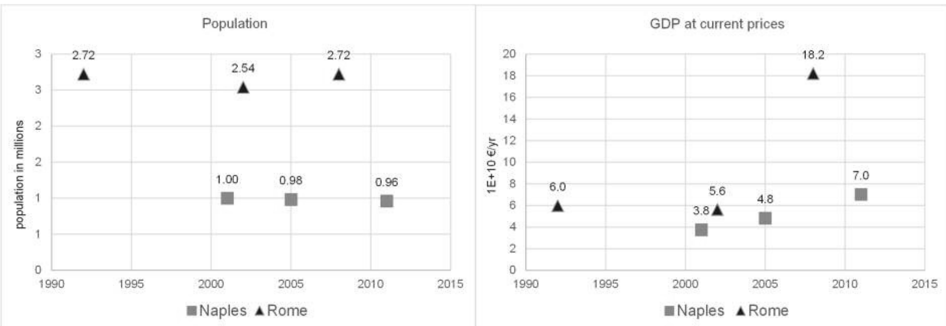

Figure 1: Population and GDP of Naples and Rome in the investigated years.

2.2 The methods

Cumulative Energy Demand (CED) (Slesser, 1978; Smil, 1991) and Emergy Synthesis (ES) (Odum, 1996; Brown and Ulgiati, 2004) methods are used in this study. CED allows estimating the commercial energy and material requirements by converting them into units of oil equivalent (grams of oil equivalents or Joules). ES takes into the account also the work done by nature to generate resources (natural capital) and ecosystem services. It expresses all resources on a common basis, in solar equivalents (abbreviated seJ, for solar emergy Joules), which makes the work of environmental systems and human systems comparable and analytical insights more comprehensive (Brown and Ulgiati, 2011).

In this paper direct and indirect fossil energy consumption has been used to estimate the gaseous emissions (CO_2, CO, N_2O, NO_x, SO_x, CH_4) generated both at local and global scale by the urban system. Emission values were used to analyze the level of sustainability, expressed as area needed to absorb the emissions generated by metabolic activities to make the system sustainable.

Emissions can be estimated, on a yearly basis, by means of a calculation procedure expressed in the following equation (1):

$$W_e = \sum f_i * w_i \qquad i = 1,\ldots,n \qquad \text{(Eq. 1)}$$

Where W_c is the cumulative mass of each kind of emission released by the process, f_i is the i^{th} input flow of energy to the process and w_i is the mass of emissions associated to the flow f_i, that includes emissions from local and outside processes. The resulting cumulative mass of emissions is the sum of local emissions and emissions released elsewhere over the supply chain. The two scales can be also kept separated. Similar procedures can be implemented for other kinds of airborne and waterborne emissions (heat, leakage), in order to be able to calculate the emergy support for their dilution and abatement.

Based on such values, the volume of air (or water) needed for their dilution down to the biosphere background level (or, at least, down to the threshold required by the enforced laws) can be calculated:

$$M_{dil} = d * \frac{W}{c} \qquad \text{(Eq. 2)}$$

(where M_{dil} is the mass of dilution air (or water), d is density (1.23 g/dm^3 for air, 1.0 g/dm^3 for water), W is the annual amount of a given emission from the plant, and c is the acceptable or background concentration).

Obviously, dilution is not a final solution, but at least alleviates the local impact by spreading it to a larger, less populated area. However, our goal is to calculate the minimum environmental service needed for such result, although partial.

Limiting to airborne pollutants (waterborne emissions can be treated in a like manner), the kinetic energy of the mass of dilution air can be calculated from the well-known equation:

$$K = M_{dil} * \frac{v^2}{2} \qquad \text{(Eq. 3)}$$

where K is kinetic energy and v is wind speed.

When kinetic energy (K) is multiplied by transformity of the wind (tr_{wind}), it gives a measure of the environmental service (R_1) that is required in emergy units (seJ):

$$R_1 = K * tr_{wind} \qquad \text{(Eq. 4)}$$

Finally, the additional area needed to capture R_1 is calculated as:

$$A_1 = \frac{R_1}{ED_{ren}} \quad \text{(Eq. 5)}$$

where ED_{ren} is the renewable empower density in the area, namely the amount of renewable emergy that is available per unit of area and time (seJ*m^{-2}*yr^{-1}.

CO_2 emissions are not affected by dilution, because the global warming is not a local impact. CO_2 concentration in atmosphere needs to be reduced to decrease the impact. The easiest solution might be allowing a forest plantation to grow, for CO_2 uptake and storage. At a given Net Primary Production rate (ton biomass production per ha; ton CO_2 sequestered per ha), we have:

$$A_2 = \frac{W_{CO_2}}{S_{CO_2}} \quad \text{(Eq. 6)}$$

where A_2 is the land needed for biomass growth; W_{CO2} and S_{CO2} are respectively CO_2 released and CO_2 sequestered.

Considering that energy carriers are not the only input to a process or system, an evaluation only based on combustion-generated emissions is not complete. Brown and Ulgiati (2002) suggested a different way to assess the “renewable carrying capacity” of a system, based on the total non-renewable emergy input (including construction materials, goods, etc) compared with the renewable emergy that is locally available. Their carrying capacity indices are still expressed as land area required to support an economic activity. Such area A_3 is derived by dividing the local (N) and imported (F) nonrenewable emergy input to a system, by the average renewable empower density of the region in which the system is located:

$$A_3 = \frac{N+F}{ED_{ren}} \quad \text{(Eq. 7)}$$

A_3 is the area of the surrounding region that would be required if the economic activity were conducted using solely the renewable emergy inputs available in that region. This ideal situation can be considered, according to Brown and Ulgiati (2001) a lower limit to environmental carrying capacity because it requires the largest support area, there by placing the highest limits on development. In order to calculate the amount of land needed in areal situation and to constraint to be acceptable, Brown and Ulgiati (2002) calculate the Environmental Loading Ratio (ELR) of the investigated process and compare this value with the average ELR of the country’s economy where the system is embedded. The constraint to be imposed was:

$$ELR_{system} \leq ELR_{country} \quad \text{(Eq. 8)}$$

not to generate a worsening of the larger-scale dynamics. From Eq. 8, new values R* and A* are then calculated, consistent with the actual loading ratio of the country’s economy. Eq. 9 constitutes an upstream approach, alternative to the “hybrid” downstream approaches used for chemical emissions and CO_2 uptake. The area calculated by means of the upstream approach (supply-side) and the area calculated by means of the hybrid downstream method (user-side) can be added, because the former is related to the generation and supply of resources, while the latter is linked to the “disposal” of the emissions, two different processes supported by different amounts of driving forces in different times.

A direct follow-up of Brown and Ulgiati (2002) is the possibility to impose a stronger sustainability constraint based on the Emergy Sustainability Index (ESI), which includes both the sustainability from the local self-reliance point of view (EYR) and the sustainability from the environmental loading point of view (ELR):

$$ESI_{system} \geq ESI_{economy} \qquad \text{(Eq. 9)}$$

where $ESI_{economy}$ is the ESI of national economy.

Eq. 9 allows a different way to calculate the needed buffer land A*and support emergy R*. A* is the support area needed to capture the renewable emergy R* needed under the condition that the ESI of the investigated system is at least equal to the ESI of the country.

Calculations translate into a larger demand for support area than available, to capture more renewable emergy, decrease the loading ratio ELR and increase the EYR. The approach is sensitive to the large-scale performance of the economy and therefore provides an indicator of relative sustainability, only aimed at not worsening the present country's performance. Based on NEAD (2014[1]), the National Environmental Accounting Database, the highest national ESI values in the world are all lower than 10. Therefore, a reasonable reference value for a fully, ideally sustainable economy can be an ESI equal to 10.

3. Results and Discussion

The so-called "emergy signatures" of Naples and Rome are shown in Figure 2. It clearly appears that both urban systems are highly dependent from imported non-renewable emergy.

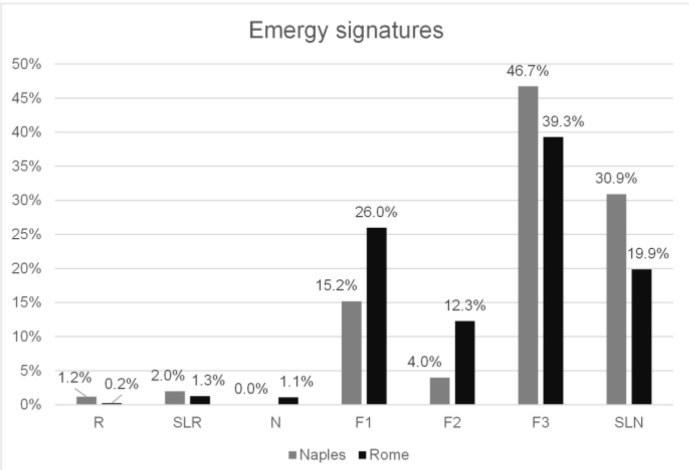

Figure 2: Emergy signatures of Naples (2011) and Rome (2002).
R for renewables, SLR for the renewable fraction of labor and services, N for local non-renewables, F1 for imported energy, F2 for imported food and water, F3 for other goods, SLN for the non-renewable fraction of labor and services. Values are % of total emergy U.

Table 1 lists the main calculated indicators for the two urban systems. For the city of Naples, a decline trend is noticeable for the indicators related to the land area and

[1] http://www.cep.ees.ufl.edu/nead/

population. On the other hand, same indicators calculated for the city of Rome show an opposite trend. Intensities per monetary unit have a declining trend due to the increase of GDP at current prices. Performance indicators such as the ELR in the three years reduced the value of 15 and 30 point for Naples and Rome respectively. The huge difference between the calculated ELRs for the two cities stems from the difference in the renewability of emergy supporting the systems. In the case of Naples renewables are equal to 3.2% of the total emergy, instead for Rome they represent just the 1.5%. The EYR and ESI have almost constant values in both cases.

Table 1: Main indicators from CED and Emergy Synthesis.

Index	*unit*	Naples 2001	Naples 2005	Naples 2011	Rome 1992	Rome 2002	Rome 2008
Energy intensity per person	g oil_{eq}/person	2.91E+06	3.07E+06	2.64E+06	4.72E+06	6.51E+06	7.60E+06
Energy intensity per euro	g oil_{eq}/€	2.01E+02	1.92E+02	1.61E+02	2.80E+02	2.28E+02	1.67E+02
Energy intensity per area	g oil_{eq}/m^2	2.39E+04	2.52E+04	2.17E+04	3.07E+04	3.96E+04	4.90E+04
Emergy intensity per person	seJ/person	4.96E+16	4.64E+16	3.35E+16	6.36E+16	5.45E+16	5.94E+16
Emergy intensity per euro	seJ/€	2.01E+02	1.92E+02	1.61E+02	2.80E+02	2.28E+02	1.67E+02
Empower density	seJ/m^2	4.25E+14	3.90E+14	2.74E+14	1.35E+14	1.08E+14	1.26E+14
EYR	U/(F+L+S)	1.01	1.01	1.01	1.01	1.02	1.01
ELR	(N+F+L+S)/R	45.61	40.11	30.69	94.73	64.47	65.25
ESI	EYR/ELR	0.02	0.03	0.03	0.01	0.02	0.02

Table 2 summarizes the calculation procedure used to estimate the land area needed to capture a renewable emergy flow needed to dilute emissions produced by the metabolic activity of Naples. To dilute emissions locally produced to natural background values an area more than 350 times bigger the one occupied by the city would be needed. On the other hand, to dilute pollutants locally released into the atmosphere, only referring to the legal limits, an area two times the one of the city would be required. If also indirect emissions are taken into the account these areas are much larger.

