



MinFuture

MinFuture Roadmap

A roadmap towards monitoring the physical economy



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List of abbreviations

CA	Consortium Agreement
CC	Consortium Committee
CRIRSCO	Committee for Mineral Reserves International Reporting Standards
DOA	Description of Action
EGRC	Expert Group on Resource Classification of the UNECE
ESSC	European Statistical System Committee
GA	Grant Agreement
IEA	International Energy Agency
IRP	International Resource Panel
JRC	Joint Research Centre of the European Commission
OECD	Organisation for Economic Co-operation and Development
PCG	Project Coordination Group
PO	Project Office
PRMS	Petroleum Resources Management System
SPBTT	Science-Policy-Business Think Tank
UNCEEA	UN Committee of Experts on Environmental-Economic Accounting
UNECE	United Nations Economic Commission for Europe
UNFC	United Nations Framework Classification for Resources (UNFC)
UNSD	United Nations Statistics Division
WP	Work Package

Executive Summary

Raw materials are the backbone of all industrial supply chains. They play a prominent role in global socio-economic development and their production and use shape the pathways towards the low-carbon and circular economy. Global material production and consumption have increased substantially in recent years. Complex supply chains have been developed to satisfy our material needs and to underpin economic growth.

In order to tackle the problems associated with past unsustainable practices and to improve our capacity for forecasting and scenario development, it has now become imperative to monitor the physical economy. Existing monitoring practices focus primarily on the monetary dimension and do not address the physical dimension of supply chains. Current monitoring is characterised by datasets describing isolated flows (e.g. mine production) rather than whole systems (e.g. material cycles). There are considerable uncertainties in existing data. In addition, there are substantial data gaps that are not always explicit. There is serious fragmentation and discrepancies in data reported by different countries, different economic activities and different supply chain dimensions (e.g. production and trade). Existing data commonly lack a system context, which often leads to false assumptions, misinterpretations and wrong decisions. Furthermore, there are few incentives to share data, while confidentiality rules reduce transparency and result in fragmentation. Thus, the existing monitoring practice is inefficient and not suited to inform robust policies and strategies for addressing some of the most relevant societal challenges.

Due to these shortcomings, existing monitoring practices fail to provide the evidence base needed for assessing impacts on climate change, for monitoring progress towards implementing the circular economy, achieving the sustainable development goals and securing long-term supply of raw materials. Monitoring the physical economy can enhance our perception of society's metabolism, improve our understanding of the interactions between economic activities and the environment and facilitate the identification of those intervention points in the supply chains that can lead to better outcomes.

This roadmap provides a series of 'strategic' recommendations for moving towards the monitoring of the physical economy. The overarching goal is to **move away from monitoring individual, isolated flows to monitoring systems at company, national, regional (e.g. EU) and global levels**. For this to happen the development of systems and data that accurately reflect the supply chains for a wide range of commodities is required. The lack of systems and data is a serious barrier at present and it will require substantial coordinated efforts and collaboration across different communities, including academics, government and industry, to enable their further development. The recommendations in this document are designed specifically to assist in overcoming this barrier.

1. Establish a data infrastructure for material and energy stocks and flows that will enable the monitoring of the physical economy

The establishment of a data infrastructure requires the development of **legal** conditions, **technical** procedures and **institutional** changes to support the initiation stage and the long-term use and maintenance phases.

- **Legal interventions** should evaluate the options available for the development of a data infrastructure for physical accounting. In Europe, legal options to be considered include the possibility of either **amending the existing INSPIRE Directive or preparing a new Directive** for monitoring the physical economy. The INSPIRE Directive sets a common framework and implements rules to ensure compatible spatial data across all Member States. It is important, therefore, to investigate if an extension to INSPIRE would be suitable to accommodate material stocks and flows data (which includes both, spatial and non-spatial data), or

whether a new Directive would be more suitable. An expansion of the INSPIRE Directive with data on the physical economy may have the advantage that it links existing INSPIRE Themes (e.g. buildings, production and industrial facilities, mineral resources). Setting out clear legal conditions is important as they provide the right motivation to national governments to move in this direction. The establishment of legal conditions for a data infrastructure on the physical economy should ensure that national data and data infrastructures on physical material stocks and flows are compatible and usable across national boundaries. The need for common implementing rules, for example in data specifications, metadata, data services and data interoperability, should be an integral component of legal interventions.

