Roadmap for a Future Comprehensive Raw Material Balance

Final Report

Technical Support Instrument

Supporting reforms in 27 Member States

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ABBREVIATION

API	Application Programming Interfaces
BMF	Bundesministerium für Finanzen / Austrian Federal Ministry of Finance
Cu	Copper
EC	European Commission
EDM	Elektronisches Datenmanagement (Electronic Data Management)
EU	European Union
IO	Input – Output
JRC	Joint Research Institute
Ltd	Limited Liability Company
MFA	Material flow analysis
Nd	Neodymium
n.q.	Not quantifiable
OWG	Operational Working Group
P	Phosphorus
RMB	Raw Material Balance
STAN	subSTance flow ANalysis
TSI	Technical Support Instrument
TUW	TU Wien (Vienna University of Technology)

SUMMARY

Project Overview

The goal of the present foresight policy project was to develop a roadmap for establishing a comprehensive raw material balance (RMB) in Austria. The establishment of a raw material accounting system was one of the central demands of the Austrian Master Plan Raw Materials 2030. Knowledge of the raw materials value chain and flows is essential for an effective and strategic raw materials policy. An RMB system aims to create a holistic view of national flows and stocks of selected raw materials. Security of supply of raw materials requires a comprehensive database that captures national production of primary and secondary raw materials, as well as imports and exports of raw materials in qualitative and quantitative terms. The implementation of an RMB system contributes to optimised long-term resource management in Austria and supports sustainable resource management.

The project was funded by the European Commission's DG REFORM under the Technical Support Instrument (TSI). The BMF, Mineral Raw Materials Policy Department, is the contracting authority and beneficiary of the project. The project was carried out by AARC, TU Wien, E3 Modelling and Repuco Unternehmensberatung GmbH in close cooperation with DG REFORM.

Project Results

As part of the project, a Generic Model for describing, illustrating, and analysing material flows and stocks was developed, which is applicable to all raw material groups as well as to different countries. In a pilot phase, the model was applied to three critical raw materials: Phosphorous, Copper and Neodymium. Based on the results of the indicator material Phosphorus, it was demonstrated how measures to support resource management in Austria can be derived from RMBs if comprehensive time series are developed and analysed.

In a participatory stakeholder process, a list of raw materials that should be part of the initial establishment of RMBs in Austria was compiled. Based on the current conditions, a two-phase approach for establishing an RMB system in Austria is outlined. While the first phase focuses on establishing the needed framework conditions, the second phase outlines the implementation of a raw material accounting unit. The roadmap and implementation of RMBs are required to secure the supply of critical raw materials for Austria in the long run.

Zusammenfassung

Projektübersicht

Ziel des vorliegenden Foresight-Policy Projektes war es, einen Fahrplan für die Erstellung einer umfassenden Rohstoffbilanz (RMB) in Österreich zu entwickeln. Der Aufbau umfassender Rohstoffbilanzen war eine der zentralen Forderungen des österreichischen Masterplans Rohstoffe 2030. Kenntnisse über die Rohstoff-Wertschöpfungskette und Rohstoffströme sind für eine effektive und strategische Rohstoffpolitik unabdingbar. Ziel eines RMB-Systems ist es, eine ganzheitliche Sicht auf die nationalen Ströme und Bestände ausgewählter Rohstoffe zu schaffen. Für die Versorgungssicherheit mit Rohstoffen braucht es eine umfassende Datengrundlage, die die nationale Produktion an primären und sekundären Rohstoffen und darüber hinaus den Import und Export von Rohstoffen in qualitativer und quantitativer Hinsicht abbildet. Die Implementierung eines RMB-Systems trägt zu einem langfristig optimierten Ressourcenmanagement in Österreich bei und unterstützt eine nachhaltige Ressourcenbewirtschaftung.

Das Foresight-Policy Projekt wurde von der DG REFORM der Europäischen Kommission im Rahmen des Technical Support Instrument (TSI) gefördert. Das BMF, Abteilung Mineralstoffpolitik, ist Auftraggeber und Benefizier des Projekts. Umgesetzt wurde das Projekt von AARC, TU Wien, E3 Modelling und Repuco Unternehmensberatung GmbH in enger Zusammenarbeit mit DG RFORM.

Projektergebnisse

Im Rahmen des Projekts wurde ein generisches Modell zur Erfassung von Materialflüssen und Lagerbeständen entwickelt, das für alle Rohstoffgruppen und verschiedene Länder anwendbar ist. In einer Pilotphase wurde das entwickelte Modell auf drei kritische Rohstoffe angewandt: Phosphor, Kupfer und Neodym. Anhand der Ergebnisse des Indikatormaterials Phosphor wurde gezeigt, wie aus RMBs Maßnahmen zur Unterstützung des Ressourcenmanagements in Österreich abgeleitet werden können, wenn umfassende Zeitreihen entwickelt und analysiert werden.

Es wurde ein zwei-Phasen Plan erarbeitet, der die Implementierung von RMBs in Österreich darstellt. In einem partizipativen Stakeholderprozess wurden im Rahmen einer Umfrage Rohstoffe für erste Bilanzierungen ermittelt. Die Umsetzung der entwickelten Roadmap und Einführung nationaler RMBs trägt langfristig zu einer gesicherten Rohstoffversorgung bei und unterstützt ein nachhaltiges Ressourcenmanagement.

1. PROJECT OVERVIEW

Aim & Background

The aim of this foresight policy project was to develop a roadmap to establish a raw material accounting system in Austria. Raw materials are essential not only for the Austrian and European economies but also for developing green technologies and measures to mitigate climate change. For many (critical) raw materials, Austria and the EU largely depend on imports. The scarcity of raw materials is a growing problem for the European Union and, consequently, Austria. With regard to the growing demand for raw materials and the risk of supply bottlenecks (e.g. geopolitical crisis, natural disaster), it is crucial to develop raw material balances (RMBs) as a decision-making basis to optimise resource management in Austria, establish and strengthen a sustainable circular economy, and achieve national and international climate and energy goals.

Several recent studies emphasise the necessary shift towards a circular economy. For example, Draghi[1] stresses the need to leverage the opportunities from circularity and the potential to meet the demand for critical raw materials by enhancing recycling efforts within the EU. PwC[2] recently published another study advocating for the transition to a circular economy, emphasizing the national potential of circularity. The study projects significant economic benefits from adopting a more circular approach. This highlights the need for both national and European measures to promote a circular economy, which can be supported and evaluated by raw material accounting.

Developing methods for documenting and analysing raw material flows was one of the central demands of the Austrian Master Plan Raw Materials 2030[3]. RMBs create a holistic view of national resource flows and stocks. To ensure the security of raw material supply, a comprehensive database is required that qualitatively and quantitatively represents the national production of primary and secondary raw materials, as well as their imports and exports. Detailed knowledge about the material household enables the identification of measures to optimise national resource management. For example, many critical raw materials have a very low recycling rate due to a lack of detailed knowledge about raw material conversion along the entire value chain. A comprehensive understanding of resource flows facilitates the use of secondary resources, strengthens a circular economy and contributes to the reduction of import dependencies.

Hence, the present project's main goals were to develop a (data) model that displays the material flows and stocks for all kinds of raw materials, and to develop a roadmap

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[1] Draghi, M., The future of European competitiveness – A competitiveness strategy for Europe, 2024. https://commission.europa.eu/topics/strengthening-european-competitiveness/eu-competitiveness-looking-ahead_en

[2] PwC, Von linear zu zirkulär: Status Quo der Österreichischen Kreislaufwirtschaft, 2024. https://direkt.pwc.at/klw

[3] Federal Ministry of Agriculture, Regions and Tourism. *Masterplan Raw Materials 2030.* 2021

for establishing a comprehensive RMB system in Austria with the perspective of expanding it on EU level.

