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Sustainable Consumption and Production in the Extraction and Processing of Raw Materials—Measures Sets for Achieving SDG Target 12.2

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Abstract: As part of the European Green Deal, the European Commission recently launched the project "New European Bauhaus of the 21st Century" to promote climate-neutral, affordable, and creative design approaches and transform the built environment towards sustainability. Based on a forecasting and backcasting approach, we developed three sets of measures containing eighteen individual measures, with the overall aim of reducing the consumption of mineral raw materials in line with the sustainability strategies (consistency, efficiency, and sufficiency) from exploration through material processing, to semi-finished product production. The developed measures address in detail the reduction of primary raw material consumption, the increased use of secondary raw materials, and the intensification of access to important domestic raw material sources, as well as the efficiency and productivity progression of the Austrian raw material industry. The implementation of the measures will raise the transparency and traceability of raw material routes, material flows, and supply chains through improved and comprehensive data collection and processing. The developed measures were handed over to the Austrian Federal Government in February 2022 to push the achievement of Sustainable Development Goal (SDG) 12 in Austria.

Keywords: sustainable consumption; sustainable production; SDG 12; resource efficiency; raw materials; set of measures; circular economy; forecasting and backcasting

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1. Introduction

Sustainable Development Goal 12 (SDG 12) is aimed at developing sustainable consumption and production patterns and ensuring their competitiveness, feasibility, and practicability [1]. In order to achieve the subordinate Targets 12.1–12.8 and 12.a–12.c, a broad range of instruments must be applied, including manufacturing companies, service providers, and retailers along the entire value chain, as well as end consumers. Experts agree that far-reaching—and not merely incremental or conventional—social and economic changes will be needed that directly address the problems of rising global consumption, greenhouse gas emissions, and growing inequality and poverty [2].

A wide range of methodologies are available for the measurement and assessment of SDG 12 [3–6]. The evolution of SDG 12 in the future follows a number of megatrends that require regrowth, i.e., a reduction in personal and collective consumption [7]. In this context, building energy use, renewable energy, and energy storage are gaining importance. In addition, transport emissions must be further reduced, waste, particularly from food, must be further reduced, and consumer products must be made more durable. Collecting and separating all waste for reuse is essential. A circular economy calls for an extension of the product life cycle and the subsequent reuse and recycling of materials and products. Furthermore, the reduction of greenhouse gas emissions, environmental pollution as well

as energy, water, and raw material consumption, are indispensable for the achievement of SDG 12 [8,9].

Raw materials have formed the basis of our civilization, and the security of the supply of mineral raw materials is Austria's basis as an industrial location. With constantly increasing modernization and technologization, and growing standards of living worldwide, the demand for mineral raw materials is also increasing from day to day. However, the issue of the supply of security for mineral raw materials is one that must be considered and addressed, not locally, but globally. Thus, access to mineral raw materials at affordable and fair prices is an essential factor in improving the economic situation of countries. In this context, not only the sustainable extraction, processing, and production of mineral raw materials must be taken into account, but also a permanently sustainable and more efficient use of recycling resources (secondary raw materials) in the future [10].

Within SDG 12, Target 12.2 is measured by two indicators; raw material consumption (RMC) and domestic material consumption (DMC). The RMC illustrates the domestic raw material consumption per capita, while the DMC represents the total domestic material consumption of an economy.

The DMC per capita has remained relatively unchanged since 2010 [11]. In comparison to the EU-27, the DMC for Austria in 2020 was 19 tons per capita, which is significantly above the average for the EU-27 countries of 14 tons per capita. The material footprint, which is measured with the RMC indicator and takes into account intermediate inputs of imports and exports, also experienced little change [9]. While resource productivity (measured by the ratio of gross domestic product (GDP) to DMC) has increased by 36.5% on average in the EU-27 since 2000, this increased comparatively by only 25.8% in Austria [12,13]. When taking into consideration that resource consumption in Austria rose slightly, a relative decoupling of resource use and economic output only thus occurred. In 14 other EU countries, an absolute decoupling was achieved (increase in economic output with a simultaneous decline in resource consumption).

Since Austria cannot guarantee a self-sufficient supply of mineral raw materials (measured in terms of per capita consumption), since the necessary raw materials for this are not all available in Austria, efficient use (e.g., through recycling, reuse, increasing the share of secondary raw materials and more efficient production methods) is necessary. As a result of this situation, the Austrian Raw Materials Plan of 2012 (in line with the European strategy, EUROPA 2020—A Strategy for Smart, Sustainable and Inclusive Growth), focuses on the three pillars of securing long-term access to domestic deposits, ensuring fair and non-discriminatory access to mineral raw materials on world markets, conserving primary resources, and using raw materials efficiently by increasing resource efficiency and improving recycling [14].

The most significant initiative of the Federal Ministry of Agriculture, Regions and Tourism, (BMLRT) in this context, is currently the elaboration of the Austrian Raw Materials Strategy 2030. The focus here is on strengthening the domestic resource base and ensuring secure international procurement. Only a combination of these factors can meet the demand for raw materials and at the same time strengthen the resilience of the domestic raw materials sector. To strengthen the competitiveness and sustainability of the industry, the focus must be on innovative solutions along the entire value chain. This concerns the sustainable extraction, processing, production and use of domestic resources, as well as those raw materials that are either not found in Austria, or only insufficiently and therefore have to be imported. Disruptive events demonstrate the importance of domestic production for both regional development and national supply. The expansion of the circular economy (CE) will help to strengthen the sustainable supply of resources. The Austrian Raw Materials Strategy 2030 provides solutions for this challenge [15].

This integrated raw materials strategy is based on the requirements of the CE, as well as the SDGs, and if actually implemented, should, at the same time, result in a positive impact on Austria's primary raw materials production. In addition to the goals of the Austrian Raw Material Strategies, Austria, as well as 196 other countries, declared its willingness to implement the 2030 Agenda [16].