- **Technical procedures** should develop common implementing rules, as specified in a predefined legal framework that ensure the reporting of data in a system context. The MinFuture project recommends the **establishment of a technical expert group** that will analyse existing Themes of the INSPIRE Directive to determine the relevance of existing data specifications to the monitoring of the physical economy. The group will also assess the requirement to expand or create additional Implementing rules and technical guidelines (data specifications) that can accommodate physical accounting and coordinate efforts at the national level and from different data providers. The technical expert group should provide feedback to the EC and inform the development of legal interventions.
- **Institutional interventions** will be essential for establishing a data infrastructure for the physical economy. There is a need for institutions with a mandate and the necessary resources to coordinate efforts and integrate data at the national, EU and global levels. The MinFuture projects calls for the **establishment of a high-level working group** which will evaluate institutional options to coordinate the monitoring of the global physical economy. These may include the establishment of new institutions or redefining the role of existing institutions. Organisations such as the IRP, IEA, OECD, UNSD, IGF and UNECE could play an important role in establishing such a group. The high-level working group should produce specific recommendations that will assist institutions at national, EU and global levels to consider, implement and, therefore facilitate physical accounting. The implementation bodies, namely institutions, such as statistic offices and public authorities, should be granted a mandate and provided with adequate resources to support implementation and coordination activities.

2. Address key knowledge gaps that inhibit the monitoring of the physical economy

Fragmented physical datasets are available, but they do not cover all the stages of material cycles. The MinFuture project has identified four areas with important knowledge gaps that the scientific community, but also governments and industry, should address to enable physical accounting.

- **Physical accounting of geological stocks** with comprehensive coverage does not currently exist Given that global demand for raw materials is very likely to continue to increase such knowledge is important to ensure that adequate and sustainable supplies can be secured. Related questions concerning resource depletion, potential conflicts of mining with other land uses and increasing energy use due to declining ore grades also depend on the availability of such data. **Current geological information is not suitable to address these questions in a consistent and satisfactory way.** The MinFuture project calls for the development of:

- a **framework for reporting mass-balance-consistent figures of geological stocks** over time and space, including system definition, terminology and robust assessment methodology;
 - Further **developments and improvements in 3D geological models** that provide important underpinning knowledge about geological stocks.
- **Physical accounting of anthropogenic stocks** is considered to be in its infancy and there are several challenges related to the resolution of current accounting methods, the availability of data and the integration of existing calculation approaches. Our recommendations include the **development of a standardised methodology and framework for physical accounting of anthropogenic stocks**, which will provide consistent terminology, calculation methods and enable the integration of existing accounting approaches. In addition, the production of data on anthropogenic stocks is deemed crucial and this recommendation calls for the development of city-level datasets and the use of techniques and tools, such as remote sensing, GIS, 3D city models and others, describing the built environment.
 - **Physical accounting of supply chains** depends on a consistent integration of production and trade statistics. Currently, there is no action at the global level that investigates inconsistencies between trade and production statistics. This is crucial for monitoring the physical economy and improving our understanding of supply chains. We recommend **the establishment of an international expert group working on a long-term goal to monitor global supply chains by harmonising production and trade statistics**. This recommendation has already been discussed with key stakeholders, such as UNSD, who endorse it and would be willing to find ways to move it forward.
 - **Physical accounting within companies** is currently taking place only to a very limited extent. However, the potential benefits to companies and to society as a whole are expected to be very high. For example, physical accounting can lead to resource efficiency gains, which at the company level can translate to cost savings. Also, the implementation of the system approach can assist companies to improve their reporting procedures, whether these are for national governments or for corporate reasons (e.g. annual reports, strategy development). Ultimately, the monitoring of physical economy relies on interactions between the industry and governments and the sharing of data and knowledge, as industry plays a pivotal role on how raw materials are produced and transformed into products and services globally. We **recommend the use of bottom-up real-time data from process control systems to build a resource flow picture for industrial plants**, to optimise plant performance and benchmark processes across similar operations. It is important therefore that future industry-based projects are developed to promote physical accounting in companies and to ensure that the benefits of so doing are widely disseminated.