Project Governance

Project Team

The project was carried out by an international consortium covering different areas of expertise, including methodological, technical, and project management skills. The operational project team comprised the Vienna University of Technology (TUW), Repuco Unternehmensberatung GmbH and E3 Modelling. The team of TUW contributed with its extensive knowledge about raw materials, and expertise in material flow analysis (MFA) and resource management. The team of Repuco Unternehmensberatung GmbH contributed with its experience in the Austrian public sector, project management skills and stakeholder engagement strategies. E3 Modelling added value by linking economic analysis with (national) material flows. DG Reform and AARC accompanied the project.

Steering Committee

A steering committee was set up to monitor project activities and ensure effective coordination and participation. Meetings were held approximately quarter-yearly. The role of the Steering Committee during the project was to guide and steer the project to discuss essential changes and potential deviations from the plan, to approve working methods, and to advise on approaches presenting the political point of view.

The steering committee was represented by:

- Robert Holnsteiner (Federal Ministry of Finance (BMF)
- Mauro Sibilia (DG REFORM)
- Nicholas Holmes (AARC)
- Nadine Heimberger (REPUCO)

Operational Working Group (OWG)

The operational working group was made up of representatives from the following organisations:

- Repuco Unternehmensberatungs GmbH
- TU Wien (TUW)
- E3 Modelling

The OWG held bi-weekly meetings throughout the project to discuss the project's operational management. Among other things, this committee was responsible for preparing decisions, managing the operational implementation and reviewing the technical and methodological implementation. Most meetings were held online, and additional meetings were held if needed.

2. KEY RESULTS

The first goal of the present project was to develop a data model that comprehensively displays the material flows and stocks of a region. The second goal was to develop a roadmap for establishing a comprehensive RMB system in Austria. Thus, the first project milestone was developing a generic data model, which will be referred to as the 'Generic Model' in the following. Based on three indicator raw materials – phosphorus (P), copper (Cu), and neodymium (Nd) – the Generic Model was developed and designed in an iterative process to be applicable to all kinds of raw materials in any region (e.g. other EU member states).

Based on the insights gained in developing the Generic Model and gathered in stakeholder interviews, fields of action were analysed and, subsequently, a roadmap for establishing a raw material accounting system in Austria was outlined. Additionally, an online assessment addressing all relevant stakeholders and important industry members was planned and conducted during the present project. The survey aimed to develop a list of raw materials that should be part of the initial rollout of an RMB system in Austria.

2.1. Development of the Generic Model

To document and analyse national raw material stocks and flows, a model that allows for a holistic and differentiated raw material view is needed. After analysing already existing material flow models, the JRC model, developed for the European Commission (EC), was taken as a starting point for developing the Generic Model. The JRC model[4] (see Figure 2), which was used in 2020 to analyse 14 critical raw materials for the system boundary EU27, is a revised version of the Deloitte model[5] (see Figure 1), which was initially used in 2015 to analyse an additional 31 critical raw materials for the EU28. It is also similar to the Yale University model developed and used in the so-called STAF project[6]. Figure 1 and Figure 2 show all processes (material life cycle stages), flows and stocks considered in these material system analyses. The main difference between the Deloitte model and the JRC model is that, in the latter, markets and new flows were introduced.

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[4] Torres de Matos, C., Wittmer, D., Mathieux, F., Pennington, D., Revision of the material system analyses specifications, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-10734-7, doi:10.2760/374178, JRC118827

[5] BIO by Deloitte, Study on Data for a Raw Material System Analysis: Roadmap and Test of the Fully Operational MSA for Raw Materials, Prepared for the European Commission, DG GROW, 2015.

[6] Graedel, T. E.; van Beers, D.; Bertram, M.; Fuse, K.; Gordon, R. B.; Gritsinin, A.; Kapur, A.; Klee, R. J.; Lifset, R. J.; Memon, L.; Rechberger, H.; Spatari, S.; Vexler, D., Multilevel Cycle of Anthropogenic Copper. Environmental Science & Technology 2004, 38, (4), 1242-1252, doi: 10.1021/es030433c