However, the indicators only reflect the situation at the macro level (country level). An examination of behavior at the micro level (establishments) would be of great benefit for increasing raw material efficiency. Furthermore, the exclusive consideration of DMC paints a distorted picture of reality, as the trivial ratio of imports to exports and self-production falsely leads to the conclusion that Austria is self-sufficient in raw materials. A precise raw material flow analysis would be helpful to clarify the path of a raw material or the quantities of raw materials and to elicit any losses from this. Pure data on the raw material consumption of a country or per capita are only of limited significance, as these only represent an overall view. It would be helpful if these indicators could be specified and linked to the raw material shares in consumed products. However, the necessary data on the actual quantities of raw materials used, both in production and in recycling, is lacking.

This article answers the research question of what measures need to be implemented by Austrian policy makers to contribute to SDG 12, specifically Target 12.2, by presenting the developed sets of measures, which consist of 18 individual measures. The article is derived from the actual degree of achievement of SDG 12 in Austria as well as the formulated indicator critique of Target 12.2. The overarching goal of the presented sets of measures is to reduce the consumption of mineral raw materials in line with sustainability strategies (consistency, efficiency, and sufficiency), starting with exploration and extraction through processing, to the production of semi-finished products. A detailed description of the developed individual measures can be found in Appendix A and also in the Supplementary Materials.

2. Materials and Methods

2.1. Definition of System Boundaries

A common frame of reference is necessary in order to create a common goal orientation for this broad topic area involving many actors, such as producers, traders, and consumers, in the context of waste and the CE, and to enable the congruent integration of the targets of SDG 12. The concept of the CE lends itself for this purpose, both due to the essential regulatory developments and due to the content coverage. The overall objective of a CE is to use natural resources more efficiently and to achieve better compatibility of the substances used and utilized with the natural environment. Since the end of 2014, the EU has set the course for sustainable consumption and production with the adoption of the first Circular Economy Package and the new Circular Economy Package published in March 2020 [17].

In this context, a broader approach is advocated that goes beyond the strategies of "closing" (i.e., material recycling), "slowing" (i.e., increasing product lifetimes and associated consumption patterns), and "narrowing" (i.e., increasing efficiency) [18,19]. Figure 1 shows the system boundary and the relationships between each objective of the CE framework, as well as the scope of each strategy.

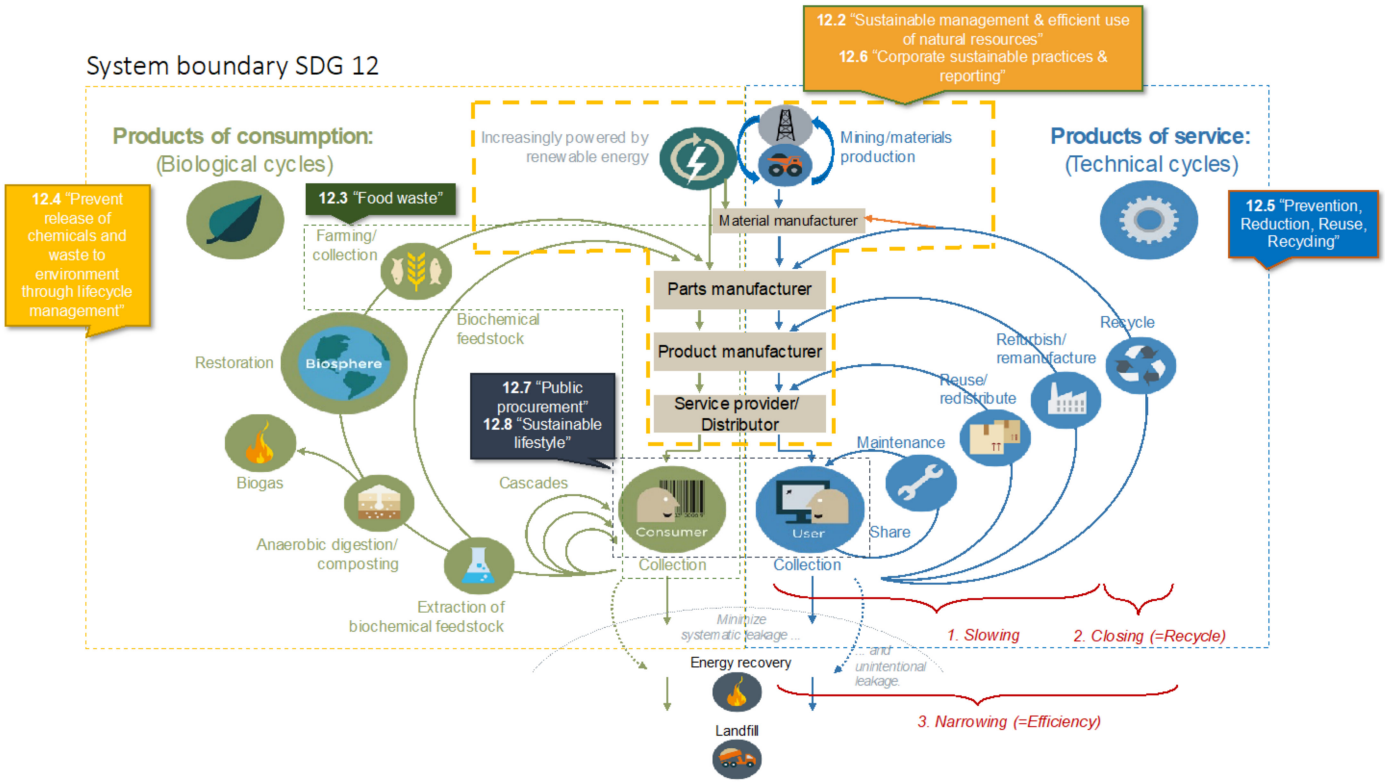

Figure 1. System boundary for SDG 12 according to the Circular Economy Framework published by the Ellen MacArthur Foundation [20].