Table 2: Calculation of the land area needed to capture renewable emergy needed to dilute emission produced by the city of Naples (2011).

Absolute Sustainability: Diluition to Natural Background Values		*Relative Sustainability: Diluition within Legal Limits (D.Lgs 152/06)*	
Overall Emissions (CO, NO_2, SO_2, Particulate, N_2O)			
Global Scale	Local Scale	Global Scale	Local Scale
Diluition Air Mass M_{dil} (gr) = d*(W/c) (Eq. 2)			
2.95E+19	8.72E+18	1.44E+18	5.04E+17
Kinetic Energy of M_{dil} K (J) = M_{dil} * $(v^2/2)$ (Eq. 3)			
4.46E+20	8.83E+19	2.18E+16	5.11E+15
Environmental Support			
R (seJ)= K* UEV_{wind} (Eq. 4)			
7.04E+23	1.40E+23	3.44E+19	8.07E+18
"Buffer" Area			
A (m^2) = R/ED_{ren} (Eq. 5)			
2.17E+11	4.31E+10	1.06E+07	2.49E+06
A/A_{Nap}		% Naples Area	
1852	367	9	2

Table 3 shows the calculation of the buffer area needed to uptake CO_2 emissions produced by Naples in 2011. Assuming a Net Primary Production rate of 1.50E-04 ton CO^2/m^2, to uptake CO_2 produced locally and globally the area needed resulted to be 57 and 434 bigger than the city area.

Table 3: Calculation of the buffer area needed to uptake CO_2 emissions produced by Naples (2011).

Absolute Sustainability: CO_2 Uptake	*Relative Sustainability: CO_2 Uptake*
Global Scale CO_2 Emissions *$W CO_2$ (ton)*	*Local Scale CO_2 Emissions* *$W CO_2$ (ton)*
7.63E+06	*1.01E+06*
Absorption Rate $S CO_2$ (ton/m^2) = ton CO_2/m^2	
1.50E-04	
"Buffer" Area A (m^2) = WCO_2/SCO_2 (Eq. 6)	
5.09E+10	*6.73E+09*
A/ A_{Naples}	
434	*57*

Aiming at not worsening the present country's performance the city should have a higher ESI than the country. As shown in table 4, for Naples to reach this goal the area needed to capture renewable emergy and so make the city sustainable at the same level of Italy should be five times the actual city area. An ESI value equal to 10 (considered as ideal) is taken as reference for an absolute sustainability. To reach this value the area needed would be more than 800 larger.

Table 4: Calculation of the area needed to capture renewable emergy to decrease the ESI of Naples to relative and absolute levels of sustainability.

Absolute Sustainability *Requirement: $ESI_{Nap} = 10$*	*Relative Sustainability* *Requirement: $ESI_{Nap} \geq ESI_{It}$*
Environmental Support *R (seJ) = $ESI*(N+F+S)*(F+S)/U_{Nap}$*	*Environmental Support* *R (seJ) = $ESI_{It}*(N+F+S)*(F+S)/U_{Nap}$*
3.21E+23	2.08E+21
"Buffer" Area A (m^2)=R/ED_{ren} (ED_{ren} = $R/Area_{Naples}$)	
9.90E+10	6.42E+08
A/A_{Naples}	
843	5

4. Conclusions

CED provided a measure of the dependence of the cities from fossil energy. Emergy Synthesis resulted to be a comprehensive method able to assess and quantify the sustainability of the investigated urban systems.

Emissions generated by the metabolic activity of Naples were translated into environmental support needed to make the system sustainable. It was demonstrated and quantified how the city is far from a relative and absolute sustainability.

In this perspective to reach an increased level of sustainability several solutions can be suggested capable to decrease the use of imported and nonrenewable resources, for instance:

- increase forms of recycling and reuse (if waste cannot be upstream avoided);

- promote renewable energy sources (solar, geothermal, wind, among others);
- increase efficient use of resources (prioritize public transport versus private);
- recover and, if possible, increase agricultural and urban green areas.

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Decoding Energy Inclusiveness for India 2015

Dr. Debesh C Patra
Deputy General Manager, LPG Strategy, Bharat Petroleum Corporation Ltd, Mumbai

patradc@bharatpetroleum.in

Abstract

Disparity in energy consumption resulting in increasing divide between rich and poor is socially, economically and environmentally unsustainable. Access to modern energy is essential for the provision of clean water, sanitation, lighting, heating, cooking and telecommunications services. Energy deprivation is not only an economic evil; it also causes much social malaise.

The paper attempts to reflect on the following questions:

- What is acceptable definition of energy poverty and access to modern energy?
- What are the concepts and tools used in literature to indicate energy inclusiveness in India
- What is the scene of energy inclusiveness in India, putting together all indicators?
- Where should lie the focus of action, if energy inclusiveness in India has to improve?

The paper is structured in three sections. Section I attempts to portray the macro view of energy scene in India. Section II provides the concept and definition of energy deprivation and accessibility. Section III provides five methods and tools that are used in literature to measure and indicate energy inclusiveness in India. Each of the tools and indicators has been quantified to build a consolidated picture of energy inclusiveness or otherwise that prevails in India. Actionable points are provided in conclusion.

Key words: Energy, India, per capita energy consumption, energy inclusiveness

International Energy Agency (IEA) estimates that 1285 million people, equivalent to 18% of the world population and 22% of those living in developing countries, did not have access to electricity in 2012. India remains the country with the largest population without electricity access at 304 million people; with national electrification rate at 75% (urban 94% and rural 67%). (IEA, 2014)

IEA also estimates that more than 2679 million people, almost 40% of the global population, relied on the traditional use of biomass for cooking in 2012; 38 million more people than in the previous year. This deteriorating situation is primarily due to population growth outpacing improvements in the provision of clean cooking facilities. In India, 815 million people, around two-thirds of the population relies on traditional biomass. (IEA, 2014) National Sample Survey conducted by Government of India for the period July 2011 to June 2012 reports that 83.5% households in rural India and 23% in urban India use firewood and chip for cooking. (NSSO, 2014)

1. Section I: Energy Scene in India

India’s commercial energy basket has a mix of all the resources available including renewable energy sources. India's coal dependence is borne out from the fact that 64% of primary energy used is coal and 60% of the electricity generated is from coal based power plants. Other renewables such as wind, geothermal, solar, and hydroelectricity represent a 2% share of the Indian fuel mix. Nuclear holds 1.5% share, as presented in Table 1.

Table 1: Total Primary Energy Supply in India – 2013-14

Primary Energy Supply	Kilo Tonne Oil Equivalent	% share to Total
Coal	382355	64.1
Crude Oil	232043	38.9
Oil Product (Net Export)	-48923	-8.2

Natural Gas	9896	1.7
Nuclear	8913	1.5
Hydro	11587	1.9
Solar, Wind & Others	-	0
Electricity (Import)	482	0.1
Total	596352	100

Source: CSO, 2015

Combustible renewables and waste constitute about one fourth of Indian energy use. This share includes traditional biomass sources such as firewood and dung, which are used by more than 800 million Indian households for cooking.

In 2013, India was the 4th largest energy consuming country in the world, consuming 4.7% of total world consumption of energy, following China (22%), US (17.8%) and Russia (5.5.%). India's share of global demand rises to 8% in 2035, accounting for the second largest share of the BRIC countries with China at 26%, Russia 5%, and Brazil 3%.

Table 2: Top Five Primary Energy Consuming Countries in World in 2013

Sr. No	Country	Primary Energy Consumption (Million Tonne Oil Equivalent)	Growth over previous year (%)	Share to World (%)
1	China	2852.4	4.7	22.4
2	USA	2265.8	2.9	17.8
3	Russia	699.0	0.2	5.5
4	India	595.0	4.1	4.7
5	Japan	474.0	-0.6	3.7

Source: BP (2014)

From the perspective of this paper, that is inclusiveness in energy use, we observe the following:

13.2% of total energy used in 2011-12 in India is for residential purpose. Energy use in the residential sector is defined as the energy consumed by households, excluding transportation uses. In the residential sector, energy is used for equipment and appliances that provide heating, cooling, lighting, water heating, and other household demands.

2.1% of total energy used in India in 2011-12 is for commercial and public service. 4.4% is used for agriculture and forestry.

Only Oil products and electricity are two energy carriers which have got use in transport, residential and commercial activities. These are the activities which promotes energy inclusiveness. 19.9% of Oil products and 18.8% of electricity have been used for residential purpose in 2011-12 in India.

Two energy carriers which touches everyday life of all people, namely petroleum products and electricity are import intensive for their raw material (Petroleum products for crude oil and electricity for gas). During 2012-13, India imported 84% of crude oil and 35% of gas used in the country. Therefore energy inclusiveness needs country's strength on external front, particularly, on foreign exchange balance.

A micro assessment made by India's Central Electricity Authority brings out that during 2013-14, power availability increased by 5.6% over the previous year, still there was deficit of 4.2%. (Against requirement of 1,002,257 MU, availability was 959,829 MU, leaving shortage of 42,428 MU). (CEA, 2014)

From the above statistical premises and from author's experience of working in the Oil Industry for last 28 years, we would say; India is not only an energy deficit country, it is an energy starved country. The energy market in the country is supply driven. Given the price, energy is consumed, if available; otherwise, life in India goes on without commercial energy; on its native way.

2. Section II: Energy Poverty & Modern Energy Access: Definition

Energy poverty is lack of access to modern energy services. These services are defined as household access to electricity and clean cooking facilities (e.g. fuels and stoves that do not cause air pollution in houses).

Two definitions and concepts of modern energy are access is presented here for their robustness and computability.

UN Secretary General's Advisory Group on Energy and Climate (AGECC) defines energy access as access "to a basic minimum threshold of modern energy services for both consumption and productive uses. Access to these modern energy services must be reliable and affordable, sustainable and where feasible, from low-GHG-emitting energy sources"

International Energy Agency (IEA) defines modern energy access as "a household having reliable and affordable access to clean cooking facilities, a first connection to electricity and then an increasing level of electricity consumption over time". By defining access to modern energy services at the household level, it is recognized that some other categories are excluded, such as electricity access to businesses and public buildings that are crucial to economic and social development, i.e. schools and hospitals. This definition and measurement captures the sense of energy inclusiveness very closely.

3. Section III: Measures of Energy Inclusiveness

The following five methods, tools and indicators have been used to assess the status, trend and progress of energy inclusiveness in India.