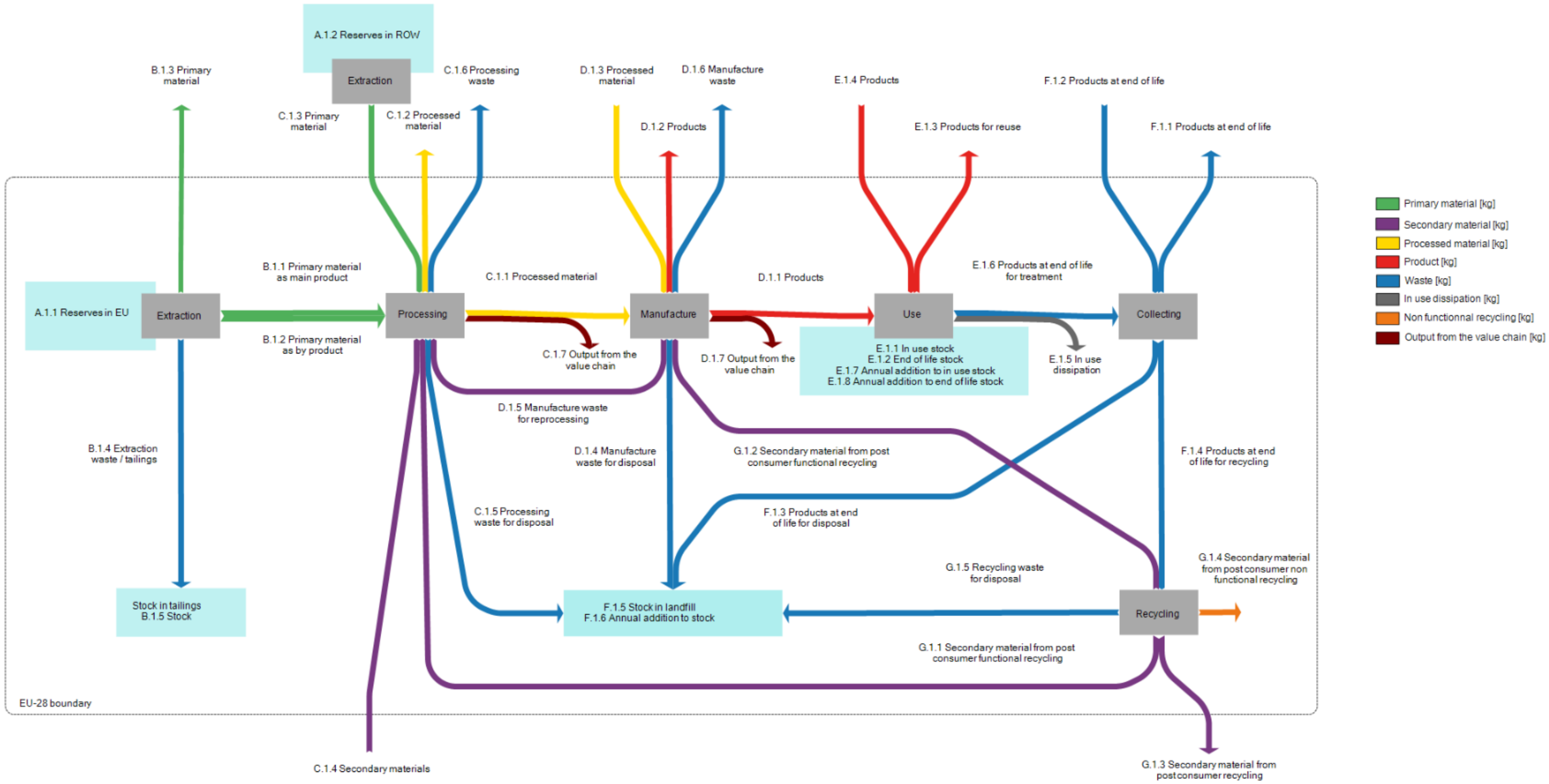

Figure 1. *Original Deloitte Model, 2015.*

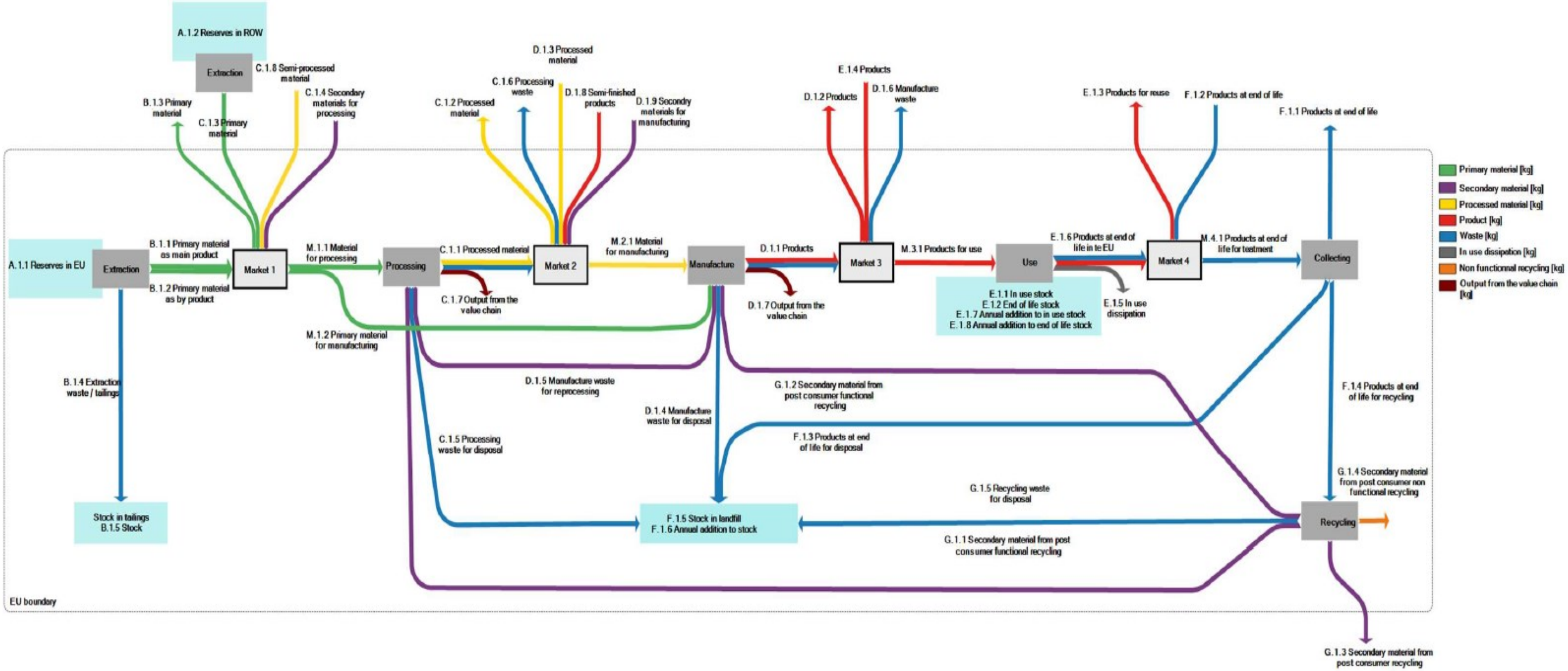

Figure 2. *Revised JRC Model, 2020.*

To be able to perform computations considering data uncertainties, the JRC model was converted into a STAN model. STAN is a free software (www.stan2web.net) developed at TUW, which has been specially designed to support MFA under the consideration of data uncertainties. During the conversion process, a few improvement options were identified, which were incorporated into the STAN model. While additional flows have been added where necessary, some (e.g. "output from the value chain") have been eliminated from the model. In the new Generic Model, all materials used or generated in non-market processes come from or go to markets. The only exceptions are flows to or from the environment. Additionally, all markets offer the possibility to import and export products and wastes. Lastly, some of the processes have been renamed for better clarity. The developed model was revised in several iterations until the final Generic Model was derived (see Figure 3).

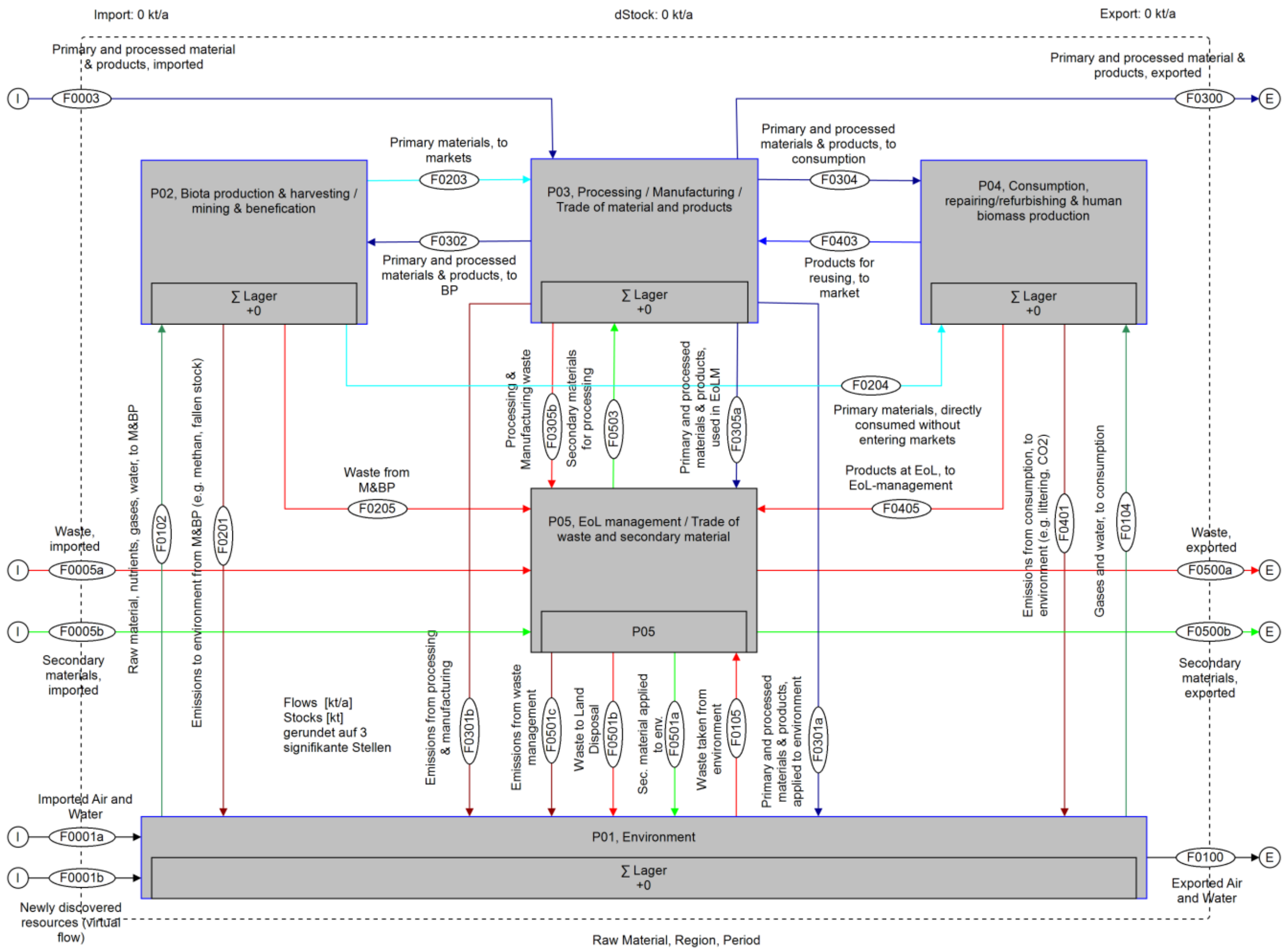

Figure 3. Generic STAN Model.