The framework described, which also represents the system boundary for SDG 12, therefore encompasses both a product and use perspective, as well as a location perspective and includes all actors involved and affected. Along with this, the CE frame of reference is understood to be one that includes all three dimensions of sustainability in an integrated view, seeking to override the often-isolated consideration of the three pillars of sustainability [21]. The framework thus focuses on environmental and social aspects, (e.g., in the area of the supply chain of products) (i.e., under which environmental and social conditions are materials obtained, processed, and manufactured into products), as well as in the use phase, where social and also psychological aspects play an essential role. In the context of a CE, on the one hand, the economic aspects are understood as an instrument for implementing these environmental and social aspects, and on the other hand, a CE that is implemented in a meaningful way also has a positive impact on economic aspects, (e.g., strengthening regional value creation) [22]. All actors, (i.e., companies, consumers, public authorities, NGOs), can contribute to changes, in the sense of the SDGs, through appropriately coordinated actions. This requires framework conditions that promote innovative action, a pioneering spirit, a willingness to take risks, and new forms of cooperation between all these groups of actors [23].

In order to specify this far-reaching system boundary of SDG 12 to the individual targets, more detailed system boundaries were defined for all targets. The system boundary of Target 12.2 initially includes the primary sector, which primarily comprises exploration, mining, and processing. Following the raw material processing industry (i.e., metallurgy industry, construction raw material industry, industrial mineral industry, chemical and fertilizer industry), which produces semi-finished products, semi-manufactured products, or products. Furthermore, the secondary sector is also taken into account, which is primarily concerned with reprocessing and material recycling. Finally, possible potentials within the system boundary are also considered, such as the extended use of previously unused raw material sources, urban mining, tailings, and stockpiles. Figure 2 shows the defined system

boundary of Target 12.2, within which suitable measures for improving the efficient and effective use of raw materials are derived.

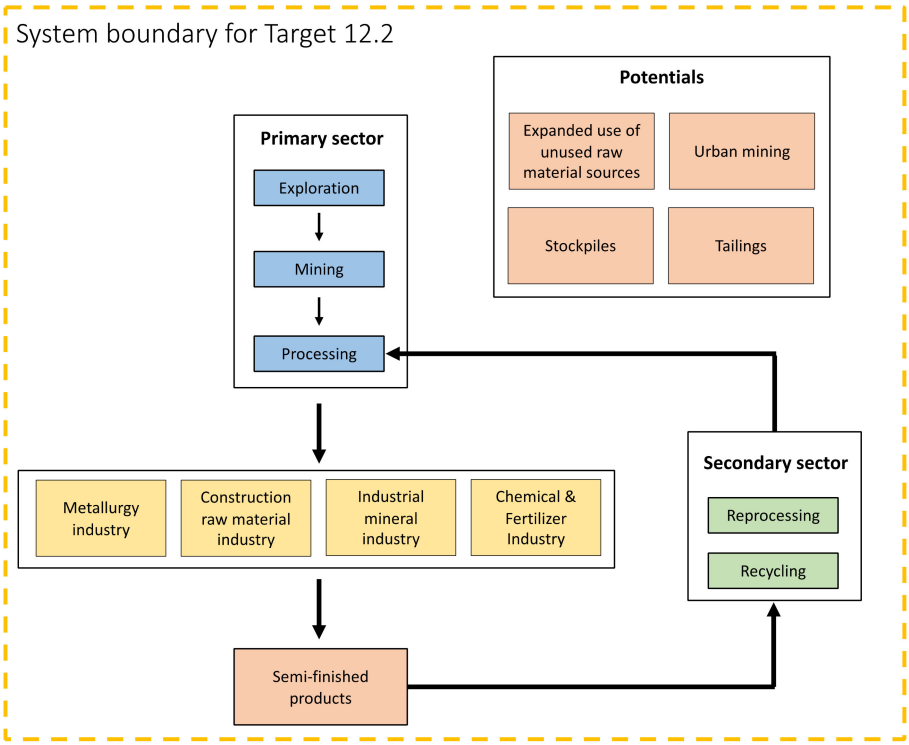

Figure 2. System boundary for Target 12.2.

The spatial system boundary is in the Austrian context and area of responsibility. In today's global value chains, it is not always possible to influence all factors in the supply chain. The boundary for SDG 12 should therefore be drawn where Austrian companies and actors no longer have any influence on upstream or downstream supply chains. The temporal system boundary extends beyond 2030, as the achievement of some of the SDG 12 targets requires long-term action.

2.2. Forecasting and Backcasting

The methodological development of the sets of measures for SDG 12 was carried out in a working group within the Austrian research project UniNEtZ through knowledge and information exchange in numerous workshops as well as through a forecasting and backcasting method. In the inter- and transdisciplinary research project UniNEtZ, 17 universities in Austria are working together to develop sets of measures for the Austrian federal government to fulfill the SDGs [24,25]. Figure 3 illustrates the methodology used in detail and outlines the process of developing and selecting the measures. In the first workshops, a common understanding of SDG 12 and its targets was created within the expert group, which consisted of members from 17 universities of different disciplines (business, engineering, construction, mining, recycling, climate, energy technology, sustainability, and geology). In the process, criticisms were also formulated, which revealed weaknesses in the formulation and broad scope for interpretation. In addition, the measurability of the targets was analyzed and the underlying indicators critically questioned. In a second step, scenario techniques (i.e., forecasting and backcasting) were applied.