Our recommendations have been discussed with different stakeholder groups, including policy makers, industry, public authorities and international institutions. Discussion have continued throughout the project life, which endorse the interest of the community in this subject, but also the need to move forward. It is suggested that the MinFuture roadmap is read together with the MinFuture Framework report, which sets the principles and system approach advocated for the monitoring of the physical economy.

1 Introduction/Rationale

1.1 Rationale

Material cycles are complex due to influences by many factors including globalisation, demographics, technology and industrial production, environmental conditions and political circumstances. Mineral raw material production and consumption have grown considerably over the years. Raw materials find use in numerous products and applications, and they are used in multiple different combinations. Increased global demand for mineral raw materials has resulted in wider and complex supply chains, which contributed towards economic growth. This in turn has also created challenges for humanity, such as environmental implications, climate impacts, social and political uncertainties and resources impacts.

Global challenges include sustainable development and climate change, which are interlinked with material supply chains. Actions taken to address global challenges include circular economy plans, targets to minimise the impacts of climate change, the sustainable development goals and actions towards a low carbon future. In Europe, the Raw Materials Initiative and the European Innovation Partnership (EIP-RM) has developed the Strategic Implementation Plan that sets actions for the sustainable supply of raw materials.

Understanding the physical economy can provide many advantages including greater knowledge about the interactions between economic activities and the environment, better interpretation of existing data, harmonisation of data and information, and insight about the linkages between different datasets. The monitoring of the physical economy would allow the development of models that underpin decision-making and strategy/policy improvements.

There is no systematic approach to physical accounting. Governments and public authorities monitor certain aspects of the physical economy only. For example, geological surveys and ministries of mines monitor mineral resources, reserves, mineral/metal production, and consumption. Environment agencies collect and report data on waste, emissions and pollutants and statistics offices collect information on traded good and the production of manufactured goods. All these actors however work in isolation and no attempts are made to combine data for the physical accounting across material cycles.

The lack of a system perspective in existing attempts made to monitor the physical economy means that this is not feasible. There are substantial gaps in the data and information collected, which are often hidden due to the lack of a system perspective. For example, for many of the minor metals, often deemed as critical, important data gaps exist, including limited understanding of their supply chains.

Limited recent actions taken to integrated data from various sources exists, for example the Eurostat Economy-Wide material flow accounts (EW-MFA), the EU commissioned study on Raw Material System Analysis (RMSA) and attempts by trading associations to track individual metals. Although, these comprise positive steps forward, their resolution and accuracy vary considerably.

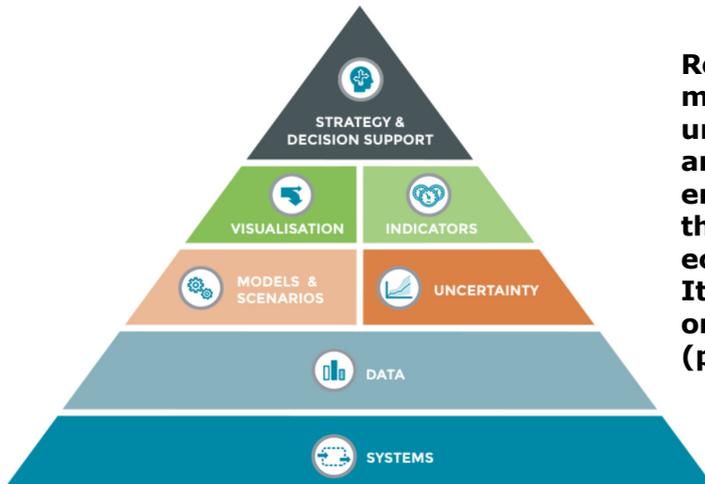
The focus of monitoring at present is on the monetary economy, where a systematic approach is available. The same is required for physical accounting to allow for a mass balance consistent understanding of the economy to be developed.

In order for physical accounting to become common practice, two key elements are required:

- A framework that outlines the key components of a physical economy monitoring programme.