2.2. Strengths and Weaknesses of the Model

The Generic Model was designed to cover as many requirements as possible. On the one hand, it was kept as simple as possible and, on the other hand, complex enough to provide a good initial overview of any specific RMB of a national economy. Depending on the use and data situation for a specific raw material, the Generic Model can be expanded to the desired level of complexity (full-scope model) by introducing sub-layers (i.e. processes are converted into sub-systems, which can be modelled in more detail). In this way, the RMB can be adapted flexibly to cover the specifics, demands and requirements of any raw material adequately. Additionally, this approach establishes a uniform materials accounting procedure for all raw materials, facilitates comparisons between raw materials and EU members, and supports scale-ups from country to EU level.

The biggest weakness of the Generic Model is that it was designed by one party (TUW) only. Thus, the consent of other parties assumed to work with this model might be missing. Additionally, allowing each user of the model to design its own sub-systems, makes their comparison difficult. Therefore, it is recommended to also seek agreement on a commonly used sub-system layout for specific materials, even though it must be assumed that, due to the data situations in different member states, this individuality will be sometimes necessary.

2.3. Potential of RMBs

The results of the indicator materials (P, Cu, Nd) show how RMBs can be a beneficial tool for policymakers. In the example of P, which has the best data coverage, measures have been proposed to reduce, for example, the dependency on national imports. RMBs represent static MFAs with a temporal resolution of usually one year. Static MFAs (where flows and stocks are related to other flows in the same period only, e.g., via transfer coefficients) can be used to identify measures that help to reduce the import dependency (= the net import into a system) on, e.g., critical raw materials via simulations. Implementing these measures often means approaching a circular economy and, thus, reducing the vulnerability to bottlenecks in advance. It should be noted that implementing those measures usually takes years, which is why RMBs should be regarded as a tool to foster change toward a more circular economy and to support long-term resource management. They are less suitable for reacting to possible supply bottlenecks at short notice.

In the P model created by Tanzer et al.[7] at TU Wien, based on the model of Zoboli et al.[8], the reduction of the P import dependency due to the application of specifically identified measures was quantified, and their respective implementation times were estimated.

In these publications, 15 measures were identified for the Austrian P household, which can be used to reduce the import of P and the loss of P to soils, landfills, and water bodies. These measures are listed in Table 1 and are described in more detail in Zoboli et al.[8] They can be divided into those that serve to increase P recovery and recycling,

[7] Tanzer, J.; Zoboli, O.; Zessner, M.; Rechberger, H., Filling two needs with one deed: Potentials to simultaneously improve phosphorus and nitrogen management in Austria as an example for coupled resource management systems. Science of The Total Environment, 2018.

[8] Zoboli, O.; Zessner, M.; Rechberger, H., Supporting phosphorus management in Austria: Potential, priorities and limitations. Science of The Total Environment, 2016.

those that bring a reduction of P demand and consumption, and those that mean a reduction of emissions to water bodies.

Table 1 also shows estimates by TUW for the average implementation times for these measures. It can be seen that none of the measures could contribute to reducing a bottleneck in the short term, i.e., within one year. However, implementing all 15 measures would drastically reduce Austria's dependence on P imports in the medium to long term. Mapped into the Generic Model, in Figure 4, the Austrian P budget for 2015 is shown, and in Figure 5, how the budget would look if all of the 15 measures of Table 1 were implemented. The result is that the mass of net imported P could be reduced by approximately 75%, and the import of commercial fertiliser could be eliminated entirely (a reduction of 100%) without having to accept losses in agricultural production or feeding the population[9].

The results show that Austria is still very poorly positioned regarding the effective use of P as a raw material. In comparison, optimisation with regard to environmental impact is already further advanced. Here, the loss of P to water bodies could only be improved by approximately 30%. This is a typical finding for highly developed economies: environmental protection is already quite well established, but there is still room for improvement in the efficient use of raw materials (resource conservation). However, for P and the Austrian situation, there are no shortages or bottlenecks to be expected. If a P bottleneck should appear, fertiliser use could be reduced for a couple of years without affecting the harvest since there is enough legacy P in the Austrian soil[10].

Nonetheless, this example shows how developing and analysing a national RMB can lead to measures by which a country can minimise its vulnerability to bottlenecks in the supply of raw materials in the long run by structurally reducing import dependency for that given raw material.

For Cu and Nd, no similar measures could be derived because, for Austria, the required data was not available in the same depth as for the P model (which is the result of two PhD theses). Thus, we limited ourselves to trying to map the flows and stocks of existing EU models (a dynamic copper model created by Soulier et al.[11] and a dynamic neodymium model created by Ciacci et al.[12] into the main layer of the generic model. However, this trial was only partially successful because the EU models did not cover all the flows and stocks of the Generic Model.

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[9] Tanzer, J.; Zoboli, O.; Zessner, M.; Rechberger, H., Filling two needs with one deed: Potentials to simultaneously improve phosphorus and nitrogen management in Austria as an example for coupled resource management systems. Science of The Total Environment, 2018.

[10] Buczko, U., van Laak, M., Eichler-Löbermann, B. et al. Re-evaluation of the yield response to phosphorus fertilization based on meta-analyses of long-term field experiments. Ambio 47 (Suppl 1), 50–61, 2018. https://doi.org/10.1007/s13280-017-0971-1

[11] Soulier, M.; Glöser-Chahoud, S.; Goldmann, D.; Tercero Espinoza, L. A., Dynamic analysis of European copper flows. Resources, Conservation and Recycling, 2018.

[12] Ciacci, L.; Vassura, I.; Cao, Z.; Liu, G.; Passarini, F., Recovering the “new twin”: Analysis of secondary neodymium sources and recycling potentials in Europe. Resources, Conservation and Recycling, 2019.