1. Per capita energy consumption – time series data
2. Sustainable Energy for all Initiative – multi country data
3. Energy 'Development', 'Efficiency' and 'Sustainability' Indices
4. Empowerment Line – normative value for people in energy excluded category
5. Access to Clean Cooking Fuel – Industry sourced micro data

3.1. Per Capita Energy Consumption

Per-capita energy consumption is a measure of energy inclusiveness under assumption that there is equity and parity in the availability and accessibility of energy to all people across the country.

An average Indian consumed 1204.39 kwh of energy in 1970-71. 40 years after that, in 2011-12, he is consuming 6419.53 kwh of energy; 5.3 times the level of 1970-71, a cumulative annual growth of 4.06 percent, indicating marginal improvement in inclusiveness, assuming that accessibility to energy source is available equitably over socio economic and regional diversities.
a) It is a reflection of higher level of energy consumption per person on average on longitudinal study.

b) It is caused by the fact that total energy consumption in the country on CAGR basis has grown at a higher rate, 6.01%, than the growth of population, which is 1.86% CAGR basis.

3.2. Sustainable Energy for All

IEA made a study to identify energy deprivation in all countries which gives us status of India vis-à-vis other countries of Asian Region and countries elsewhere in the world at a comparable state of development, summarily presented in table 3.

Table 3. People without access to modern energy services

	Without access to electricity					Traditional use of biomass for cooking				
	2010		2011		2030	2010		2011		2030
	Population	Share of Population	Population	Share of Population	Population	Population	Share of Population	Population	Share of Population	Population
	Million	%	Million	%	Million	Million	%	Million	%	Million
Nigeria	79	50%	84	52%		117	74%	122	75%	
South Africa			8	15%				6	13%	
India *	293	25%	306	25%	147	772	66%	818	66%	730
Pakistan	56	33%	55	31%		111	64%	112	63%	
Indonesia			66	27%				103	42%	
China	4	0%	3	0%	0	387	29%	446	33%	241
Brazil			1	1%				12	6%	
World	1267	19%	1258	18%		2588	38%	2642	38%	

*Indian data are pre-2011 census

In terms of energy deprivation, on both accounts, access to electricity and use of biomass, as captured in the table above, India is at lower position than countries like China, South Africa and Brazil. As per projection, 147 million people will remain without access to electricity and 730 million people will continue to use biomass for cooking in 2030.

3.3. Energy Development, Equity and Sustainability Indices

3.3.1. Energy Development Index

International Energy Agency (IEA) has devised Energy Development Index (EDI) in order to better understand the role that energy plays in human development. EDI is a composite measure of a country's progress in transiting to modern fuels and modern energy services. EDI is a multi-dimensional indicator framed by IEA that tracks energy development country-by-country, distinguishing between developments at the household level and at the community level. In the former, it focuses on two key dimensions: access to electricity and access to clean cooking facilities. When looking at community level access, it considers modern energy use for public services (e.g. schools, hospitals and clinics, water and sanitation, street lighting) and energy for productive use, which deals with modern energy use as part of economic activity (e.g. agriculture and manufacturing).

We present in table 4 final ranking and EDI values of last 2 years for India and for some other comparable developing countries.

Table 4: EDI ranking and Index

Country	EDI Rank		EDI Index	
	2010	2011	2010	2011
India	41	34	0.30	0.294

Sri Lanka	42	39	0.29	0.258
Indonesia	37	33	0.34	0.297
China	26	19	0.49	0.547
South Africa	14	11	0.65	0.681
Brazil	11	14	0.68	0.590

India has improved its ranking from 2010 to 2011. But in terms of EDI index, it is lower than other developing and neighborhood countries like Sri Lanka, Indonesia, China, South Africa and Brazil.

3.3.2. Energy Trilemma Index

The Energy Sustainability Index ranks 129 countries in terms of their likely ability to provide sustainable energy policies through the 3 dimensions of the energy trilemma:

Energy security: the effective management of primary energy supply from domestic and external sources, the reliability of energy infrastructure, and the ability of participating energy companies to meet current and future demand.

Energy equity: the accessibility and affordability of energy supply across the population.

Environmental sustainability: the achievement of supply and demand-side energy efficiencies and the development of energy supply from renewable and other low-carbon sources.

The Index rank measures overall performance of 129 countries and the balance score highlights how well a country manages the trade-offs between the three competing dimensions: energy security, energy equity, and environmental sustainability, presented in table 5.

Table 5: India's Energy Trilemma Index Ranking and Balance Score

	2012	2013	2014	Score
Energy Equity	110	110	105	D
Energy Security	86	76	76	C
Energy Environmental Sustainability	123	121	123	D

Source: WEC (2015)

Relevant from the point of view of this study is 'energy equity' parameter, which is low for India; but has improved in 2014. While India's ranking in 2014 is 105, ranking for Indonesia is 64, China 82, Sri Lanka 83, South Africa 85 and Brazil 86.

3.4. Empowerment Line

McKinsey Global Institute (MGI, 2014) has devised 'empowerment line', which is metric of 8 basic needs like: food, energy, housing, drinking water, sanitation, health care, education and social security. Empowerment line is the level of private household consumption needed to achieve minimum acceptable standard of living above official poverty line living condition. MGI has estimated that a person in Indian context at 2011-12 price level needs Rs 1336 per month to spend for decent life, (Rs 6680 for a family of five) assuming that infrastructure and access points are available at efficient cost. The energy component of that has been estimated to be Rs 128 per month per person (Rs 640 for a family of five). The gap between empowerment line and poverty line is shown in table 6:

Table 6: Expenditure per month per person for Empowered Line and Poverty Line

Fig – Indian Rupees at 2011-12 price level

	Total	Energy component
Official Poverty Line	874	107
Empowered Line	1336	128
Empowerment Gap	462	21

Source: MGI, 2014

As per above level of 'empowered line', India in 2012 has 680 million people (171 million in urban and 509 million in rural), which is 56% of India's population, who had consumption level below the empower line. From energy inclusiveness point of view, 680 million people have to spend Rs 128 per month per person on energy to come to a decent living, at 2011-12 price level. This is higher from the level of minimum living as defined by official poverty line by Rs 21 per person per month.

3.5. Access to Clean Cooking Fuel

Energy poverty has also been measured in terms of access to energy services. This is considered to be an important complement to consumption based measure of poverty. Number of households in the country where clean cooking fuel, that is LPG connection, is available is a measure of energy inclusiveness. On this indicator, India has made substantial progress during last 5 years. During 2010 to 2014, 62 million households were added to the base of 114 million households who already were having LPG connection in their houses (54% addition). Table 7 presents coverage of households by LPG accessibility on a national level. Regional variation in coverage exists, which is not presented here for want of space.

Table 7: Households having access to LPG for cooking

	Unit	2001	2011	2015
No. of Households in India	Million	191.96	246.69	256.48
No. of Households having LPG connection	Million	57.85	125.39	176.50
LPG Coverage of Households	%	30.1	50.8	68.8

Source: Data provided by Industry

Households covered by LPG accessibility in the beginning of 2015 stands at 68% and have improved substantially during last 5 years.

Conclusion

This paper brings together five methods, tools and indicators to present status and trend of energy inclusiveness in India. India has come a long way on the path of bringing people into the zone of inclusiveness in the domain of energy. But as the population number is quite large, large sub set of that number still remains outside the zone of inclusiveness.

This paper is a survey of literature on the subject. It has attempted to draw a conceptual framework on the topic of energy inclusiveness and has put India specific data together from diverse sources. Further studies particularly sector specific analysis in household sector, commercial sector and transport sector will throw micro results in terms of status and progress of energy inclusiveness. Then specific policy prescriptions will emerge.

One conclusion of the study is that energy inclusiveness in India will improve if focus is provided on adequate availability of LPG and electricity across the country and is used for residential purpose.

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Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) framework tested from a System Dynamics (SD) perspective: an approach to the dynamic component of a sustainability assessment

Vanessa Armendariz[1]

[1] Centre of Cyber Intelligence and Information Security, Dipartimento di Ingegneria Informatica, Automatica e Gestionale "Antonio Ruberti" from Sapienza University of Rome

lis.armendariz@gmail.com

Abstract

The current is a theory-oriented focused on an approach to perform a sustainability analysis of complex systems. MuSIASEM applicability for a dynamic systems analysis is examined from a SD perspective. An appraisal of the compatibility and feedback learning of the combination of both is developed in the light of further energy studies for sustainability, having special focus on the *dynamic* component of any sustainability assessment.

1. Introduction

The acknowledgment of biophysical limits is fundamental to understand how socio-ecological systems work, for risk avoidance and sustainability applications. Although these concerns are not new (i.e. Vernadskii 1926; Meadows, Randers & Meadows, 1972) the dominant scientific narratives, mainly economic, for decades have reproduced a paradigm that neglects feedback processes between institutional systems and the environment, its limits and its dynamic nature. Current world problems require new scientific narratives and tools to integrate system understanding in a coherent way and make strategic actions. One of the latest frameworks developed for a bio-economic analysis is the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism, MuSIASEM (Giampietro et al, 2013). It explains how it is possible to study the feasibility, viability and desirability of transitions (adjustments) of what they call the "*societal metabolism pattern*" of a society given the interconnected dynamics between societal functions, standards of living, population size, energy use, natural funds, among many other factors. MuSIASEM is currently considered by governments and international organizations as a way to develop energy and sustainability analyses for public policy. On the other hand, it has been claimed that SD methodology has the capacity to aid the decision-making processes within dynamic systems, by improving system understanding and allowing policies testing through simulation research. The current work is a theory-oriented research. The objective is to discuss the compatibility and feedback learning of SD methodology and MUSIASEM in the light of further energy studies for sustainability, having special focus on the dynamic component of any sustainability assessment.

2. What is a sustainable socio-ecological system?

To answer this question, first we have to define: 1) What a Socio-Ecological System (SES) is and what are the current tools to understand its complexity & 2) What is sustainability?

Socio-ecological systems, as the society we inhabit, are complex systems. These act in non-linear ways, are strongly coupled and possess thresholds in their dynamics. A comprehensive understanding of linked systems, human and ecological, requires the synthesis and integration of several different conceptual frameworks (Costanza, 1993). The complexity notion states there are multiple connections among different scales or hierarchies in a system, sharing at the same time, feedback processes of elements within scales, structure driven pattern, emergence and unpredictable change regarding initial conditions (Waldrop, 1992., Allen, 1996., Koestler, 1967., Prigogine, 1972). The feedback loops in complex systems makes it hard to distinguish cause from effect, space and time lags, discontinuities and limits (Constanza, 2002). Thus, it is very hard to keep track of all interactions, find appropriate ways to measure it and even more, plan solutions with appropriate risk or impact assessments, especially with regard to sustainability. Socio-ecological computer models are being used in the quest for practical solution. Beyond a tool for certainty and control, those are also considered an aid for social exploration, understanding and design through an iterative process of simulation research (Meadows, 2002).