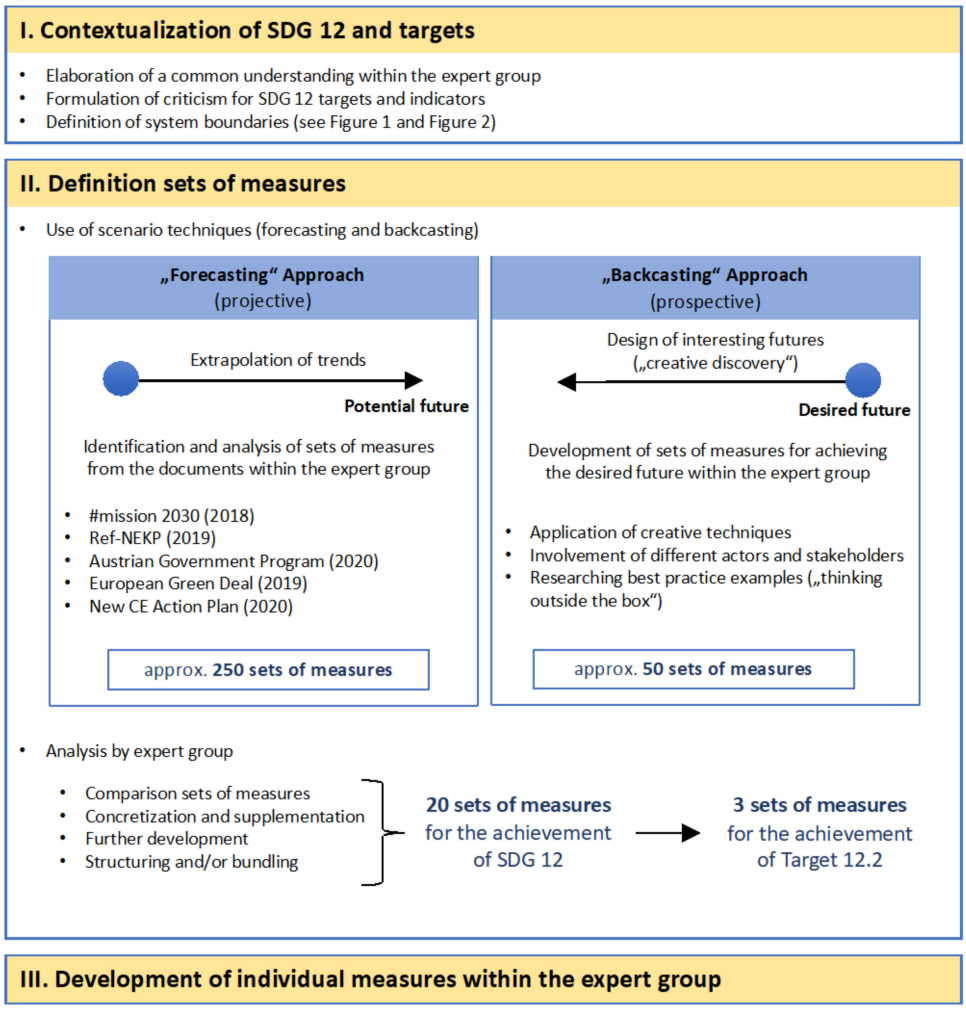

Figure 3. Methodological approach for the development of the sets of measures.

Forecasting is a prediction technique for anticipating the future using the outcomes of previous data. It includes a detailed analysis of past and current trends in order to predict future occurrences [26,27]. The forecasting is based on the analysis of relevant existing initiatives and programs, (i.e., #mission 2030, Ref-NEKP, Austrian Government Program 2020, the European Green Deal, the New Circular Economy Action Plan) [17,28–31]. From these five documents reviewed, around 250 sets of measures were identified that contribute to the achievement of SDG 12.

The backcasting method was used to expand the identified sets of measures from the forecasting method or to develop new missing sets of measures that contribute to the achievement of SDG 12 and its targets. In addition, different actors and stakeholders were invited to discuss and expand the developed sets of measures. Backcasting is a method of planning which begins with the definition of a desirable future [32,33], followed by working backwards to identify strategies and policies that link the defined future to the present. In the SDG 12 expert group, which is composed of representatives from Austria's scientific institutions, together with representatives from various industries, the identified sets of measures were first assessed individually, according to the focus of the target, and a target-specific selection of measures was then determined. The expert group linked the measures from the forecasting and backcasting approaches to identify gaps and also to develop both additional measures sets and additional individual measures. The combination of these techniques resulted in a pool of possible sets of measures from which the final sets of measures were selected. The sets of measures were then analyzed and further developed by experts with scientific backgrounds in business, engineering, construction, mining,

recycling, climate, energy technology, sustainability, and geology [34]. Out of the twenty identified sets of measures for the achievement of SDG 12, three sets are of great importance for the achievement of Target 12.2. These sets of measures and the 18 individual measures developed are explained in more detail in the following results section.

3. Results

3.1. Sustainable Design of Production Processes in the Raw Materials Processing Industry

The background of this set of measures is the high consumption of primary raw materials, inefficient and non-transparent production processes, and Austria's dependence on imports. This first set of measures is therefore primarily intended to reduce the share of primary raw materials in products, optimize production processes, promote the CE, reduce negative production emissions on the environment, and secure the domestic supply of raw materials, thus reducing dependence on the international raw materials market. The four individual measures to achieve these goals are presented in Table 1.

Table 1. Individual measures within the set of measures "Sustainable design of production processes in the raw materials processing industry.".

No.	Individual Measures
01	The development of a taxation system on primary raw materials.
02	The introduction of an efficiency rate in manufacturing processes.
03	The increase of the proportion of recycled materials in materials and semi-finished products.
04	The increase in environmental production methods through increased promotion legal requirements.