Table 1. *Fields of action (measures) to make the Austrian P household less import-dependent and more environmentally compatible[13].*

Field of action (Increase of P recovery and recycling)	**Scope for reduction of import dependency**	**Uncertainty**	**Implementation period (years)**	**Main challenges**	**Main data gaps**
Increase P recycling from meat and bone meal	16%	Moderate	**5 - 10**	Legal framework and market uncertainties for recovered fertilizers	P concentration
Increase P recycling from sewage sludge	22%	Moderate	**<5**	Legal framework and market uncertainties for recovered fertilizers	Technological performance and product quality
Increase P recycling from compost	10%	High	**<5**	Regulation/coordination of sales in large number of composting plants	Current use shares; P concentration
Increase P recycling from digestates	n.q.	Low	**<5**	Large number and heterogeneity of biogas plants	Feedstock amounts and composition
Increase P recycling from biomass ashes	2%	Moderate	**5 -10**	Lack of economic incentives that offset logistical costs	Current recycling rate; ash quality
Increase P recycling from manure	n.q.	High	**<5**	Enhancement of agricultural advice services	Livestock excretion factors
Improvement of municipal and industrial organic waste management	2%	Moderate	**<5**	Resistance of households and similar establishments to further increase separate collection	P concentration in MSW; industr. by-products use

Field of action (Reduction of P demand and consumption)	**Scope for reduction of import dependency**	**Uncertainty**	**Implementation period (years)**	**Main challenges**	**Main data gaps**
Balanced and healthy diet	20%	High	**5 - 15**	Resistance to behavioral change Opposition of meat producers	Complexity of system feedbacks
Use efficiency in crop farming	40%	Moderate	**<5**	Enhancement of agricultural advice services	Livestock excretion factors; P content in crops
Optim. of P content in feedstuff	19%	High	**<5**	Enhancement of agricultural advice services	Current state of optimization; complex feedbacks
Reduction of P in detergents	4%	Low	**<5**		-
Reduction of P in other industrial uses	n.q.	High	**5 -10**	Substitutability of P	Materials flows in industrial applications
Reduction of accumulation in green areas	10%	High	**<5**	Resistance to behavioral Coordination of large numbers of people	Home composting; sales of compost to privates

Field of action (Reduction of emissions to water bodies)	**Scope for reduction of *Import dependency***	**Uncertainty**	**Implementation period (years)**	**Main challenges**	**Main data gaps**
Reduction of point discharges	n.q.	Low	**<5**	Higher Fe levels in sewage sludge would pose a problem for several P recovery technologies	Loads and perform. of industrial treatment plants
Reduction of erosion from agricultural soils	11%	High	**<5**	Implementation at large scale Identification of hotspots	Retention processes and transport of „legacy“ P

n.q.: non-quantifiable <1: within 1 year <5: within 5 years 5-10: between 5 and 10 years >10: more than 10 years

[13] Zoboli, O.; Zessner, M.; Rechberger, H., Supporting phosphorus management in Austria: Potential, priorities and limitations. Science of The Total Environment, 2016.

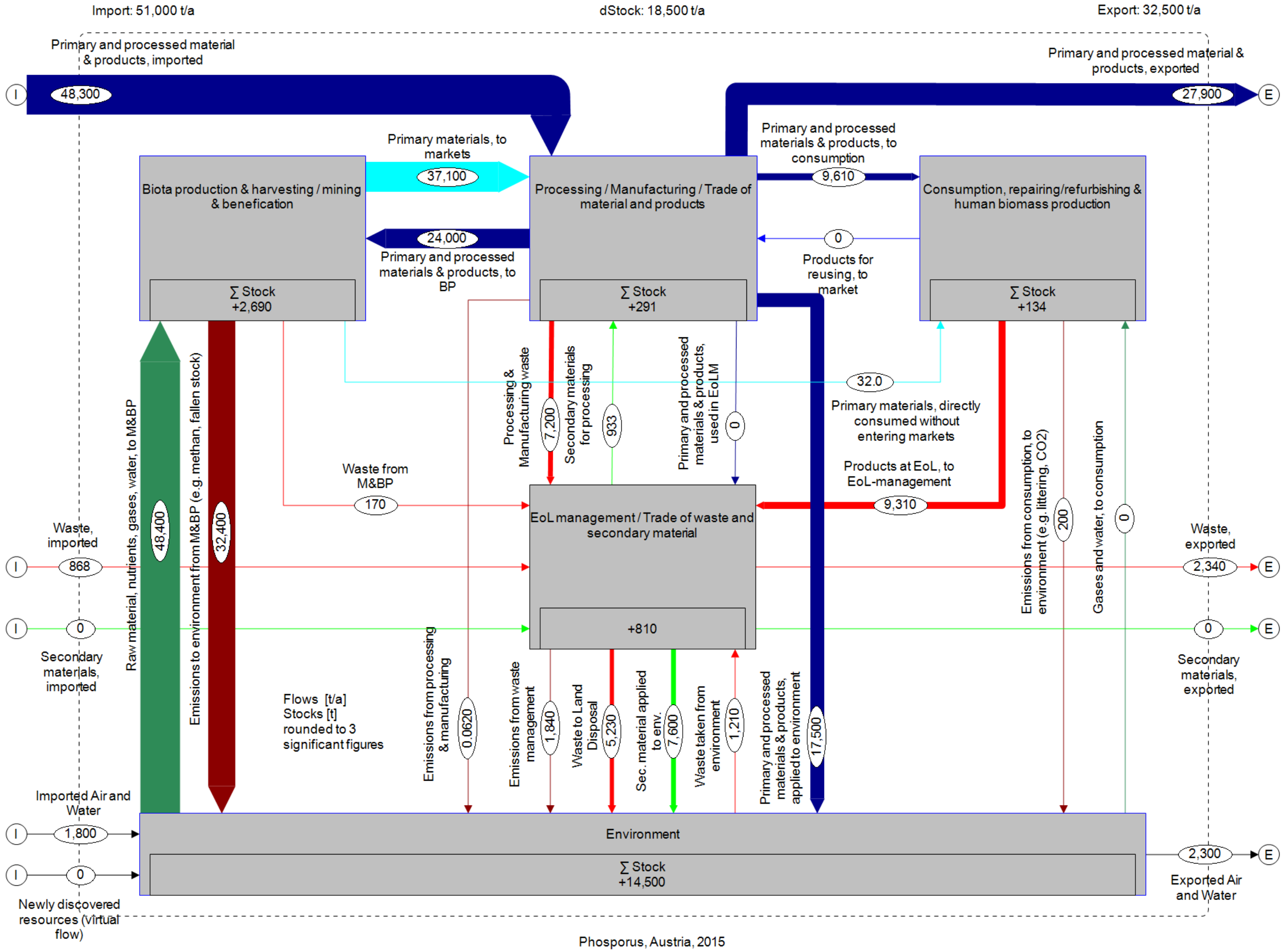
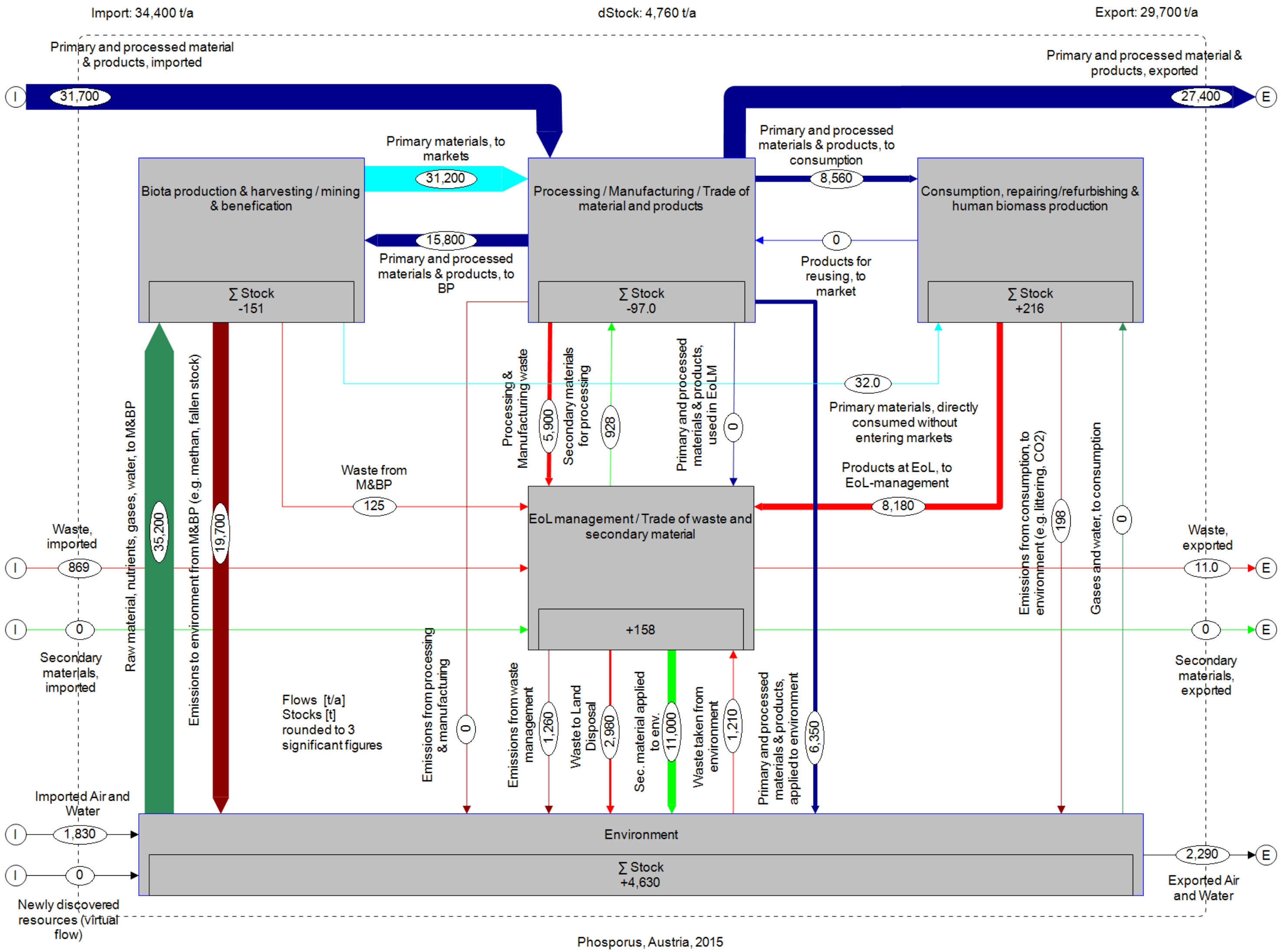