According to Constanza (1993) any framework or methodology intending a sustainability assessment of complex systems using computer modeling must take into consideration: a) Application of the evolutionary paradigm: uncertainty, surprise, learning, path dependence, multiple equilibrium, suboptimal performance, lock-in and thermodynamic principles applicability. Multiple-measures of system performance are a key issue. b) Scale and hierarchy: definition of hierarchical levels interactions with each other and how to develop basic methods of scaling, also to explore how the chaotic-systems dynamics and fractal theory can be applied in this area. c) Nature and limits of predictability: nonlinearities raise the questions on the influence of resolution on the models performance. Models have shown that behavior or the system state is very sensitive to the change of initial conditions thus better measures of the model fidelity with reality and long-term behavior are stressed. The criteria: generality, realism and precision, is proposed to be incorporated in the observations and measurement development.

The difficulty to define what a sustainable SES is, it is because sustainability as concept it has increasingly lost its operational value. Goodland (1995) dimensions: economic, social and environmental fall into the bounded disciplines problematic. The strong-weak categories still present different paradigms that often justify the resource depletion for social immediate benefits or visceversa. The “future generations” speech is not critical enough to current material standard of living. None of these, the most common approaches, present an operational definition of sustainability. An operational definition would be Daly’s (1990) rules for resources maintenance: 1) renewable resources: harvest rate should not exceed the rate of regeneration, 2) pollution: rate of waste generation should not exceed the assimilative capacity and 3) nonrenewable resources: depletion should require comparable development of renewable substitutes. In the next section we will explain how an operational definition of sustainability can potentially be built from MuSIASEM framework basic concepts and how SD, as a complex systems modeling tool, can contribute for a sustainability assessment using this framework.

3. MuSIASEM and SD as tools for sustainability assessments of complex systems

3.1 MuSIASEM basic premises and indicators

MuSIASEM proposes sustainability "checks" regarding the feasibility, viability and desirability of the societal metabolic pattern of a society (Fig. 3). The metabolic pattern of a society (exosomatic metabolic rate, EMR) is measured by the amount of energy consumed and lost (exosomatic throughput, ET) per hour of *human activity (HA)* in the production side and/or consumption side of the society. The metabolic pattern is associated to: (i) the amount of hours of *human activity* allocated to economic activities vs. household sector (non-paid work, leisure plus physiological overhead), and (ii) within the economy, the amount of hours of *human activity* allocated to the different economic sectors (production of energy carriers, food, goods, transportation, and other basic services). The given profile of allocation of *human activity* across different functions, is the result of a complex set of relations (productivity of labor in the various sectors, that in turn is related to the amount of power capacity, level of technology and consumption of energy carriers used for the different tasks and these to the external constrains or resources availability of that specific society). A significant change in the profile of distribution of any one of these production factors (labor, power capacity, energy carriers, energy sources) over a compartment of the society might bring system instability.

The metabolic rate (ET/HA) can be calculated by levels: National, Paid work and Households and Economic sectors (Fig.2). Services and Government, Building, Leisure, Education and Physiological activities are functions related to the societal consumption side or energy dissipative part, i.e., the energy wasted that cannot be further invested in any function. Energy, Mining and Agriculture sectors have a production and consumption side. These represent the *hypercyclical* part. The energy invested here allows the primary energy flows maintenance. HA depends on the society population composition.

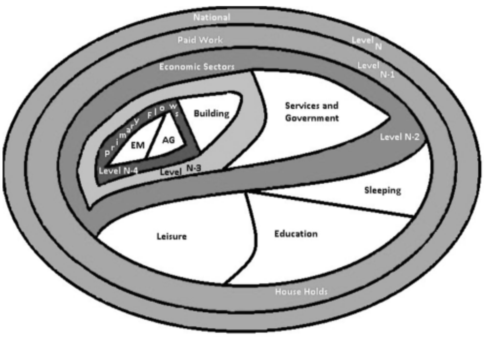

Fig. 2 Societal Levels according to MuSIASEM. Own Elaboration.

MuSIASEM proposes a variety of indicators according society levels to monitor the amount of energy consumed and lost per hour of human activity while fulfilling certain functions. Specifically, the sustainability checks based on those indicators (Fig.3) are the following :

Fig. 3 MuSIASEM sustainability checks. Own elaboration.

Feasibility of scenarios	Viability of scenarios	Desirability of viable scenarios
• Coherence of the system with its external constraints or boundary conditions. It is evaluated by looking at the local supply and sink side flows. • Tool: environmental impact matrix	• Congruence across sectors of the requirement and supply of flows. e.g. data aggregated on consumption at the whole level should match with the supply at local scales. • Tool: multilevel, multidimensional matrix	• Comparison of the resulting metabolic pattern (flow/fund ratio) regarding the functions at a local scale with benchmark values of certain types of socioeconomic systems. • Example: congruence with social values and institutions.

3.2 System Dynamics

SD is a methodology for understanding, discussing and simulating complex systems over time (Sterman, 2001). Important systems dynamics concepts (Zock, 2004) are: Stocks and Flows: stocks (or levels) consist of *accumulation* within the systems while flows (or rates) are the transport of some content of one level to another. Time delays: as levels are changed only by the rates measured in a determined time interval. Feedback loops: a decision alters the state of the world, but at the same time indirectly influences itself, defines the situation we will face in the future, and triggers side effects and delayed reactions. Positive loops reinforce or amplify what is happening in the system. Negative loops counteract and create balance and equilibrium. Fundamental concepts of SD are: 1)Accumulation process which states that stocks are integrations that cannot change instantaneously; they accumulate or integrate during time according the results of actions in the system and 2) Endogenous point of view that refers to the existence of a closed boundary from where the dynamic behaviour arises due to the internal feedback loop structure of the system (Richardson, 2011).

3.3 Conceptual compatibilities

The similarities found between MuSIASEM and SD were the use of Georgescu-Roegen's model, recurrence to the endogenous point of view and hierarchy and scaling considerations. The funds and flows from Georgescu-Roegen's model for the categorization of the variables has high compatibility to SD basic premises of the existence of system stocks which are modified by material or information flows over time under a certain system boundary, from where the dynamic behavior arises. MuSIASEM provides a form of accounting the societal energy requirement in different levels or boundaries (national, economic level, households and specific sectors) grounded on a society's internal configuration (such as population composition or socio economic identity) regarding its functions, and on its external constraints (primary energy sources and natural resources availability). The closed boundary selection of the system implies the need for focusing the study on the structure driving the behavior of the energy and material flows and human activity required by that system. MuSIASEM divides society in four different hierarchical levels, which have specific processes on the material, energy and human activity flows or allocation. The integration of levels must give place to the aggregated behavior of society. The sustainability analysis is based also on the congruence of the dynamics between each level, within the external constrains of the society as a whole. The consideration of the existence of a pattern of energy use in the society according to its structure and its recurrence to that pattern of MuSIASEM approach is based on the thermodynamic equilibrium state commonly used to explain characteristics of complex systems. It states that all systems tend to evolve characterized because within itself all the system properties are determined for intrinsic factors and not external influences, i.e., the equilibrium states are coherent with the system boundaries and the constrains to which it is subjected. If one part of these intrinsic factors resulted modified for any reason the system tend to show resilience capacity meaning it will tend to not move to another equilibrium state. Thermodynamic laws are applicable to the study of ecological economic systems (Eriksson, 1991). This could imply the existence of a balancing feedback loops in the system –SD reasoning-, but it can be also result of a emergent behavior or adaptation capacity driven by changes in the agents within the system, out of SD scope. In the next section the results of a testing exercise of MuSIASEM from a SD perspective are briefly described.

3.4 Testing results

In Armendariz (2014) MuSIASEM is tested using SD methodology in order to analyze its applicability for dynamic systems analysis. The test consisted on three modeling exercises were performed under MuSIASEM theoretical guidance and following SD principles. The first text was performed on an analysis on Argentina metabolic pattern from 1990 to 2007 (Recalde & Ramos Martin, 2012) made by applying MuSIASEM methodology. The article information resulted insufficient to make a proper dynamic assessment on the issue under study, i.e, the results were not possible to replicate using SD methodology given the categorization of variables, clarity on the equations, structure lacking of declared feedbacks, specific delay times and appropriate causality of how variables are changing. Two other attempts, the model on Human Activity (HA) and the model on Dynamic Energy budget, were perform using directly MuSIASEM narrative, assuring fidelity by avoiding framework misuses.

The HA model showed that when HA is considered flow, not fund, modified by the fund *Population* and other variables of the socioeconomic system, a better understanding of the elements that modify the societal metabolism pattern can be obtained. This perspective also increases the possibilities for a sustainability assessment; given that is not just a snapshot or indicator's development what will determine the "sustainability" of the energy use pattern but a close observation on the change of funds (stocks in SD terms). Thus, understanding the interrelations of variables on others leading the changes in the system over time is essential. The dynamic energy budget modeling-attempt showed gaps of information in the energy grammar impeding a dynamic modeling using just the MuSIASEM narrative. Further description on variables that seem essential as the Energy Returns on Investment (EROI) or the Strength of the Exosomatic Hypercycle (SHE) is missing from the narrative. The findings of these two modeling exercises show that MuSIASEM framework needs still to be refined in order to sustain a dynamic and operational analysis. The modeling exercises made possible a detailed analysis on the compatibilities between SD principles and MuSIASEM (See Annexes, Table 2). In the next section the implications of these results for a sustainability analysis are discussed.

3.4 Critical points for an operational sustainability analysis

3.4.1 Dynamic component of sustainability

MuSIASEM provides variables characterization and units for a quantitative analysis of energy use. It focuses on the assessment of the structural components and functions a society performs, and from this, it develops indicators based on economic and biophysical variables. The former can be part of an operational perspective of sustainability highly based on material issues. Nevertheless, it is insufficient; questions such as "*what type of changes would be required in the society (re-organizations of organs) to cut 50% of the actual energy consumption*?" or "*what type of changes in technology would be required to guarantee the viability of the resulting dynamic budget?*, are part of the framework "black box". These questions are strongly related to the system sustainability and they require a dynamic assessment for which the framework needs to be taken to an operational level. MuSIASEM

Authors acknowledge the framework just allows for the development of quantitative characterizations in relation to what happens inside the black box.

3.4.2 MuSIASEM and SD potentialities

SD methodology could help clarifying what they call the *black box*, understood as the dynamic processes inside the society that explain the consumption of energy, composition of economy, population change and supply of human activity, among others. One big challenge addressed in the book, also expressed to be out of the scope of the MUSIASEM framework and referred to as fundamental on energy analysis, is how to establish a relation between the gross energy requirement for expressing the metabolic pattern and the requirement of primary energy sources that are beyond human control, considered funds. In this case, SD could provide the possibility of linking, and characterize the relation between external constrains, internal organization structure of economy, population composition and its change over time, in order to see what is the relation between the gross energy requirement and the availability of primary energy sources that for sure, is changing over time. Other proposals are described in Table 1.

Table. 1 SD improvements to MuSIASEM sustainability checks. Own elaboration.