By taxing the primary fraction, an increase in the secondary fraction can be achieved. In this context, a reduction in resource consumption is additionally driven by the increased introduction and constant monitoring of a defined efficiency ratio. The efficiency ratio must be influenced by the factors of resources share, energy consumption, and greenhouse gas (GHG) emissions. The substitution of imported primary raw materials by recyclable domestic raw materials must be demanded in order to achieve an increased use of recycled materials. This can be implemented, for example, by introducing a legally prescribed but realistically feasible secondary raw material quantity in manufactured products. However, it must be noted that possible tax introductions and the requirement to increase recycled materials must be a well thought-through system that does not result in impossible, undesired rebound effects. Finally, there is also a need for the environmental improvement of production processes through modern technologies. This includes, among others, the promotion of autonomous energy supply in companies through renewable energy sources, the minimization of transport routes, and the expansion of a sustainable transport system. A detailed description of the individual measures can be found in Appendix A in Table A1.

3.2. Holistic Use of Raw Materials and Alternative Raw Material Sources

The background to the second set of measures is the unused raw material potential in waste heaps, landfills, and overburden, the current handling of mineral waste, and the negligence of the embodied GHG emissions of products. The aim of the second set of measures is, firstly, to make better use of the currently neglected potential for economically viable raw materials from the mentioned alternative sources; secondly, to improve the treatment of product waste; and thirdly, to introduce mandatory life cycle assessment (LCA) as part of the procurement process for mineral raw materials in order to promote the use of more sustainable alternative products. The four individual measures to achieve these goals are presented in Table 2.

Table 2. Individual measures within the set of measures "Holistic use of raw materials and alternative raw material sources."

No.	Individual Measures
05	The holistic extraction and recycling of raw materials from all sources.
06	The implementation of LCA in procurement processes.
07	The consideration of embodied GHG emissions when conducting LCAs.
08	The improvement of sorting solutions and recycling processes.

In order to implement these measures, the legal framework for the extraction of secondary raw materials from waste heaps, landfills, and overburden needs to be adapted. Further legal steps are needed in the tendering and awarding of construction projects in order to establish the mandatory implementation of an LCA in the course of the procurement process. The life cycle concept (i.e., the consideration of embodied GHG emissions) must be at the forefront of this process. Finally, a different treatment of mineral waste must be achieved, since currently, according to § 6 Abs. 2 RBV, mineral waste represents a common fraction and is not treated differently. A detailed description of the individual measures can be found in Appendix A in Table A2.

3.3. Sustainable and Intelligent Raw Material Management

The background to the third set of measures is the non-transparent trade in secondary raw materials, non-transparent raw material supply chains and product compositions, the high environmental impact of transport by road and sea due to long distances involved and GHG emissions, the energy- and cost-intensive manufacturing and recycling processes, and the high consumption of primary raw materials in general. The aim is, therefore, to increase the transparency of raw material supply chains, shorten transport routes, and use environmentally friendly mining methods, in addition to improving recyclability through more sustainable product design. Furthermore, the aim is to handle the purchase of secondary raw materials via a nationwide trading platform and thus shift the focus to domestic raw material extraction, as well as to drive digitalization, promote research and development, and raise awareness. The ten individual measures to achieve these goals are presented in Table 3.

Table 3. Individual measures within the set of measures "Sustainable and intelligent raw material management.".

No.	Individual Measures
09	The creation of a trading platform for secondary raw materials.
10	The strengthening of the European extraction of raw materials under sustainable standards instead of imports.
11	The promotion of research and development in the field of the substitution of raw materials.
12	The promotion of industrial symbioses.
13	The promotion of digitalization investments in raw material producing companies.
14	The introduction of "material–product labeling," including proof of origin.
15	The creation of sustainable and transparent supply chains and raw material flows.
16	The further and new development of indicators for sustainable resource use.
17	The exploration of mineral resources and reassessment of domestic resources.
18	The development of attractive processes for the disposal of construction waste for private consumers.

The creation of a trading platform for secondary raw materials and the necessary legal framework must be accompanied by an improved organization of industrial sites as a kind of "cluster," (i.e., production, service, recycling). To support this, increased European exploration initiatives are needed as well as the introduction of a "passport" of products, or raw materials and other materials, which must include information on the raw materials types and their origins, (i.e., mining country, company, mining conditions, supply

chains, and the environmental footprint). A continuous updating of the "passport" with information on further areas of use, disposal, and recycling, as well as the derivation of a digital "information regime" for consumers that enables informed purchasing decisions must be strived for. With regard to the consumer, more appealing, uncomplicated, and user-friendly collection systems, as well as free disposal options for private individuals, for example, during a construction phase, must also be created. Finally, investments must be made in research and development and in new digital technologies. A detailed description of the individual measures can be found in Appendix A in Table A3.

4. Discussion

The key findings of the study show that, despite the numerous requirements and guidelines in various documents such as #mission 2030, Ref-NEKP, Austrian Government Program 2020, the European Green Deal or the New Circular Economy Action Plan, there is a need for further measures to achieve the goals of Agenda 2030. These findings were obtained by using the forecasting approach and by analyzing the proposed measures of the addressed documents with regard to their contribution to the achievement of the Agenda 2030 goals. Using the backcasting approach, a gap was then identified with regard to the fulfillment of SDG 12, especially Target 12.2, followed by the development of specific sets of measures by expert groups.

The three developed sets of measures are the sustainable design of production processes in the raw materials processing industry, the holistic use of raw materials and alternative raw material sources and sustainable and intelligent raw material management. In summary, these three sets of measures include 18 individual measures. These 18 individual measures are briefly described in Appendix A to provide a better understanding of their purpose.