- A roadmap that outlines existing challenges and provides recommendations for the implementation of the physical accounting.

1.2 The MinFuture Framework



Robust strategies for sustainable resource management depend on a solid understanding of the physical economy – the anthropogenic stocks and flows of matter and energy. MinFuture provides a framework for the description and monitoring of the physical economy using Material Flow Analysis (MFA). It distinguishes seven components, which are organised in a hierarchical structure (pyramid).



SYSTEMS

Importance and challenges:

Systems describe where materials are located (stocks) and where they are moving (flows), without quantities.

The knowledge about systems of the physical economy is often highly fragmented, particularly for minor metals, critical raw materials and for end-of-life management.

Key messages:

- Monitoring the system of the physical economy on various scales (site, company, region, country, global) is indispensable for effective resource management and emissions control.

Read more: <https://minfuture.eu/theme/svsystems>



DATA

Importance and challenges:

Data about the physical economy tend to be highly fragmented or lacking entirely.

The reference points of data collected are often unclear (described in words only), which results in ambiguous meaning and misinterpretation of the data.

Key messages:

- Reporting data with their system context ("coordinates") adds clarity and robustness and facilitates data harmonisation.
- Government authorities should consider describing their data with metadata about the system location of the measurements.
→ Monitor systems, not isolated flows

Read more: <https://minfuture.eu/theme/data>



MODELS & SCENARIOS

Importance and challenges:

Models are mathematical representations of material cycles and their drivers. They are used to forecast resource demand and supply and to test strategies under different conditions.

The robustness of models is usually limited by a lack of robust data and system understanding.

Key messages:

- Adding mass and energy balance constraints to resource and emission models enhances the robustness of forecasts.
- Improving system understanding and data quality is the most effective way to improve the quality of forecasts.

Read more: <https://minfuture.eu/theme/models-and-scenarios>



UNCERTAINTY

Importance and challenges:

A model can never perfectly represent a natural system.

Uncertainties in MFAs are caused by data paucity and errors in system definitions:

Ignoring uncertainty can result in wrong interpretations of the results.

Key messages:

- Uncertainty analysis makes uncertainties transparent and enables users to identify the strengths and weaknesses of the model.
- Systematically evaluating uncertainty enhances the robustness of results and interpretations.

Read more: <https://minfuture.eu/theme/uncertainty>



INDICATORS

Importance and challenges:

Indicators are used to measure the performance of a system or to capture the essence of a system with numbers.

Indicators are often poorly defined.

Strategies to enhance the indicator performance often cause in problem shifts.

Key messages:

- The definition of indicators (or indicator sets) can be enhanced through an explicit system definition.
- This adds clarity to the definition and facilitates a robust selection of indicators that capture potential problem shifts.

Read more: <https://minfuture.eu/theme/indicators>



VISUALISATIONS

Importance and challenges:

Visualisations are used to capture the essence of complex systems using images, and to communicate the results in an effective way.

The systems analysed tend to include several dimensions, which are difficult to communicate in words.

Key messages:

- Visualisations can capture multiple dimensions, which adds clarity and transparency, and provide interpretations of complex systems.
- Visualisations can be strengthened by integrating different modes of communication (images, words, and numbers).

Read more: <https://minfuture.eu/theme/visuasilations>



STRATEGY & DECISION SUPPORT

Importance and challenges:

Strategies for resource management tend to be ineffective and shift problems if they are not based on a robust system understanding.

Strategies for monitoring individual aspects of the physical economy tend to be expensive and of limited use for resource strategies if they are not based on an explicit system definition.

Key messages:

- Improving the robustness of the system understanding and the data is the most critical aspect for improving resource strategies.
- MFAs can inform strategies for monitoring the physical economy by providing a language for integrating data and for identifying key points for measurements.

Read more: <https://minfuture.eu/theme/strategy-and-decision-support>

1.3 Purpose of the Roadmap

This document provides a series of key recommendations and steps deemed essential for moving towards the monitoring of the physical economy. The roadmap deals specifically with the challenges related to systems and data that comprise the foundation of physical accounting in the MinFuture framework.