Figure 4. *Status quo of the Austrian P model for the year 2015.*

Import Dependency (ID) = (Sum of Imports – Import via Water/Air) – (Sum of Export – Export via Water/Air)

ID_s.quo = (51000 – 1800) – (32500 – 2300) =19000 t/yr



Import Dependency (ID) = (Sum of Imports – Import via Water/Air) – (Sum of Export – Export via Water/Air)

ID_opt = (34400 – 1830) – (29700 – 2290) = 5160 t/yr

Change of ID = (ID_opt/ ID_ s.quo – 1) * 100 ≈ -73%

Figure 5. *Optimised Austrian P model for the year 2015.*

2.4. Roadmap

As a result of the project, the BMF, as beneficiary, was presented with a roadmap for establishing future comprehensive RMBs in Austria. As a starting point, the main fields of action for establishing an RMB system in Austria have been identified based on the insights gained during stakeholder interviews and the results of the data analysis carried out in the project. Identifying and analysing these fields of action is essential to defining an implementation strategy, as they reflect the long-term vision of RMBs. Concrete implementation measures can only be described, planned, and implemented if the (long-term) vision of national RMBs is first specified. These analysed fields of action and their different implementation options are shown in Figure 6.

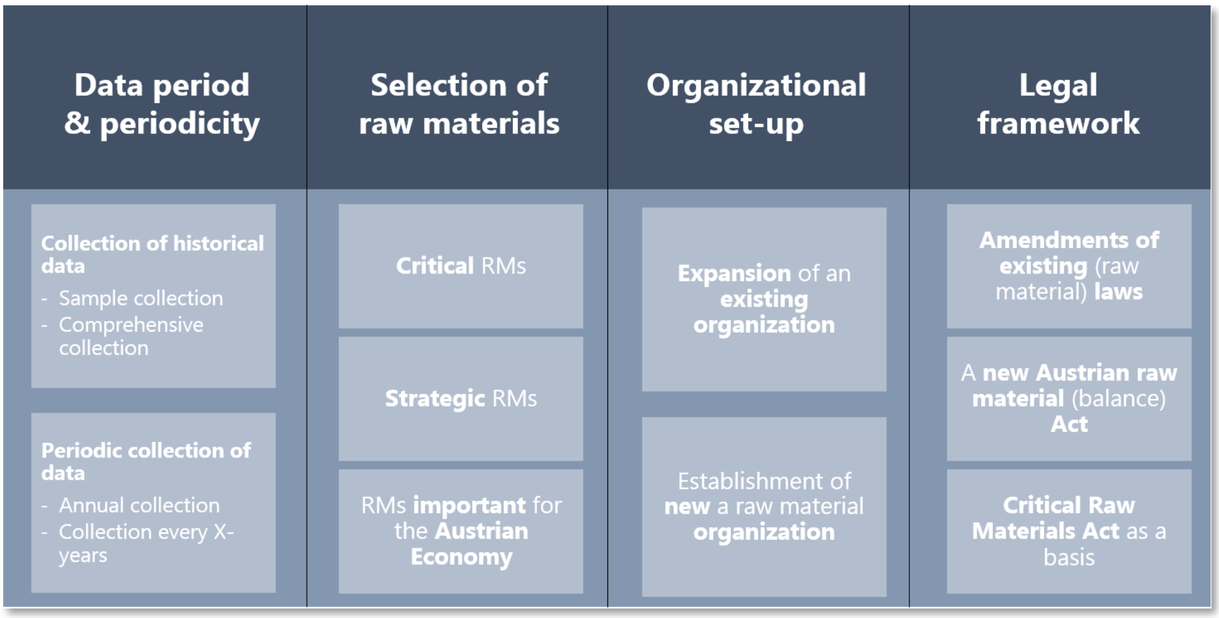


Figure 6. *Fields of Action for establishing a national RMB system.*

Based on the analysed fields of action, a roadmap for establishing national RMBs has been developed. Due to the relationships and interdependencies between the fields of action, iterative processes may be necessary to establish a comprehensive RMB system in Austria. For example, the fields of action "data period & periodicity" and "legal framework" are closely related. Legal foundations are necessary for the collection of raw material data. However, the question of which specific data should be collected for RMBs can only be answered after the first substantial data analyses have been conducted. Thus, the establishment of RMBs should be seen as an iterative process. The roadmap presented in the following might, therefore, change or be adapted in the process of further analyses. To implement an RMB system, it is recommended to set up a project team to plan and monitor the tasks and implementation of measures.

The roadmap recommends a two-phase approach (see Figure 7) for implementing national RMBs. In the first phase, the necessary framework conditions must be further analysed and determined. The determined options should then be subsequently implemented. This includes legislative adjustments to provide the framework conditions for establishing an RMB system in Austria.