Regarding the implementation of the individual measures, it should be noted that the taxation of imported goods also represents an economic burden for the domestic economy. Primary raw materials should, therefore, only be taxed under certain conditions, (i.e., mining which takes place in disregard of human rights, the violation of labor protection, imports from third-party countries, low or no environmental standards, the import of raw materials that can be mined in Austria). Environmental improvements often require high additional investments in their initial stage and thus must always be considered by companies over a longer period of time. Various new and more targeted funding measures or more transparent framework conditions for funding by the public sector are therefore required. Furthermore, the substitution of primary raw materials can contribute to sustainability and climate protection, but does not always necessarily lead to a more sustainable and environmentally friendly use of resources.

Many production and recycling processes are location-bound and cannot be centralized, or can only be centralized with difficulty. In this context, regional planning also plays a decisive role. The tunnel construction sector also plays an important role in the topic of using waste dumps and overburden as a raw material source, because tunnel excavation work produces a considerable amount of excavated material, which is usually stored in waste dumps close to the tunnel construction site and renatured or incorporated into excavated soil landfills. Such spoil heaps are subject to the Waste Management Act in Austria due to their definition as "waste." As a result, it is currently difficult to use this excavated material as a source of raw materials. The transparency of supply chains often fails due to the lack of traceability and the difficulty of obtaining and recording data. Unfortunately, there is also a lack of corresponding official data on the amount of raw materials actually used in Austria, both in production and recycling.

The findings of the study are limited due to the chosen system boundary. The developed measures represent reasonable measures for the Austrian federal government to achieve the targets of SDG 12. For other countries, these developed measures cannot be directly applied. There is a further limitation in the context of interactions occurring between the measures. The interactions of one measure (i.e., synergies or trade-offs) with another

measure or with other SDGs that occur were not considered in this article. However, these numerous interactions are currently being assessed as part of the UniNEtZ research project and are provided online. Different methods to analyze SDG entity interactions can be found in [35].

Finally, it must be mentioned that the current measurement of Target 12.2 in Agenda 2030 by the two indicators, RMC and DMC, should also be critically questioned. The RMC illustrates the domestic RMC per capita, while the DMC represents the total DMC of an economy. Both indicators only reflect the situation at the macro level (country level). Here, an investigation of behavior at the micro level (establishments) would be beneficial for increasing raw material efficiency. Since pure data on raw material consumption per country and per capita only give an overall view, a linkage of raw material shares in consumed products with specified indicators would be helpful. Unfortunately, there is a lack of corresponding official data on the raw materials quantities actually used in Austria, both in production and recycling.

For implementation in practice, these individual measures must be examined in detail and, if necessary, only parts of the proposed measures should be implemented.

The next possible steps for Austria with regard to the implementation of the 2030 Agenda are published in an "options report" and were handed over to the Austrian Federal Ministry of Education, Science and Research (BMBWF) in February 2022. The "options report," including more than 150 developed options and their sets of measures, can be found in the Supplementary Materials.

5. Conclusions

By ratifying the Paris Agreement, 197 countries have committed to implementing the goals of the 2030 Agenda. One of these 17 SDGs is SDG 12, "Responsible Consumption and Production," which consists of 11 targets. Although there are numerous guidelines and directives in various documents such as #mission 2030, Ref-NEKP, Austrian Government Program 2020, the European Green Deal or the New Circular Economy Action Plan that directly or indirectly address the achievement of SDG 12, there is still a need to develop further specific measures to fulfill the 2030 Agenda in Austria.

In this article, we used a forecasting and backcasting methodology to identify gaps in the aforementioned documents and develop sets of measures that contribute to the achievement of SDG 12, in particular Target 12.2 "By 2030, achieve the sustainable management and efficient use of natural resources," in the Austrian context.

The findings present three sets of measures resulting from a total of eighteen individual measures. These measures were developed by a group of experts and relate primarily to sustainable consumption and production in the extraction and processing of raw materials. The three developed sets of measures are the sustainable design of production processes in the raw materials processing industry, the holistic use of raw materials and alternative raw material sources, and sustainable and intelligent raw material management. The overarching goal of the developed sets of measures was to reduce the consumption of mineral raw materials in line with sustainability strategies (consistency, efficiency, and sufficiency) from exploration through material processing to semi-finished product production, which mainly contributes to Target 12.2. These three sets of measures contain eighteen individual measures, which are focused on the development of a taxation system on primary raw materials, the introduction of an efficiency rate in manufacturing processes, and the increase in ecological production methods through raised legal funding requirements and the proportion of recycled materials in finished and semi-finished products. The measures presented should also enable the furthering of sustainable and transparent supply chains and raw material flows. The developed measures were submitted to the Austrian Federal Ministry of Education, Science and Research (BMBWF) in February and are currently being prepared for practical implementation.

The implementation of these sets of measures, as well as the implementation of other sets of measures developed in the UniNEtZ research project, offer, above all, enormous

added value for the future strategic orientation of Austrian policy. Depending on the extent of policy implementation, the measures developed also play an important role for the 5Ps (i.e., people, the planet, prosperity, peace, and partnership) as they are summarized in the Agenda 2030.

The UniNEtZ research project was the first attempt of an interdisciplinary cooperation of Austrian universities to combine scientific expertise in different fields and to jointly develop solutions for the federal government related to the SDGs [36]. The myriad interactions between the individual SDGs, the 169 targets, the more than 150 options with numerous sets of measures, and the well over a thousand individual measures included in them must therefore be analyzed more closely and should not be overlooked. An interaction assessment of the measures related to the individual SDGs is currently being finalized, since there is no single perfect measure, but instead many synergies and trade-offs between SDGs/targets. With the help of a tool currently under development, it will also be possible for policy makers to implement individual measures and thus contribute to the achievement of the SDGs.