The following sections of this document are split into two separate parts. Section 2 explores challenges that relate specifically to physical accounting. It discusses issues with existing practices that are perplexing and problematic and provides recommendations that may resolve them. Section 3 looks at what instruments, conditions and rules are needed to be in place to enable the implementation of the physical economy monitoring. Section 3 also investigates all the 'peripheral' conditions and transformations required, for example changes in legal frameworks, financial support, technical requirements, institutional changes and educational needs to realise this vision.

The challenges described and recommendations provided in this document amalgamate the findings of a series of discussions and stakeholder engagement workshops undertaken during the two years of this project. These included commodity specific workshops, which identified challenges and recommendations relevant to different materials, as well as a workshop specifically on the roadmap that discussed the different prerequisite conditions to enable the implementation of physical accounting.

The purpose of this roadmap document is not to provide an exhaustive list of recommendations, but instead:

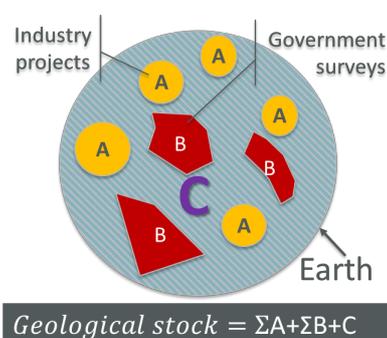
- to identify key areas where challenges with physical accounting exist
- to provide overarching recommendations about the steps needed to address such challenges
- to discuss the future implementation conditions required.

2 Challenges and recommendations for physical accounting

2.1 Physical accounting of geological stocks

Goal: Monitoring of geological stocks

Geological stocks are indispensable for global sustainable development. To secure future minerals supply, we need data, information and models on geological deposits that describe the quantities and qualities of materials stored in the Earth's crust. The goal is to have reliable data of total geological stocks, including both known and undiscovered resources, and an understanding of how they change over time. Current systems of reporting of mineral resources and reserves are based on the CRIRSCO template or the United Nations Framework Classification for Resources (UNFC), and are intended for stock market financing and government taxation of individual projects. However, the aggregated totals of the reported project quantities do not equal the total geological stock. There is no mass-balance consistent framework for integrating these numbers into national resource inventories, and there are limited studies attempting to quantify undiscovered resources (e.g. European MAP project¹). Unless we develop figures that describe the total geological stock, it is not possible to make robust assessments of resource availability, mineral depletion, and sustainable resource management.



Issues affecting ΣA :

- 1) Dynamic nature; change with market conditions;
- 2) Data availability – varies by country;
- 3) Data quality – varies by country, company, date;
- 4) Lack of data standardisation and harmonisation

Issues affecting ΣB :

- 1) Dynamic nature; change with market conditions;
- 2) Data availability – varies by country;
- 3) Data quality – varies by country, company, date;
- 4) Lack of data standardisation and harmonisation

Figure 1: Understanding geological stocks

There are significant challenges to attaining this goal. These include:

- lack of a framework for reporting mass-balance-consistent figures of geological resources over time and space, including system definition, terminology, and robust assessment methodology;
- lack of robust, comprehensive, and standardised datasets for estimation of geological stocks; and
- lack of standards and protocols to integrate, harmonise and exchange information on geological stocks derived from industry sources and national or global data inventories

Recommendations

- Develop a standardised methodology and framework for physical accounting of geological stocks. Promote dialogue between MFA specialists, resource geologists, geodata scientists and existing working group, such as the Expert Group on Resource Classification (EGRC), to develop an appropriate framework. This recommendation might be implemented in a number of ways, such as a new EU call (e.g. H2020, Horizon Europe, GeoERA) and by assessing the role of existing bodies, such as the Minerals4EU Foundation.
- Develop and improve 3D geological models to enhance quantification of total geological stocks and associated uncertainties.