System Dynamics improvements to MuSIASEM Sustainability checks	
Feasibility	System boundary selection and characterization of flows and funds within the boundary. Check the responses of the system to a change on external constrains through simulation exercises (tool).
Viability	Open the *blackbox* and clarify the dynamics that create the requirement of human time and material and energy flows. Identify those variables or leverage points that question the viability of the system.Tool: Specialized modeling on the socioeconomic sector.
Desirability	Close the loops to regulate and balance dynamics or make intervention on variables to increase or reduce certain effects.Tool: policy eliciting by goal or target selections and simulation trials to asses the effects.

Dynamic and systemic indicators

The importance of the indicators is that they show values according to the internal organizations of the society, (i.e., organization of economic activities, technology development, population composition). These belong to different hierarchical levels. Meadows (1998) states indicators are relevant because they manage the existing differences in world views, should be about time, thresholds, efficiency, sufficiency, equity and quality of life and coherent information systems, organized in scales. The former implies an understanding comprehensive with the acknowledgment of the socio-ecological systems we inhabit. She proposes the information systems must be organized in scales, from which the indicators are to be developed; decreasing the specificity and increasing the scale. Therefore, it is manageable to create, understand and support decision-making processes. As well, indicators might be useful learning tools that, according to Meadows, imply an evolutionary process. In this sense, MuSIASEM indicators meet some of these suggestions and could be considered milestones in a SD model building process.

3.4.3 MuSIASEM and SD limitations

Constanza (1993) stated 3 key issues on modeling ecological complex systems. SD and MUSIASEM manage the scale and hierarchy consideration. On the application of the evolutionary paradigm, neither SD nor MUSIASEM are capable of explaining any spontaneous endogenous change, in order to rearrange functions and activities based on the available funds. MuSIASEM talks about thermodynamics equilibrium but it does not explain how this will actually work within the societal context. The adaptative capacity given the critical organization of complex systems, also known as the Zipfs law, could express the existence of balancing or negative loops, yet unknown, or adaptations of the system individuals or organizations provoking emergent behavior. For this, modeling approaches as agent based modeling (ABM) are better. On limits of predictability, every modeling activity is limited due to the selection of what the system is believed to be plus a high level of aggregation. In additions, there is always a frontier of what is known, for instance, the system initial conditions . Models are as tools to generate scenarios under certain assumptions and transparency is a crucial. None of these disciplines, SD and MuSIASEM try to be predictive.

4. Conclusions

From a SD perspective, it was discovered that MuSIASEM has to address some challenges in order to properly provide a systemic view consistent with dynamic system analysis. Some of these challenges are the right categorization of funds and flows and the detailed explanation of the main processes of the energy transformations it attempts to assess. MuSIASEM's idea of sustainability it is based on the maintenance and reproduction of the fund elements in the metabolic process of society during the period of analysis, but it does not say how. No practical recommendation is provided to change what they call –the metabolic pattern- of the society. The importance of a dynamic perspective of the metabolism pattern of a society could improve significantly a sustainability assessment and intervention proposals. SD, through simulation exercises, can provide insights in order to make operational the sustainability assessments for understanding and develop policy or interventions. The coherence of the human processes with the external constraints could be achieved designing more *viable* dynamics at different societal levels that regulate the supply and consumption flows, finding opportunities to close loops or establishing controls, to substantiate, what they call, the desirability of the metabolic pattern.

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6. Annexes

Table 2. SD principles according to Forrester (1968) extracted from Zock (2004) and its compatibility with MuSIASEM framework.

SYSTEM DYNAMICS PRINCIPLE	MUSIASEM
1. Closed boundary: dynamic behavior arise within the internal feedback loop structure of the system	Compatible MuSIASEM states different societal levels in order to analyze the metabolic pattern of society. Within each level there are variables to take into consideration. At level N-2, N-3 and N-4, we found narrative that talks about the existence of what they call an "hypercycle" that takes part of the material and energy flows available for consumption, again to the production process to keep the material and energy flows production. This hypercycle could not be explicitly modeled because of a lack of specifications on what stocks or flows it is related to.
2.Feedback loop as structure element of the system: causally closed path coupling system state, observation of this state and decisions based on this information. Dynamic behavior is generated from the feedback. Complex systems are assemblies of interacting feedback loops.	Compatible Loops are elicited from the narrative (see figure 21) but the dynamic component has not been developed in the application cases or the tools used of this approach.
3. Decisions within feedback loops: decisions control actions that alter the system levels that at the same tie influence the decision. A decision process can be part of more than one feedback loop.	Compatible There was found a possibility to close an open loop within the Human Activity sector in order to develop policy (Example: Figure 20, B2 loop).

4. Levels and rates as loops substructures: a feedback loop is conformed by levels (states or stocks) and rates that can be altered by other variables.	Compatible It uses Georgescous's fund and flow model to categorize the variables within the analysis. The rates are mentioned in the narrative to be susceptible to other variables of the socioeconomic system.
5. Levels are integrations: levels or stocks are variables that cannot change instantaneously and they accumulate or integrate according the results of actions in the system.	Compatible. Theoretically, by using the Georgescus Roegen's categories, it is understood that funds are integrations. Nevertheless, MuSIASEM has not addressed yet a way of making its analyses dynamically.[1]
6. Levels are changed only by the rates: the previous level is altered by rates that flow over the intervening time interval.	Compatible and aligned with Georgecus Roegen's model and the right selection boundary definition.
7. Levels completely describe the system condition: just values of level variables or stock are needed to describe the condition of a system.	Compatible. In MuSIASEM the levels or stocks responds to "what the system is"
8. Rates not instantaneously measurable: no rate can control another rate without an intervening level variable.	Unexplored. Specifically in the hypercycle explanation it is not clear if this could be a flow modifying other flow in a given period of time or how does it work.
9. Rates depend only on levels and constants: no rates depends directly from another rate, no rate equations of a system are of simple algebraic form, don't involve time or solution period, they don't depend on their past values.	Unexplored. MuSIASEM narrative does not provide explanation on the changes of all relevant flows driving the dynamic energy budget processes or equations or further elaboration on how rates are modified.
10. Rate substructure or system sub-sub structure or goal, observation, discrepancy, action structure: a policy or rate equation recognized a local goal towards a decision point, the difference between the desired point and the actual state is the discrepancy which is used to guide the dimension of the action.	Compatible There has been identified an opportunity to extend the *desirability check* in order to regulate the allocation of human activity in the economic sector and households as a policy or establish a mechanism of control depend on the purpose of the policy. (Example: it could be a policy to respond to the labor demand in a period of time until a threshold to not affect the education or leisure activities).
11. Level variables and rate variables must alternate: any path trough the system structure encounters alternating stocks and rates.	Unexplored. MuSIASEM does not picture a complete system structure; nevertheless, out of the narrative preliminary system structures could be built that presented alternation between stocks and flows.
12. Levels and rates not distinguished by units of measure: the units of measurement of variables do not distinguish between levels and rates. The identification should clarify the difference between a variable created by integration (level or stocks) and the ones that are a policy or a flow in the system (rates) feeding the levels.	Compatible but not described as such. MuSIASEM framework stresses the importance of unit consistency because of the relevance of in order to have a proper accounting on how funds are changed by the flows. MuSIASEM does not talk about integration as characteristic of funds or stocks but it mentions that funds should be conserved during the analysis boundaries and its flows should be able to maintain them. In sustainability terms it also mentions that the system funds have to be maintained.

[1] In MuSIASEM literature has been described the intentional avoidance of using mathematic assessments related to the critique to prediction aims of complex system features. It is considered that the factors and variables of the system are changing constantly therefore it is not desired to use a deterministic tool to address the dynamic adaptation capacity of complex systems.

Transmission Process Analysis of Energy Technology Spillover Effect

Xiaoqi Sun[1,2,3], Haizhong An[1,2,3]*, Xuan Huang[1,2,3], Xiaoqing Hao[1,2,3]

1 School of Humanities and Economic Management, China University of Geosciences, Beijing 100083, China

2 Key Laboratory of Carrying Capacity Assessment for Resource and Environment, Ministry of Land and Resources, Beijing 100083, China

3 Lab of Resources and Environmental Management, China University of Geosciences, Beijing 100083, China

Corresponding Author e-mail: ahz369@163.com

Abstract

Technological innovations in the energy field are vital to sustainable development. Technological innovations not only benefit directly linked economic sectors but are also favorable for indirectly related economic sectors through intersectoral input-output linkages. This phenomenon is called the intersectoral technology spillover effect. In this paper, we propose a novel perspective for investigating the mechanism of the intersectoral technology spillover effect using a combination of the input-output technique and complex network theory. R&D funds constitute one common measurement of technological innovations, and the embodiment concept depicts the complete intersectoral input-output linkages. Based on China's input-output data for 2009 and data on the R&D funds in the electricity and gas sector, we construct one embodied R&D fund complex network model in which economic sectors are set as nodes and the input-output linkages are set as edges. The results show the following: (1) the basic metals and fabricated metal, construction, chemical and chemical products, and electrical and optical equipment sectors are the dominant sectors in terms of spreading the intersectoral technology spillover effect; (2) the transportation, modern service, and agriculture, hunting, forestry, and fishing sectors are the major media for the transmission of this spillover effect; and (3) gross fixed capital formation, exports, and the construction, basic metals and fabricated metal, and electrical and optical equipment sectors are the main beneficiaries of this spillover effect. These results are useful for understanding the role of technological progress in the electricity and gas sector with regard to economic structure transition and sustainable development.

1. Introduction

With growing energy demand and increasing environmental protection concerns, clean fuel technologies innovations and new energies are being intensively pursued and investigated (Ellabban et al., 2014). It is well recognized that technological innovations own the property of spillover because of their non-rivalry and non-excludability (Bascavusoglu, 2004). There are two types of technology spillover, disembodied spillover and embodied spillover. Disembodied spillover consists of learning about new technologies and materials, production processes, or organizational methods. On the contrast, embodied spillover emanates from imports of goods and services that have been developed by trade partners (Coe and Helpman, 1995). Previous studies on this spillover phenomenon focus on the diffusions of technologies across national boundaries either in embodied way or disembodied way (Coe and Helpman, 1995; Grossman, 1993; Lee, 2005; Parrado and De Cian, 2014; Shih and Chang, 2009; Tang and Koveos, 2008).

However, there is another perspective to look at technology spillover, which focuses on the technology transmission between economic sectors within one country, i.e., intersectoral technology spillover. In this paper, we define this technology spillover as the positive effect (or benefits) that technological progress in one sector has on other sectors through input-output linkages. For example, the energy efficiency technological progress in the energy-intensive sector not only benefits that sector but also indirectly improves the energy efficiency of the other sectors that consume products from that energy-intensive sector. There are many aspects of the intersectoral technology spillover effect, some of which, including the impact of this effect on the innovation of new technologies, are beyond the scope of this study. The primary purpose of this study is to investigate the mechanism of the intersectoral technology spillover effect, i.e., how this effect spreads through the entire economy. This investigation involves three dimensions, the dominant sectors in the spread of the technology spillover effect, the broker sectors in the diffusion of the technology, and the primary sectors benefitting from the technological progress.