Supplementary Materials: Supplementary data related to this article can be found at https://www.uninetz.at/optionenbericht (accessed on 28 June 2022) and https://www.uninetz.at/optionenbericht_downloads/SDG_12_Option_12_01_pdf_Pt_freigabe.pdf (accessed on 28 June 2022).

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Extension of the Results

Table A1. Detailed description of the developed measures within the set of measures "Sustainable design of production processes in the raw materials processing industry."

No.	Measure	Detailed Description
01	The development of a taxation system on primary raw materials.	In order to reduce the consumption of resources, it is necessary to reduce the proportion of primary raw materials in materials and semi-finished products, while at the same time increasing the proportion of secondary raw materials. By taxing the primary fraction, an increase in the secondary fraction can be achieved. In this context, however, it should be noted that taxation (in the classical sense) represents an economic burden for the domestic economy. Since both Austria and the EU strive for sustainable economic development and a large proportion of the raw materials are imported into the EU, taxation for this must also be designed in a consistent manner. Thus, primary raw materials should only be taxed under the following conditions: - the primary raw material is not extracted under sustainable conditions (human rights, labor protection, etc.); - the primary raw material is imported into the EU from third-party countries; - the primary raw material can be extracted in Austria, but is imported.
02	The introduction of an efficiency rate in manufacturing processes.	In order to continuously improve the efficiency of the production of materials and semi-finished products, the implementation and continuous measurement of a defined efficiency rate is necessary. This enables the evaluation of existing manufacturing processes and a transparent assessment of them. This efficiency rate can, for example, be presented as a value consisting of the parameters, costs, resource share, energy consumption, and GHG emissions. Increasing efficiency in areas such as procedures, processes, and technology should be considered in this context.
03	The increase of the proportion of recycled materials in materials and semi-finished products.	Since Austria does not have all the raw materials needed for the economy at its disposal, recycled raw materials offer great potential for closing this gap, thus advancing the circular economy. An increase in the share of recycled materials in products can be achieved on the one hand by taxing the share of primary raw materials (see measure 1), or on the other hand by introducing a legally prescribed minimum share of secondary raw materials (possibly with an annual increase rate). Regardless of the method used to increase the proportion of recycled materials, the proof of origin of the primary and secondary raw materials is imperative. Without this evidence, it can be lucrative to simply recycle the primary material after production and then resell it as secondary material. Furthermore, it is necessary to identify all secondary material sources in the form of a cadaster and to make them accessible.

Table A1. *Cont.*

No.	Measure	Detailed Description
04	The increase in environmental production methods through increased promotion legal requirements.	In order to make production or production processes in the raw materials processing industry more environmentally friendly, there are essentially three options available which can be applied individually or in combination. The first possibility is the further development of sustainable, environmentally friendly, but still economical production processes. For this, stronger cooperation between industry and research is certainly one of the driving forces, with the public sector also playing an important role in shaping the framework conditions. Another option is to substitute existing, less sustainable production methods with more environmental ones. Since this usually entails additional investments, such more sustainable production processes must be advantageous for the companies not only from an environmental but also from an economic point of view. Therefore, various (new, more targeted) support measures or better and more transparent framework conditions for public funding are needed. The third possibility is the environmental improvement of an existing production plant or method. To achieve this the following basic considerations should be addressed: - reduce the energy consumption or increase the share of autonomous supply with energy; - switch to renewable energy sources - make logistics more environmentally friendly (e.g., rail transport instead of truck transport); - reduce and minimize transport distances; - increase production volumes with unchanged operating times (increasing efficiency); - optimize primary raw material qualities (e.g., through the use of low-carbonate clay raw materials for the brick industry to reduce GHG emissions in the production process or the use of alternative fuels in the cement industry).

Table A2. Detailed description of the developed measures within the set of measures "Holistic use of raw materials and alternative raw material sources."

No.	Measure	Detailed Description
05	The holistic extraction and recycling of raw materials from all sources.	Ores, rocks, and sediments are not the only sources for raw materials; raw materials can also be found in dumps, landfills, or overburden. These alternative sources arise during the mining and processing of a raw material as a by-product or through the disposal of goods, commodities, products, and construction materials by waste management. During tunnel excavation work, a considerable amount of excavated material is produced. This material is usually stored on dumps (spoil heaps) close to the tunnel construction site and renaturalized, or incorporated into excavated soil landfills. Such spoil heaps are subject to the Austrian Waste Management Act, as they are defined as waste and must therefore be disposed of. This source of raw materials, which is defined as waste by the Waste Management Act, is to be made usable by amending the law accordingly.

Table A2. *Cont.*

No.	Measure	Detailed Description
06	The implementation of LCA in procurement processes.	A mandatory implementation of a life cycle assessment in the course of the procurement process of mineral raw materials can contribute to more environmentally friendly production methods. Consumer demand usually regulates manufacturing processes and therefore strongly influences the sustainable development of manufacturing companies. The legal implications of this measure should be considered before procurement, also referred to as the pre-procurement phase, as well as after procurement, also referred to as the post-procurement phase. In this context, we are currently working on the ongoing research project "Transition of the procurement process towards Paris compatible public buildings," financially supported by the Klima- und Energiefonds, on the implementation of LCA in the procurement process of buildings.
07	The consideration of embodied GHG emissions when conducting LCAs.	In terms of a holistic life cycle approach, embodied emissions should also be taken into account in the production of products and semi-finished products in addition to operational emissions. These include, for example, around eleven percent of global energy- and process-related GHG emissions from the production of building products for new buildings and refurbishments. The latest IPCC report addresses this issue of embodied GHG emissions in buildings and underlines their ever-increasing importance.
08	The improvement of sorting solutions and recycling processes.	In the context of the sorting and recycling of deconstructed materials, the construction industry plays a huge role. In line with Basic Requirement 7 "Sustainable use of natural resources" [37], the deconstruction of buildings in Austria is carried out in accordance with the Recycling Building Materials Ordinance [38] "with the aim of promoting the CE and material efficiency, in particular preparing building components for reuse and ensuring a high quality of recycled building materials, in order to promote the recycling of construction or demolition waste in line with Union legal targets." There is an obligation to separate, whereby mineral waste is managed as a common fraction compared to excavated soil material, finishing asphalt, wood waste, metal waste, plastic waste, and municipal waste (§ 6 Abs 2 RBV). A separation of the bricks and concrete used can be carried out, however, by means of sensor-supported sorting, whereby robot-supported systems are used for coarse grain sizes. In addition to the separation of waste concrete into aggregate and cement paste, mechanical disintegration, which can be carried out by means of electrodynamic fragmentation, can be implemented [39].