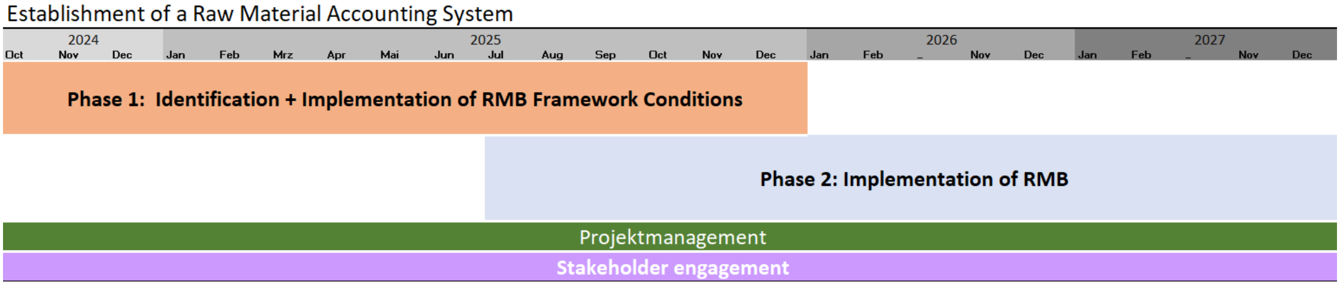


Figure 7. *Two-Phase Approach for the Establishment of an RMB System in Austria.*

In the first phase, the implementation scenario for a national RMB system should be specified including the selection of raw materials and data periodicity. It is recommended to focus on the historical data of a small number of selected raw materials in the initial rollout of RMBs. By collecting historical data, a comprehensive picture of raw material stocks and flows in Austria can be obtained. The selection of raw materials for the initial rollout of RMBs should take the result of the survey for assessing the national criticality of raw materials into account (see 2.5.). Once the scope is defined the organisational set-up can be specified.

To create, analyse and interpret RMBs a team of experts is required. A task profile for the RMB expert team and the requirements for an RMB unit should be defined. The "RMB expert team" should carry out its work in an eligible organisational setting. The two different approaches for building the organisational set-up are shown in Figure 6. The following possible organisational structures should further be analysed for their suitability:

- Association
- Limited Liability Company (Ltd.)
- Federal Agency

A financing strategy for implementing and maintaining the established organisational structure should be developed and integrated within the necessary legal framework conditions. In parallel the technical requirements, such as a compatible database or material flow software, to create and analyse RMBs should be planned and implemented.

In order to be able to implement an RMB system in Austria, legislative adjustments and additions are necessary to provide the framework conditions for establishing an RMB system. First, a legal framework is needed to get access to the data that is required for the establishment of raw material balances. Second, as described above, the legal framework conditions for the organisational set-up of an RMB expert team need to be created. There are several possible approaches and methods for making the necessary legislative adjustments and integrating laws and regulations into the

Austrian legal system that enable an RMB system. The existing legal norms should be analysed in depth in the first phase of establishing an RMB system in Austria. Next, including relevant stakeholders, legal drafts for the necessary legislative adjustment to implement national RMBs should be developed and subsequently implemented to start the initial rollout of RMBs.

After the framework conditions have been developed, the policy measures should be implemented, and phase two of establishing an RMB system starts. It is recommended to initiate building an RMB expert team and start with the collection of historical data in the initial rollout. In the implementation phase of a national RMB system the focus will be on collecting the historical data of selected raw materials. It is intended to develop raw material-specific data protocols for subsequent data collections to continuously monitor the raw material household of the selected raw materials. The results of the data protocol and the insights gained in the initial data collection process will most likely require some legal and technical adjustments in terms of data access and transmission. Thus, the legal and technical requirements should be evaluated and adapted after the first initial rollout of RMBs.

After the initial rollout, the intention should be to expand the RMB expert team and increase the amount of raw materials to be monitored. The expansion of the RMB expert team should include economic expertise, as the measures and recommendations developed by the commodity-specific experts must also be evaluated from an economic (macroeconomic) perspective. Further, necessary activities should be identified, and the transferability of the implemented measure to other EU member states should be evaluated. The planning and subsequent establishment of a common European RMB system can lead to a uniform approach of raw material accounting within the European Union.

To ensure the success of the measures to be implemented, it is essential to involve relevant stakeholders right from the start of the preparation for implementation, and to ensure their sustained commitment and active support. During the project, key stakeholders were consulted, and their remarks were taken into account for the development of the roadmap. The continuous engagement of the existing stakeholders is recommended to keep them involved and secure their support.

Considering that it will take time until the first results from RMBs can be derived, it is recommended to initiate the first steps toward a national RMB system (e.g. planning data collections or evaluating the STAN software) in the near future. However, once the project has been completed, it is up to the ministries to establish a political commitment to implementing these measures and subsequently plan, carry out and evaluate their concrete implementation.

2.5. Raw Material Selection

To assess which raw materials should be analysed in the initial rollout of an RMB system, an assessment matrix was developed and shared with stakeholders. An online survey was sent out to stakeholders including industry members and representatives, as well as people from academia. The survey was open for a month and in total 18 people completed the survey, which reflects a response rate of 37%. Only a small number of respondents provided their name and institution. Among those who did, there was an equal distribution between participants from science and research, and industry representatives.

The survey included 40 raw materials, which could each be assessed by a set of five questions. The questions aimed to assess the four main criteria for selecting raw materials: the economic importance, the supply risk, the environmental impact, and the data situation for raw materials. An example question measuring the economic importance of a raw material was “Please estimate the importance of the raw material for the industry and Austrian economy.”. Most questions are answered on a Likert scale from e.g. 1 = “not important/ very unlikely” to 10 = ”very important/likely”. The full list of questions and answers is attached in Annex IV. The respondents were asked to only rate the raw materials that are within their expertise to keep the time to fill out the survey as short as possible. Additionally, they were given the opportunity to name additional raw materials that should be considered for RMBs.

To analyse the national criticality of raw materials, the items assessing the economic importance, the supply risk and the environmental impact were combined. The mean of the average responses per question was calculated. The results of the national criticality and data availability of the 40 raw materials is shown in Figure 8. The results in the top right corner of the graph indicate high national criticality and good data availability. The size and colour of the datapoint reflects the number of respondents that rated a raw material. Since experts were asked to only rate the raw materials within their area of expertise there was a maximum of 10 responses for a raw material (e.g. aluminium, bauxite) and a minimum of two responses for a number of raw materials (e.g. Helium, Zirconium). The number of responses should be taken into account in interpreting the results of the raw material assessment.

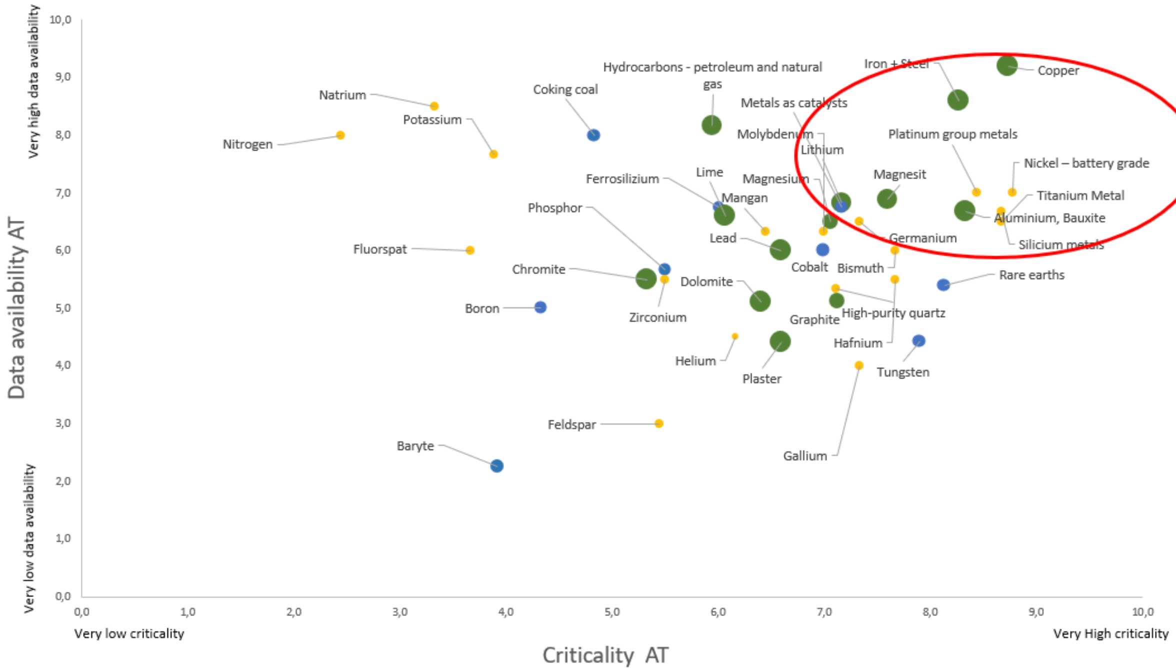


Figure 8. *Results of the national criticality and data availability of the 40 assessed raw materials.*

Based on the results, it is recommended to focus on the raw materials that are shown in the top right corner of the graph for establishing a national RMB system. Table 2 shows the mean national criticality and data availability of those raw materials with the highest results.