Based on our definition, intersectoral technology spillover is similar to the embodied technology spillover definition, but our measurement of embodied spillover is different from the conventional calculation as (Griliches, 1991) did. Our calculation is based on input-output table. The more one sector absorbs from the other sectors, the more it benefits. The details of this calculation will be addressed in methodology part. Furthermore, intersectoral technology spillover is a comprehensive term dealing with mechanisms for diffusing technological innovations across economic sectors and the effective diffusion of technology into the recipient sectors. Thus, it involves complex processes, resulting in policy making in this area being especially complex and requiring deliberate consideration at the multi-sectoral level. For this purpose, we introduce complex network theory that consists of structure analysis of nodes and edges. By setting economic sectors as nodes and technological input-output linkages between them as edges, we construct intersectoral technology spillover network model, through which we analyze the structure characteristics of intersectoral technology spillover network and thus learn the mechanism of the intersectoral technology spillover effect.

The rest of this paper is organized as follows: section 2 provides the methodology to process relevant data and construct a complex network model. Section 3 presents the results. The last section includes our conclusions and some policy suggestions.

2 Methodology and Data

2.1. Calculating embodied R&D data

The IO technique is one of the main tools used to analyze the intersectoral effect by calculating embodied data. Embodied data represent the measurement of the total input to generate the total output of one sector (Chen and Chen, 2013). The embodied data are calculated by adding one row to the Leontief matrix for the R&D funds in the electricity and gas sector, which supplies R&D funds to all of the other sectors (Lenzen et al., 2007). The difficulty in applying this technique here is that we do not have data on the R&D funds that the electricity and gas sector supply to the other sectors. Therefore, we first calculate the R&D funds per unit output and then multiply the electricity and gas sector row by this coefficient. In this way, we estimate the R&D funds that the electricity and gas sector supplies to the other sectors.

For the entire economy, the balance of the embodied R&D funds is as follows:

$$D^T + X^T A^T = YA^T \tag{1}$$

where

$$D^T = \begin{pmatrix} d_1 \\ d_2 \\ \cdot \\ \cdot \\ \cdot \\ d_n \end{pmatrix}; X^T = \begin{pmatrix} x_{11} & \cdot & \cdot & \cdot & x_{n1} \\ \cdot & \cdot & & & \cdot \\ \cdot & & \cdot & & \cdot \\ \cdot & & & \cdot & \cdot \\ x_{1n} & \cdot & \cdot & \cdot & x_{nn} \end{pmatrix}; A^T = \begin{pmatrix} \alpha_1 \\ \alpha_2 \\ \cdot \\ \cdot \\ \cdot \\ \alpha_n \end{pmatrix}; Y = \begin{pmatrix} \sum_{j=1}^{n} x_{1j} + f_1 & 0 & \cdot & \cdot & 0 \\ 0 & & \cdot & & \cdot \\ \cdot & & & \cdot & \cdot \\ \cdot & & & \cdot & \cdot \\ 0 & & \cdot & \cdot & \cdot & \sum_{j=1}^{n} x_{nj} + f_n \end{pmatrix}.$$

where d_i denotes the direct R&D funds input of sector *i*, α_j denotes the embodied R&D funds intensity of sector *j*, x_{ji} denotes the intermediate input *j* to produce product *i*, and f_i denotes the sum of final consumption. $\alpha_i \times \sum_{j=1}^{n} x_{ij}$ represents the indirect R&D funds.

Because *Y* is a symmetric matrix and $(Y - X)$ is reversible and guaranteed due to the construction standard of the economic input-output table (Miller and Blair, 2009), we obtain

$$A = D \times (Y - X)^{-1} \tag{2}$$

After obtaining the results of the embodied R&D funds intensity of every sector, we multiply China's input-output monetary table, Z_m, with the embodied coefficients; see Eq. (3). Finally, we obtain China's embodied R&D funds input-output table, Z_e.

$$Z_e = A^* \times Z_m \tag{3}$$

where $A^* = \begin{pmatrix} \alpha_1 & \cdot & \cdot & \cdot & 0 \\ \cdot & \cdot & & & \cdot \\ \cdot & & \cdot & & \cdot \\ \cdot & & & \cdot & \cdot \\ 0 & \cdot & \cdot & \cdot & \alpha_n \end{pmatrix}; Z_m = \begin{pmatrix} x_{11} & \cdot & \cdot & \cdot & f_1 \\ \cdot & \cdot & & & \cdot \\ \cdot & & \cdot & & \cdot \\ \cdot & & & \cdot & \cdot \\ x_{n1} & \cdot & \cdot & \cdot & f_n \end{pmatrix}; Z_e = \begin{pmatrix} z_{11} & \cdot & \cdot & \cdot & z_{1n} \\ \cdot & \cdot & & & \cdot \\ \cdot & & \cdot & & \cdot \\ \cdot & & & \cdot & \cdot \\ z_{n1} & \cdot & \cdot & \cdot & z_{nn} \end{pmatrix}.$

2.2. Construction of a complex network model

Based on the embodied R&D funds input-output table, we build a complex network model. A complex network consists of nodes and edges that link the nodes. In this study, economic sectors are set as nodes and the technological input-output linkages between those nodes are set as edges. Because different edges carry various embodied R&D funds, the edges are weighted. Using these notations and equations, the directed, weighted China's embodied R&D funds network is established with 37 nodes and 1139 edges.

2.3. Data Source

China's input-output data are derived from the World Input-Output Database (http://www.wiod.org/database/). The R&D funds data in the electricity, water and gas sector are derived from the official website of the National Bureau of Statistics of China (http://data.stats.gov.cn). Because 2009 is the latest year for which R&D funds data are available for the electricity, water and gas sector, for the sake of consistency, we use China's input-output data for the same year for the analysis. In addition, because water supply accounts for only 3% of the supply of the electricity, water and gas sector, the data bias here is acceptable.

3. Results

3.1. The dominant sectors in the spread of the spillover effect

To determine the dominant sectors in the spread of the technology spillover effect, we draw on the weighted out-degree from complex network theory. The weighted out-degree, O_i , reflects the extent to which one sector affects the economy cumulatively. The higher the weighted out-degree, the more influential the sector is.

$$O_i = \sum_{j=1} w_{ij} \tag{4}$$

where w_{ij} denotes the amount of embodied technology R&D funds from sector i to sector *j*.

Our results show that the first 35.13% of the sectors in the economy spread 80.88% of the total spillover effect. Of these sectors, the basic metals and fabricated metal sector, the construction sector, the chemicals and chemical products sector, the electrical and optical equipment sector, and the machinery, n.e.c. sector represent the top five sectors and account for 15.95%, 11.69%, 9.68%, 9.24%, and 5.84% of the spillover effect, respectively.

3.2. The primary sectors benefitting from the technological progress

The weighted in-degree, I_i, reflects the effect absorbed by one sector from other sectors. Specifically, this indicator symbolizes the extent to which one sector benefits from the cumulative spillover effect of the other sectors. The larger the weighted in-degree of sector *i*, the greater its absorption of the technology spillover effect from other sectors.

$$I_i = \sum_{j=1} w_{ji} \tag{5}$$

where w_{ji} denotes the amount of embodied technology R&D funds spilling over from sector *j* to sector *i*.

The first 35.13% of sectors in the economy absorb 80.40% of the total spillover effect. Gross fixed capital formation, the construction sector, the exports sector, the basic metals and fabricated metal sector, and the electrical and optical equipment sector are the top five sectors and absorb 15.91%, 9.44%, 9.16%, 8.86%, and 7.69% of the spillover effect, respectively.

3.3. The sectors acting as a broker to spread the spillover effect

There are many intermediate processes within the complete production chain of any given industry, and every economy is constituted by numerous industries. As a result, broker sectors exist in an economy and act to diffuse the intersectoral technology spillover effect from the upstream industries to the end use sectors. To describe these brokerage sectors, we introduce the betweenness centrality concept here. Betweenness centrality measures the importance of one node in connecting the entire network (Leydesdorff, 2007). The larger the value of betweenness centrality is, the more important *k* becomes.

$$B_k = \sum_i \sum_j g_{ikj} / g_{ij},\ i \neq j \neq k \tag{6}$$

where g_{ij} is the number of geodesic paths between *i* and *j* and g_{ikj} is the number of these geodesics that pass through *k*.

The results of betweenness centrality show that the transportation sectors, the modern service sectors (such as the renting of M & Eq.) and other business activities sectors, and the agriculture, hunting, forestry, and fishing sectors are those sectors that diffuse the intersectoral technology spillover effect from the upstream industries to the end use sectors. Among the transportation sectors, land transport is the most important in diffusing the spillover effect, followed by water transport and then air transport.

4. Conclusions

In this paper, we analyze the mechanism of the intersectoral technology spillover effect in the electricity and gas sector. To describe the mechanism, we establish an embodied R&D funds input-output table, upon which the embodied R&D funds network is based. Based on the analysis of the embodied R&D funds network, we find the following three main results

(1) The dominant sectors in the spread of the intersectoral technology spillover effect are the basic metals and fabricated metal sector, the construction sector, the chemicals and chemical products sector, the electrical and optical equipment sector, and the machinery, n.e.c. sector.

(2) The primary sectors benefiting from technological progress are gross fixed capital formation, the construction sector, the exports sector, the basic metals and fabricated metal sector, and the electrical and optical equipment sector.

(3) The sectors that act as brokers for spreading the spillover effect are the transportation sectors, modern service sectors, and the agriculture, hunting, forestry, and fishing sector.

These results are useful for understanding the role of technological progress in the electricity and gas sector with regard to meeting growing energy demand and addressing environmental protection concerns. Technological progress aiming to increase energy supply or decarbonize the generation of electricity and gas will help clean up the entire economy via sectors that are dominant in the spread of the spillover effect. From the perspective of the primary beneficiary sectors, China will contribute to the resolution of climate change through its exports. Last but not least, to make better use of this spillover effect, it is important to develop those sectors that act as brokers, such as the transportation sectors.

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The impact of imported iron ore prices in China based on quantile regression model and pricing game

Wenhui Chen[a,b]; Yalin Lei[a,b,*]

[a]School of Humanities and Economic Management, China University of Geosciences, Beijing 100083, China

[b]Key Laboratory of Carrying Capacity Assessment for Resource and Environment, Ministry of Land and Resources, Beijing 100083, China

Abstract：

As industry a raw material of steel production, iron ore is very important for a country's economic and development, especially for China. According to economic theory, this paper use gray correlation analysis method to choose factors that affect the price of imported iron ore in China. Based polynomial distribution lag model (PDLs) and regression analysis, a decomposition model of Iron ore prices in China is established. The model is adopted to analyze the influence of crude steel production, China's iron ore monthly production, BDI, Iron ore imports, domestic port stocks, dollar exchange rate on Iron ore price from 2006 to 2014 in China． Further a quantile regression model is established, this model for iron ore price in China was proposed and every factor’s effect on prices of iron ore under different weights was analyzed. Then combine game theory, game model of iron ore pricing, explore different pricing in different quantile provide reference for China's steel industry, iron ore trading patterns.