¹ <https://eitrawmaterials.eu/project/map/>

2.2 Physical accounting of production and trade

Goal: Monitoring supply chains by integrating production and trade statistics

Trade and production statistics are reported using different classification systems. Trade statistics are harmonised globally to the 6-digit level using the Harmonised System through a process coordinated by the World Customs Organisation (WCO). Production classification systems (e.g. ISIC, NACE Rev. 2, U.S. NAICS etc) are also updated regularly but are harmonised only within the individual countries and not between different countries. The 'Expert Group on International Statistical Classifications'² investigates existing international classifications and make recommendations to the United Nations Statistical Commission for future updates on individual classification systems, for example the ISIC. The allocation of output products to the production sectors and traded products to the product groups in trade statistics is done in different ways that are not fully understood. There is currently no expert group to investigate inconsistencies between trade and production classification systems. In addition, production statistics representing specific sectors are released by various organisations, including geological surveys, ministries, and industry trade associations, with each using different classification systems. Conversion tables used to translate between different classification systems do not resolve sufficiently the lack of harmonization.

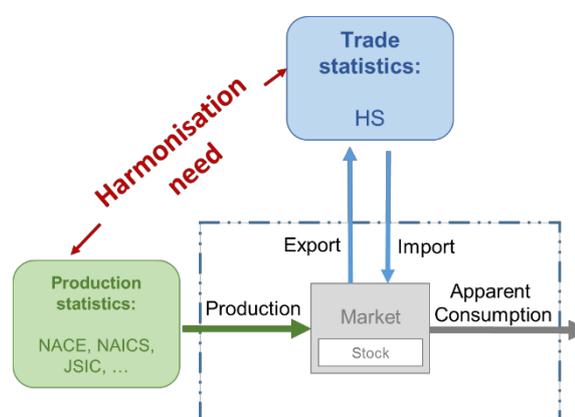


Figure 2: Production and trade statistics harmonisation needs

The collection of production and trade data is motivated chiefly by tax collection purposes and the data are therefore often only reported in monetary units, neglecting physical units. However, these data are increasingly used for monitoring global supply chains and tracking materials through the economy. This often results in serious accounting problems, for example (1) when a single product classification code includes several different product forms along the supply chain³, resulting in a risk of double-counting; (2) when they include commodities from different supply chains⁴; (3) when products at the same place in the supply chain strongly differ in composition⁵.

The collection of production and trade data is motivated chiefly by tax collection purposes and the data are therefore often only reported in monetary units, neglecting physical units. However, these data are increasingly used for monitoring global supply chains and tracking materials through the economy. This often results in serious accounting problems, for example (1) when a single product classification code includes several different product forms along the supply chain³, resulting in a risk of double-counting; (2) when they include commodities from different supply chains⁴; (3) when products at the same place in the supply chain strongly differ in composition⁵.

Recommendations

At the global level, establish an international expert group working on a long-term goal to harmonise production and trade statistics from a global supply chain and material cycle perspective. First steps include:

For trade statistics:

- Advise DG-Tax and tax offices of other WCO Member States on an amendment of the HS classification from a supply chain and material cycle perspective. This recommendation is endorsed by UNSD;

² <https://unstats.un.org/unsd/classifications/expertgroup>

³ E.g. HS code on cobalt mattes and other intermediate products of cobalt metallurgy, cobalt and articles thereof, including waste and scrap

⁴ E.g. CPC code 34220 Zinc oxide; zinc peroxide; chromium oxides and hydroxides; manganese oxides; iron oxides and hydroxides; earth colours; cobalt oxides and hydroxides; titanium oxides; lead oxides; red 2lead and orange lead; inorganic bases n.e.c.; metal oxides, hydroxides and peroxides n.e.c., except of mercury

⁵E.g. fly ash

- Include the unit “metal content” in the trade statistics. Currently, there are several additional units such as m³ for timber or karat for diamonds. An expert group should develop guidelines for standards and for the implementation.

For production statistics:

- Advise the Expert Group in charge of Prodcom, including experts in charge of production statistics for non-European countries on an amendment of the production classification system to a supply chain and material cycle perspective. A recent proposal submitted to Eurostat to improve the Prodcom codes in line with the HS codes is considered a positive move. However, further amendments and expansions will be required to accurately reflect the supply chain;
- Advance the development of relevant metadata and explanatory notes that place data in a system context, with an aim to facilitate the harmonisation between production and trade statistics This will require the reporting of statistical data in a system context (e.g explicit reference point in supply chain);

For production and trade statistics:

- Undertake in-depth analysis of problems around data reporting, their origin and impact on data;
- Establish procedures within National Statistics Offices that better link production to trade statistics and provide better data resolution for minor metals.
- Develop guidance and training for customs offices and statistics offices to assist the reporting of physical datasets.