Table A3. Detailed description of the developed measures within the set of measures "Sustainable and intelligent raw material management."

No.	Measure	Detailed Description
09	The creation of a trading platform for secondary raw materials.	The launch of a trading platform in Austria is intended to facilitate access to secondary raw materials for companies and at the same time make it more transparent. The platform serves as an intermediary between customers and buyers of secondary raw materials. The aim is that the purchase of secondary raw materials should be possible exclusively via this platform. This means that every scrap dealer and every recycling center would only be allowed to sell their raw materials via this platform.
10	The strengthening the European extraction of raw materials under sustainable standards instead of imports.	In order to reduce Austria's dependence on imports from the international market and to promote sustainable development in the field of raw material extraction through shorter transport routes and more environmentally friendly mining methods, the focus must be increasingly placed on domestic (or European) raw material extraction. This also includes an intensified European exploration initiative and the preservation or expansion of raw material geological competence in the education of geoscientists. In addition to existing mining areas, this also concerns the use of alternative sources such as dumps and landfills.

Table A3. *Cont.*

No.	Measure	Detailed Description
11	The promotion of research and development in the field of substitution of raw materials.	In addition to the recycling of raw materials, there is also the possibility of substituting raw materials. This involves replacing an existing raw material with another, more sustainable raw material with the same desired properties (consistency strategy). By investing in research and development, new knowledge can be gained in the area of raw material and material properties, which in turn has a positive effect on possible raw material substitutions, waste management, and also recycling.
12	The promotion of industrial symbioses.	In accordance with the principle of the circular economy, synergies of not only value chains but also of companies should be better exploited. Industrial sites could be organized as a kind of cluster by locating everything from the processing industry and production to service providers and recycling centers at one site, e.g., to minimize transport routes and costs.
13	The promotion of digitalization investments in raw-material-producing companies.	Increased digitalization in companies is another way to increase efficiency and productivity in the context of industrial development. Investments in new digital technologies should therefore be better promoted from the economic perspective of a possible increase in efficiency and production, and improved information and communication possibilities.
14	The introduction of "material–product labeling" including proof of origin.	In order to ensure a more sustainable product design in the future, information about product contents is essential for consumers as well as for the recycling industry. Therefore, a kind of passport or labeling for raw materials or materials should be established. This passport should contain the following information: - Type of raw material; - Information about the origin: country of extraction (and company) including extraction conditions; - Information about supply chains (traceable supply chains); - Information about the environmental footprint (e.g., GHG emissions). The passport should also be updated with further information after the raw material has been processed, such as further supply routes, area of application of the raw material, disposal, and recycling. Thus, an original raw material passport could develop into a product passport.
15	The creation of sustainable and transparent supply chains and raw material flows.	Disclosing supply chains and implementing mechanisms to ensure that supply chains are sustainable is actually part of the due diligence obligations companies have. However, this does not always reflect reality. Supply chain accountability goes hand in hand with supply chain transparency, as it is only possible to evaluate accountability (in all three dimensions of sustainability) in supply chains if it is transparent. It is therefore necessary, on the one hand, to develop a system that discloses the supply chains of products and the associated raw materials, and on the other hand, to develop a system that serves as an evaluation basis for assessing the sustainability of a substance in a supply chain, i.e., an image of the individual material flows in their life cycle and their individual effects in terms of the three dimensions (e.g., the life cycle and associated material flow of aluminum and its effects on the environment/social sphere/and the economy). This basis for evaluation makes it possible to assess the sustainability of disclosed supply chains. Based on this, an information regime for consumers should be derived that enables them to make informed purchasing decisions, as is already the case, for example, with various labels in the food industry. In any case, the use of digital possibilities should be considered here.
16	The further and new development of indicators for sustainable resource use.	The existing indicators such as DMC and RMC should be further developed and evaluated for their validity and informative value, and supplementary indicators should be developed. This can be achieved by providing the necessary funding or investments through a well-founded cooperation between Statistics Austria, industry, and various research institutions.

Table A3. *Cont.*

No.	Measure	Detailed Description
17	The exploration of mineral resources and reassessment of domestic resources.	Since exploration activities in Austria have decreased significantly since the 1980s, many technical innovations and developments were not applied in the explorations at that time. As a result, the geological structure and the potential from a depth of 100 m downwards is hardly known. Due to technological progress and lack of investment in prospecting activities, the available geological data is not up to date. Therefore, in addition to future far-reaching and comprehensive prospecting activities, a re-evaluation of existing resources in old mines due to possible new technical extraction methods has to be considered.
18	The development of attractive processes for disposal of construction waste for private consumers.	For the private consumer, the proper disposal of the construction disposal of building materials is costly and non-transparent. The following points can make it more attractive: - Assistance through appropriate collection systems, which are made available; - Training in the use of these collection systems and the properties of the resulting materials as construction requirements; - Availability of disposal facilities being made free of charge during the construction phase.

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