Key words: Influence of Iron ore prices; Polynomial distribution lag model ; Quantile regression；Game theory

Developing concepts for sustainable mobility in Curitiba, Brazil

Semida Silveira
Professor Energy Systems Planning
KTH, Stockholm, Sweden

The city of Curitiba has a long history of planning for sustainable development having worked on long-term urban planning and sustainable mobility for at least 4 decades. With continued growth and pressure to deliver quality transport while also addressing climate change, the city now aims at further developing mobility concepts. A consortium of Swedish and Brazilian stakeholders has been formed to promote system innovation, combining information technology and smart grids to develop electro-mobility, and energy efficient and low-carbon transport services in the city. In addition, the project addresses problems of energy efficiency and greenhouse gas emissions in public transportation, and opportunities created by smart grids for provision of new services

Energy and material flows in megacities

Angelo Facchini[1*], Chris Kennedy[2], Iain Stewart[2], Renata Mele[1]

[1] Enel Foundation, Rome, Italy

[2] University of Toronto, Canada

Corresponding Author e-mail: angelo.facchini@enelfoundation.org

Abstract

The understanding the drivers of energy and material flows of cities is an important activity for addressing topics such as global environmental stresses, efficiency in resource use and resource competition. Due to their sheer size and complexity, megacities represent case studies from which we can learn about many aspects of urban development, since relevant aspects, both negative (like inequalities, pollution, etc.) and positive (like innovation, economic prosperity and well living) of urbanization converge and are amplified. Furthermore, for their peculiar characteristics, megacities are more exposed to the challenges of urban sustainability, and they need extra effort for sharing and managing energy and material resources efficiently.

The object of this paper is to show the results of a comparative study of the urban metabolism of 27 of the world's megacities. In particular, we determine and compare the energy and material flows through the 27 megacities showing correlations between water use, electricity consumption, heating and industrial fuel use, waste generation in terms of climate, urban form, economic activity and population growth. Furthermore, we explore the role of utilities in providing services enabling urban development like access to water and electricity, and waste management. Finally, we propose new indicators that improve the understanding of the temporal evolution of electricity consumption in relationship with population and GDP.

1. The rise of megacities

At the pinnacle of urban growth, megacities, i.e. urban agglomeration with more that 10 million people, are a powerful example of the urban growth that our society is experiencing in the last decades. The 21st century is indeed the century of the city, since 2007 more than half of the global population lived in cities and this figure is expected to grow up to 60% by 2050. In developing countries, that in the last two decades are experiencing the most relevant growth, urbanization is assuming the characteristics of a very fast phenomenon leading to the fats formation of huge urban agglomeration. By example, the number of megacities was 7 at the beginning of the 1960, and grew up to 27 in 2010, and in 2020 the expected number is 37 (Kennedy, 2014). The massive migration from the rural areas is one of the main drivers for the increased the number of megacities, that, acting like accumulation points for urban population, contribute to significant share of urban population and GDP. By example, according to UN-Habitat (UN Habitat, 2011), in Asia Seoul represents about the 25% of the Korean population and about 50% of the national GDP, while in Europe, Paris shares about 22% and 30% of the national population and GDP, respectively. Other cities, although important, share lower values, like New York (about 8% of both population and GDP) or Shanghai (5% GDP and less than 3% of population). Sustaining the future growth of megacities is a relevant challenge, both under the point of view of the use of resources, both under the point of view of social and economic sustainability. Megacities, in fact, due to their size and complexity, tend to concentrate and amplify drawbacks of urbanization like inequalities (e.g. slum formation and unequal distribution of income), environmental pollution, GHG emissions, and unequal use of resources. On the other side, megacities are also source of best practices and good examples of sustainability solutions from which many can learn. In addition, due to their peculiar characteristics, megacities are paradigmatic case studies for urban development, and their understanding is crucial for important players like utilities, urban planners, and policy makers. Because of this, and in order to identify which mechanisms can be identified for triggering a sustainable growth, it is essential to understand how they use resources and how much they are efficient in using them. We present in this paper the results of a comparative analysis of energy and material flows in megacities. Section 2 reports the main findings, showing how the use of resources is distributed among 27 of the world's megacities in relationship with their GDP share. Section 2 is also devoted to the analysis of electricity consumption in relationship with geographic and economic characteristics of megacities. We also introduce in section 2 a new indicator, the 'growth ratio', and we show how it can be used to derive indications about the efficient use of resources. Results on provision and access to basic services are described in section 3 and, finally, in section 4 we describe the impact that the set of the investigated megacities have on the global energy and material flows.

2. Comparative analysis of energy and material flows

In order to assess the use of resources in relationship with geographic and socio-economic aspects, we refer to a common database made of data collected by means of a multi-layered survey, that investigates the main aspect (or layers) of the megacity: spatial boundaries, biophysical characteristics, urban metabolism, and role of the utilities. These 4 'layers' are all important in order to better understand the results presented in this paper. In fact, due to increasing complexity of the urbanization phenomenon, referring only to material and energy flows without considering the other components may result in a misleading interpretation of the results.

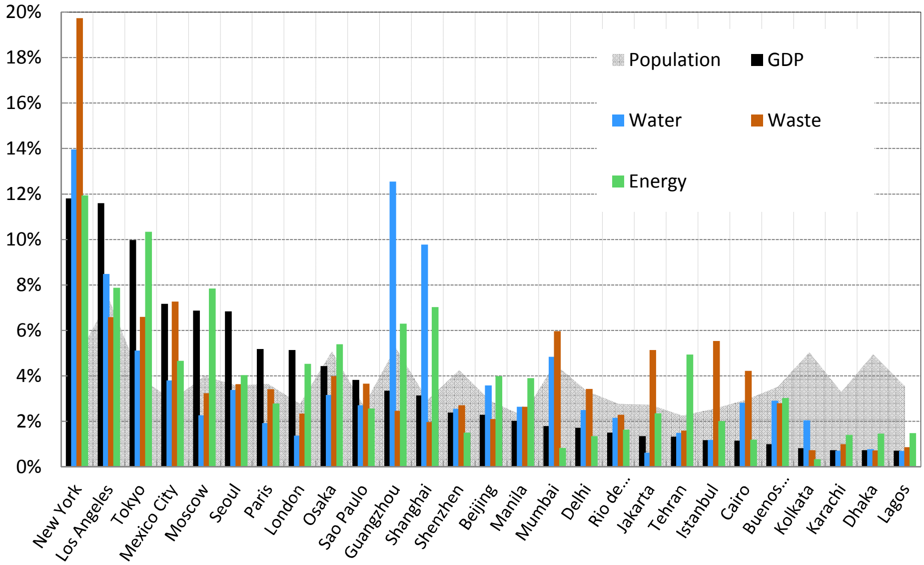

Figure 1 Overview of the metabolic flows of megacities ranked by GDP share.

Figure 1 shows, for each megacity, the share metabolic flows, as a percentage of the total resource consumed. The megacities are ranked according to ascending GDP, and flows of water, total energy consumption (electricity, transportation, fuel, etc), waste production, and population are reported as a global share of the total resources consumed. It is worth noticing that equal share of GDP (e.g. New York and Los Angeles - Mexico city, Moscow and Seoul – Paris and London) do not always lead to similar share of resource consumption. In particular, waste disposal in New York almost doubles the share of Los Angeles, while the other megacities show significant lower values. Among fast developing countries, the Chinese megacities Guangzhou and Shanghai show, with respect to the other megacities present in the area, relevant share of energy and water, suggesting a further study of the water energy nexus in China. With regards to waste collection in developing countries, it is worth considering the case of Jakarta, Mumbai, Istanbul, and Cairo, that show a significant difference between the GDP and waste collection share.

Focusing on electricity consumption, figure 2 shows the effect of the urban dispersion. In particular, for the megacity we find results consistent with (Kennedy, 2011): inhabitants of dispersed urban areas shows higher consumptions with respect to denser urban areas, showing a weak exponential distribution.

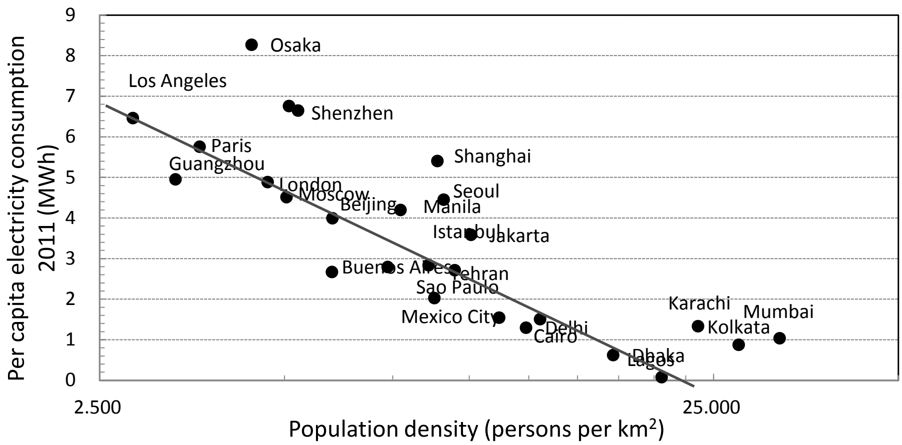

Figure 2 Relationship between density and electricity consumption showing a weak exponential decay

Considering the relevant urban expansion of the last decade, we deem worth investigating the decadal growth rate with respect to the population increase in the period (2001-2011). Figure 3 shows a significant difference between cities located in developed regions and located in developing regions. In particular, Asian megacities show the higher increases in energy consumption, while European megacities (and Mexico city) are characterized by small increase, or, as in the case of London, by a decrease in electricity consumption, that may be associated to energy efficiency measures, new technologies, and the economic crisis of the last decade.

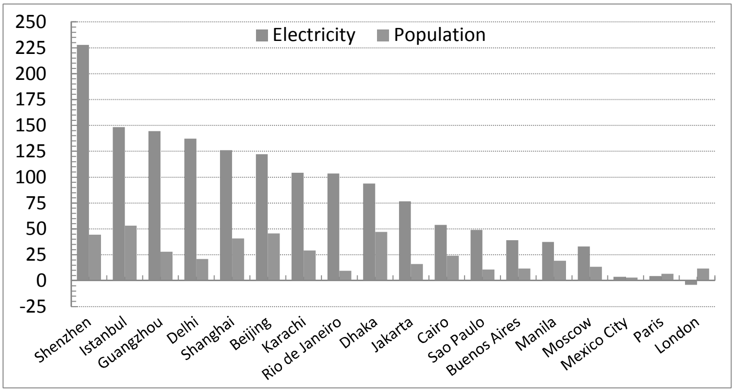

Figure 3 Comparison of decadal growth rates of electricity consumption and population (2001-2010).