Table 2. *Raw Materials with the highest rated national criticality and best data situation.*

Raw Material	National Criticality	Data Availability
Nickel – battery grade	8.8	7.0
Copper	8.7	9.2
Silicium metal	8.7	6.7
Titan metal	8.7	6.5
Platinum group metal	8.4	7.0
Aluminium, Bauxit	8.3	6.7
Iron + Steel	8.3	8.6
Magnesit	7.6	6.9
Germanium	7.3	6.5
Lithium	7.2	6.8
Metals as Catalysts	7.2	6.8

In the initial stage of establishing RMBs, the focus should be on the raw materials that are critical for Austria and have good data availability. For those raw materials that are rated as most critical for Austria, RMBs bring the most value, especially if data is already available. If, in this case, RMBs are being developed and analysed, impactful measures can be derived to foster resource management. Also, it is recommended to start with those raw materials that have good data availability to develop the needed infrastructure and Application Programming Interfaces (APIs). This is supported if data for the initial raw materials is already available for example from data sources such as Statistik Austria or the EDM system. Thus, the list of raw materials show in Table 2 should be considered for the initial rollout stage of establishing an RMB system. In particular the raw materials ‘copper’, ‘aluminium, bauxite’ and ‘iron and steel’ should be considered for the initial development of a national RMB system since those were assessed by most experts.

Additionally, it is recommended to improve the data quality of those raw materials that are assessed as having low to medium data availability, especially if they are considered critical. Table 3 gives an overview of the raw materials that were assesses as critical but having a rather low data availability.

Table 3. *Raw Materials with the lowest rated data availability and high national criticality.*

Raw Material	National Criticality	Data Availability
Rare earths	8.1	5.4
Tungsten	7.9	4.4
Hafnium	7.7	5.5
Gallium	7.3	4.0
Graphite	7.1	5.1
High-purity quarz	7.1	5.3
Plaster	6.6	4.4

But also for the raw materials that are currently assessed as less critical, it is recommended to improve long-term data availability since the national criticality might change in the future and policy makers would benefit if the data situation is addressed early on.

Respondents were also given the possibility to name additional raw materials that should be considered for RMBs in the future. The following raw materials were named by the respondents:

- Zinc
- Vanadium
- Sand
- Gravel
- Niob
- Carbon Black

If an RMB system has been established and RMBs have been developed for the most critical raw materials, additional raw materials should be considered with respect to their relevance to the national economy. In general, it is recommended to evaluate the national criticality of raw materials every few years, since geopolitical changes or technical developments can change the criticality of raw materials rather quickly.

3. POTENTIAL FOR OTHER EU MEMBER STATES

The scarcity of raw materials and considerations for securing raw material supply in the future is not only a national issue but a European matter as well. The list of critical raw materials and the Critical Raw Material Act[14] (European Commission, 2023) are two examples reflecting the relevance of the topic on a European level. The importance of access to critical raw materials and the shift to a circular economy has also been emphasized in a recent report by Draghi[15] on the future of European competitiveness. Thus, the results of the present project are believed to be of great value for other EU member states as well. In fact, it is thought that RMBs would have more excellent value if a European RMB system could be established as well. Only if raw material stocks and flows are known on a European level, long-term measures that target, for example, international trading partnerships can be identified. EU member states and companies could better plan ahead if data on primary and secondary raw materials were available on a European scale. In the recently published report[15] it is recommended that the EU should harness the potential of recycling as “the EU could potentially meet more than half to three quarters of its metal requirements for clean technologies in 2050 through local recycling”. By providing data and insights for measures to foster the use of secondary materials, the establishment of national and european RMBs would help to meet that recommendation.

Another benefit for other EU member states establishing RMBs would be the chance of international expert exchange. If RMB expert teams are installed in different member states, a pool of raw material-specific experts can be built who can exchange information and learn from each other. This can relate to the exchange of data sources and measures, but also to the analysis of differences between member states and the identification of best practice examples.

The Generic Model was developed in this project to allow other EU member states to apply the model, too. It is expected that most EU member states will be able to provide the data needed for the first layer of the Generic Model. Additionally, the model allows for the individual modelling of sub-systems. This means that EU member states can use the model and display specific characteristics on the sub-layers while comparing data between member states on the first layer.

Furthermore, it is anticipated that the roadmap for establishing RMBs in Austria, as developed in this project, will also be applicable to other EU member states. It is expected that a two-stage approach - one stage focused on establishing the necessary framework conditions and another on implementation - will also be required in other EU member states. However, the (legal) adjustments and needed measures may vary between member states.

[14] European Commission. (2023). *Critical Raw Materials Act*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202401252

[15] Draghi, M., The future of European competitiveness – A competitiveness strategy for Europe, 2024. https://commission.europa.eu/topics/strengthening-european-competitiveness/eu-competitiveness-looking-ahead_en

To be able to deal with RMBs on the EU level efficiently, it would be desirable to use standardized software. A good starting point is the freely available software STAN (www.stan2web.net), which has been developed at TU Wien. It has been specially designed to support material flow analysis under the consideration of data uncertainties (including data reconciliation and uncertainty propagation) and was used successfully in this project. However, to fully realize its potential and address the evolving needs of future RMBs (e.g., dynamic modelling, platform independence, …), further development is needed. Additionally, a standardized data protocol is recommended in order to exchange data between EU countries. An example of a data protocol to build on could be the Industrial Ecology Data Commons by Pauliuk et al.[16]. The Industrial Ecology Data Commons is a database that contains more than 200 industrial ecology related datasets from the literature, including stocks, flows, process descriptions, IO tables, material composition of products, and many more (https://www.database.industrialecology.uni-freiburg.de/.). Lastly, on the EU level, a database is required, which allows the storage of material-specific information to be accessed by all EU members.

[16] Pauliuk, S.; Heeren, N.; Hasan, M. M.; Müller, D. B., A general data model for socioeconomic metabolism and its implementation in an industrial ecology data commons prototype. Journal of Industrial Ecology, 2019.

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ANNEX IV: RAW MATERIAL ASSESSMENT MATRIX

Criterion	Question	Response Scale
Economic Importance	Please estimate the importance of the raw material for industry and the Austrian economy.	1 = not important 10 = very important
Supply Risk	*Please assess the risk of a supply bottleneck in the next 10 years. If you see a high risk, please explain the reasons.*	1 = very unlikely 10 = very likely
Environmental Impact	*Please evaluate the recyclability of the raw material. If you see potential for improvement, please explain the reasons.*	1 = no data availability 10 = very good data availability
Data Situation	*How good do you think the data availability for the raw material is?*	1 = very bad 10 = very good
Company Significance	*Please indicate the meaning for your company. If desired, you can provide further explanations.*	1 = no significance 10 = great significance

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