2.3 Physical accounting of anthropogenic stocks

Goal: Monitoring of anthropogenic stocks

Anthropogenic stocks refer to the built environment and provide the physical means/services to satisfy human needs. The total amount of material we store in our society reflect our level of economic development and determines the level of well-being. anthropogenic stock comprises buildings, roads, rails, vehicles, consumer durables, electronic equipment and so on. Having an understanding of the amount of materials residing in our anthroposphere is important because:

- They determine the energy and GHG emissions needed to maintain our current standard of living. Our anthropogenic stocks are the drivers for our indirect and direct energy and material use, and they determine the present and future patterns of energy use and their related emissions.
- They provide an extensive reservoir of secondary raw materials that could be recovered via urban mining;
- They remain in use for many years or decades, leading to spatial and temporal lock-ins in socioeconomic development.

Anthropogenic stocks can be calculated by two different approaches. Top-down in which the change in stock is the difference in inflow and outflow over time. This provides temporal patterns of the stocks usually at a global or national level. Through the bottom-up approach each individual piece of the stock is accounted for providing a finer level of resolution of the stock. Recent spatially refined studies aided by new types of data or methods (e.g. the use of remote sensing data and integration with economic models) allow for even higher resolution both temporally and spatially. The current terminology, units and classification of anthropogenic stocks are not consistent. Data on key parameters, such as product lifetime, material intensities and trade data are in general quite scarce and does not currently allow us to understand when and where potential future resources are available. In addition, a consistent framework for reporting data on anthropogenic stocks is missing. Integration of the top-down and the bottom-up approach for the calculation of anthropogenic stocks is required to improve the current resolution of accounting methods. EU projects such as ProSUM and MINEA have contributed towards this goal with the development of new data and an extension to the UNFC framework classification to accommodate anthropogenic stocks.

Recommendations

- Develop a standardised methodology and framework for physical accounting of anthropogenic stocks.
- Produce additional data on anthropogenic stocks by promoting the development of city-level datasets and the use of techniques and tools, such as remote sensing, GIS, 3D city models and others.
- Synthesise existing studies and facilitate harmonisation and glossary development in physical accounting of anthropogenic stocks;
- Integrate top-down, bottom-up, and other approaches to improve resolution and accuracy of anthropogenic stock accounting.

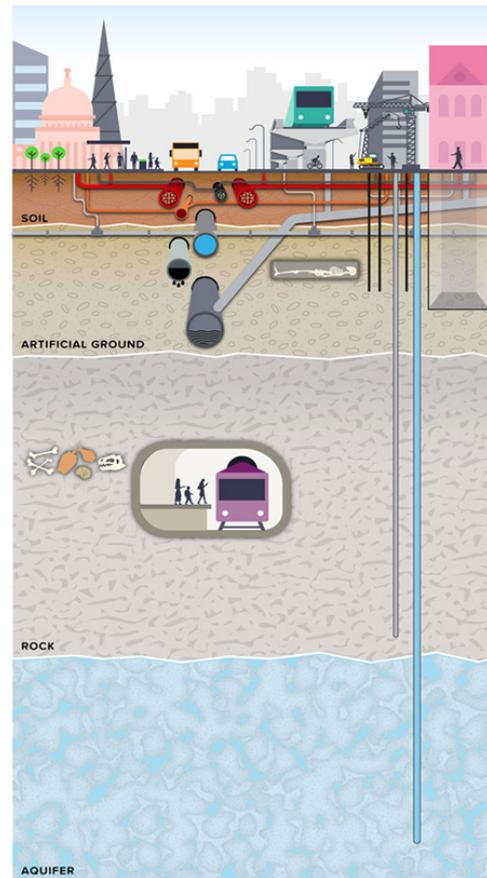


Figure 3: Anthropogenic stocks in the built environment.
FutureCitiesCatapult © 2017.