In order to have a better picture, it is also interesting to look at the ratio between the decadal growth rates of population and electricity consumption:

$$R_{EP} = \frac{\Delta E}{\Delta P}$$

By looking at R_{EP}, Rio the Janeiro is the megacity in which the value is the largest (10.8), while lower values are found in Sao Paulo and Buenos Aires in Latin America (4.5 and 3.3, respectively) and in Shenzhen, Delhi and other Asiatic megacities, that are in the range 5.1-1.9. A partial understanding of figure 3 can be provided by including information related to GDP. In analogy with electricity consumption, we introduce the ratio $R_{GP} = \Delta GDP/\Delta P$, and we plot the two values in Figure 4, in which the red line indicated the line of identity, while the blue lines indicate values over or under 20% of the line of identity (i.e. when the ratio $\Delta GDP/\Delta E$ is in the range 0.8-1.2). Rio de Janeiro is the only megacity for which the ratio is 1, while Shenzhen, Dhaka, and Karachi are within the 20% area. All the other megacities, are above in the upper side of the diagram, with Mexico City, Moscow and Sao Paulo positioned well over the other cities. We may hypothesize the (R_{EP}, R_{GDP}) diagram as a measure of the efficient evolution of the city, in which the lower part of the diagram indicate that small variation of GDP produce large variation of consumption (indicating a lower efficient use of resources). On the contrary, in the upper part of the diagram large GDP variation are only in part reflected in the resource consumption, indicating a less efficient distribution of the GDP. Future research will be devoted to the future understanding of the above mentioned indicators, with particular attention in considering wider or smaller time periods, in order to characterize short-term, mid-term, and long-term evolutionary patterns

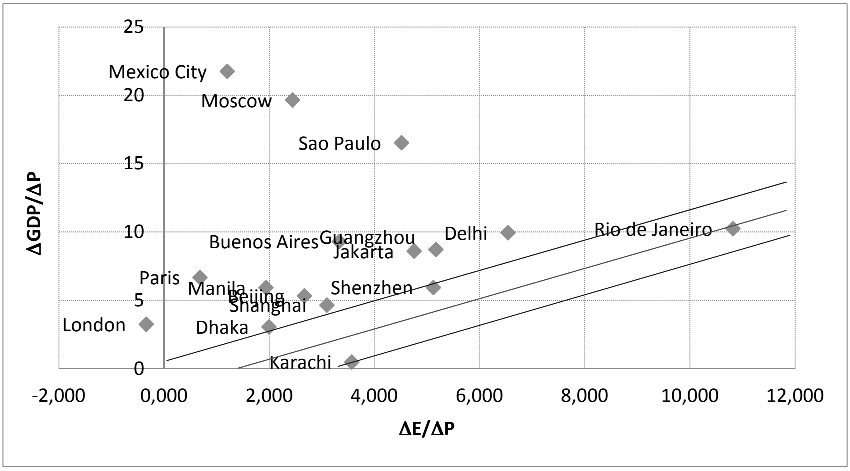

Figure 4 Name needed. Plot of growth ratios for GDP and Electricity consumption.

3. Quality of service in megacities

In addition to data on energy, water and solid waste, data on the access to resources show that many of the megacities considered are consuming resources at rates below those which support a high quality of life. Substantial proportions of residents in some megacities – particularly in South Asia – have no access to fundamental services enabling urban development, such as clean water, sewerage, electricity and formal waste disposal (Table 1). The under-consumption of resources in these cities is, however, complex and needs further investigation. For example, non-revenue water is high in many megacities, reaching over 70% in Sao Paulo and Buenos Aires. Some of this may be due to informal/illegal water withdrawals, while other losses are due to the poor state of infrastructure, encouraging investments in modern infrastructures in order to achieve a efficient and sustainable growth for all the population.

Table 1 Percentage of access to services in megacities

Megacity	***Households without direct access to water***	***Households without direct access to drinkable water***	***Water line losses as a share of total water consumption***	***Households without sewerage***	***Wastewater subject to treatment***	***Households without public waste collection***	***Households without grid electricity connection***
Mumbai	21	21	3.7	64	94	48	18
Delhi	20	22	40	64	56	-	0.9
Dhaka	7	31	33.1	65	65	10	67
Kolkata	-	39	22	37	24	-	5

Karachi	40	60	40	43	22	40	35
Jakarta	8	24	-	12	-	-	0.3
Cairo	8	19	6.1	23	6	-	-
Tehran	0	0	33.3	55	-	0	0.1
Rio	1	11	54.2	26	32	9	0
São Paulo	2	2	71.4	8	43	5	0
Buenos Aires	11	11	76.1	14	42	5	0
Mexico City	4	-	-	0.5	15	-	5
Guangzhou	0.3	2	-	15	4	1	15
Shenzhen	5	6	-	30	20	1	15
Shanghai	0	0.6	15	10	14	1	0
Beijing	0	0.3	15.3	5	5	0	0
Lagos	-	-	-	-	-	-	-

4. The global impact of megacities

While there is great diversity in the energy and material flows through individual megacities, collectively their resource flows appear to be consistent with scaling laws observed for cities over a wide range of populations. The 27 megacities had a combined population of 460 million in 2010, equal to 6.7% of global population, while their combined GDP was much larger in percentage terms, at 15.2% of global GDP. This is expected for socio-economic characteristics, which have been shown to scale with an exponent of $\beta \approx 1.15$ (Bettencourt, 2013). Furthermore, the economic power of megacities is well represented by the fact that that the GDP of New York, Los Angeles and Tokyo is well above the other megacities, with a GDP over 1000 billion dollars. The other megacities are in the range of 80.6 (Lagos) to 818.4 (Mexico City). Regarding energy and material flows, the total waste production for megacities is estimated to be 9.8% of the global amount. This value suggests that waste flows may also exhibit super-linear behavior, because of their relation with GDP. Essentially the higher amount of economic activity in larger cities entails importing relatively high quantities of goods and other materials, which apart from those that become bound in the building stock, exit cities relatively rapidly as wastes. The total energy consumption of the 27 megacities is about 21,621 PJ, which is approximately 6.0% of global energy consumption. This percentage is close to, but under, the 6.7% of global population that lives in megacities[1].

[1] The observation that megacities consume 6% of total global energy use should be treated cautiously:
i) The global energy use total includes energy consumed in global transportation of goods and people, much of which actually occurs between cities.
ii) We have reported energy consumption by cities, not primary energy use. Electrical energy use is higher if primary energy is determined.
iii) The extraction and refining of fossil fuels requires an energy premium that necessarily occurs in order to combust fuels in cities.
iv) The majority of megacities are located in warm to hot climates where requirements for heating are relatively low (only Moscow, Beijing, Seoul, London, New York, Istanbul and Paris-Isle-de-France recorded over

The final quantity compared is water use. The 51 million ML consumed in megacities (incl. losses) is about 3% of global water use, which is roughly estimated to be 2,600 million ML (Rockström, 2009). This percentage seem reasonably consistent with expectations as a large amount of global water supply is used in agriculture, which is a predominantly rural activity.

Future research will consist in understanding the role that utilities (especially electric utilities) play in triggering the sustainability transition in megacities. A further direction is to understand how the flows of information (e.g. internet exchange and telecommunication) influence the whole metabolism of the city (in particular considering the digitalization of services like electricity, water, and gas) contributing to the increase of complex structures in cities, going in the direction of a holistic view (Rosini, 2004) on the urban sustainability.

5. Acknowledgments

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2000 heating degree days in 2011). Whether or not the distribution of climatic zones for megacities is representative of that for all global inhabitants has not been determined.

Innovation in the City: Energy and Resource Efficiency

Joseph A. Tainter
Utah State University

Where science was once the province of lone-wolf naturalists, today it is mainly conducted by interdisciplinary teams working in cities. Interactions within large urban populations facilitate the spread of information, and thus of the components of innovation. One of the fundamental debates about the future of the urban, industrial way of life concerns the balance between resource depletion and technical innovation. Technological optimists claim that depletion will always be compensated by innovations that lead to more efficient use of resources (more output per unit of resource input), or by development of new resources. In this view, as a resource becomes scarce, prices signal that there are rewards to innovation. Innovators and entrepreneurs accordingly respond with novel technical solutions. Optimists believe that this will always be the case, and that sustainable resource use is therefore not an issue. Technological pessimists focus on absolute limits to resources in a finite world, on returns to investment, and on externalities such as pollution. In the history of the industrialized way of life, the optimists have so far been correct: Innovation has managed to keep pace with depletion, so that over the long run, the prices of many commodities have been constant. The factor overlooked in this debate is that innovation, like other forms of knowledge production, grows in complexity and costliness and produces diminishing returns. This presentation explores the productivity of innovation since the early 1970s to inquire whether our system of innovation can forever offset resource depletion, and even whether it can continue in its present form of interdisciplinary, expensive, urban teams.

Understanding Cities: Convergence & divergence of space, time, energy and information

Mark T. Brown* [1], **Sergio Ulgiati** [2]

[1] Center for Environmental Policy, University of Florida, Gainesville, FL, USA

[2] Department of Science and Technology, Parthenope University of Napoli, Italy

Corresponding Author e-mail: mtb@ufl.edu

Abstract

In this presentation we first summarize the various talks and workshops of this conference and provide some concluding remarks. Then we turn our attention to understanding cities from a systems perspective...a perspective that not only recognizes cities as consumers of resources, but producers of products and information. While most urban sustainability initiatives are based on strategies to decrease resource waste and luxury consumption, we examine what urban sustainability means at the region and biosphere scales and dictated by resource availability.

Many urban researchers view cities as consumers of resources and producers of waste, while suggesting that the solution to the ills of urbanization rest in fine-tuning to consume less and produce less waste while increasing livability. Other researchers view cities as being composed of a multitude of networks, and the biosphere as a network of cities, which act as organizational nodes of multiple networks of material, energy, and information flows. Still others see cities as places where political and economic forces are the principal driving forces underlying urban activity.

While these perspectives are useful in painting a picture of urban systems, what is missing is a synthetic understanding of the regulatory role of cities in the hierarchy of planetary ecosystems. We will look at urban places through the lens of hierarchy theory colored with the reality of globalization and the current self-accelerating information explosion. Within such a perspective, optimum resource use maximizes development of all hierarchical levels of a region, as well as the biosphere. And urban systems are, supported and constrained by the convergence of available resources, which dictate cycles of growth, climax and descent. In all, suggesting a different understanding of urban sustainability as the outcome of adapting to resource oscillations; ultimately contributing information and regulatory feedbacks to the lower levels.

With apparent climaxing of economic growth, what is the future role of cities in the global dynamics of the planet? How should a city structure itself to fit an oscillatory instead of a growth-oriented paradigm? After centuries of growth, can urban centers adjust to climax and descent? Is orderly descent of urban centers, economies, and lifestyles possible? To keep a society and its economy healthy after growth, new policies are required that fit the different availability of resources. Similar to the evolutionary patterns of other ecosystems and past societies, to remain vital, city-states will have to change the beliefs, laws, and constitutions that were originally reinforced by growth.

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