2.4 Physical accounting of companies

Goal: Incentivise companies to implement physical accounting

Companies collect enormous quantities of resource data, from real-time process control readings (every few seconds for every valve and sensor) to environmental and cost management data. This data is used to keep processes operating safely, maintain products within specification, ensure environmental compliance, and manage labour, capital and resource inputs on site. However, the systems view of resource flows and interactions, which was known when plants were designed and originally operated, is inevitably lost later on during routine use. Data is available within individual companies, but the necessary system-understanding and modelling capabilities are missing, limiting the options for identifying and communicating resource efficiency savings. Compounding this issue is the loss of experienced process control engineers from sites, as cost saving programmes are implemented.

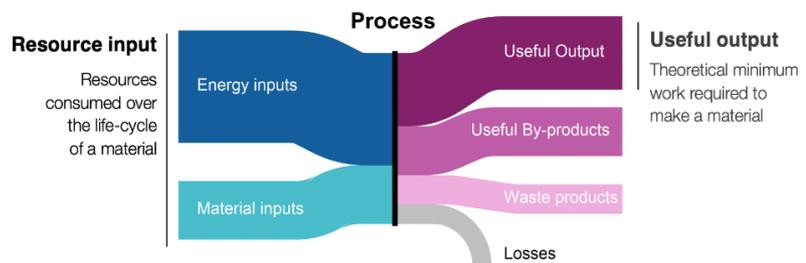


Figure 4: The resource efficiency metric compares the useful output to the total resource input, for both energy and materials.

Recently, several process solution companies, have begun to leverage control data under the banner of the digitalisation and the Industry 4.0 themes⁶. This includes focusing on single process units to identify hotspots for improvement, and benchmarking between sites to highlight best practice. A growing body of evidence shows that the potential for reducing emissions using material efficiency options is of similar magnitude to energy efficiency options⁷. The key to unlocking this potential is to understand how resources flow through and interact in industrial processes.

A key challenge to improving resource efficiency is analysing process interactions between energy and material flows to identify integrated resource efficiency savings, which are normally overlooked. New metrics and analytical approaches are required to characterise trade-offs between energy and material efficiency options, to avoid simply shifting the problem.

A second barrier to improving the resource efficiency of industrial sectors is the reluctance to share resource data between firms. Data confidentiality makes the study of resources by academics, and the identification of potential savings at the country level, difficult. This is in contrast to financial data, which is reported publicly on a regular basis under strict financial accounting rules.

Recommendations

- Make use of bottom-up real-time data from process control systems to build a resource flow picture for industrial plants, to optimise plant performance and benchmark processes across similar operations. Future industry-based projects to support the use of real time data will be beneficial for promoting physical accounting in companies. For example, this could be promoted further through an industry competition (e.g. by EIT-Raw materials), asked to demonstrate resource efficiency gains through physical accounting.

⁶ Industry 4.0 refers to the fourth industrial revolution. The term describes current automation processes integrated with data exchange in manufacturing technologies.

⁷ <http://www.withbotheyesopen.com/>

- Integrate the results from many operations at the country and regional level to monitor industrial progress, set resource efficiency targets and identify opportunities to invest in resource efficiency
- Modify Climate Change Frameworks (EUETS) to allow emission reductions from resource efficiency to be counted alongside renewable and CCS decarbonisation options.

2.5 Physical accounting in governments

Goal: Refined monitoring of the physical economy at National level

An increasing number of national governments formulate goals with respect to material consumption and implement official economy-wide material flows analysis (EW-MFA). The majority of official monitoring systems use the standard resolution of 12 to 56 raw material categories, with relatively few categories describing minerals and metals. Some monitoring systems additionally employ economic input-output models for calculations.

Apart from the economy-wide material flows accounting, some important actions towards material flows analysis are taking place including the work undertaken by the US EPA⁸, individual geological surveys (e.g. USGS, BGS) and the EC 'Study on Data Inventory for a Raw Material System Analysis'⁹.

The current official monitoring EW-MFA system have severe limitations:

- Supply chain stages are not differentiated, trade information are not detailed enough, additional layers (e.g. on energy) are missing, and the time dimension is not available.
- Material resolution, particularly with regard to metals and minerals and with regard to secondary materials, is not sufficient;
- The disaggregation level of employed economic models does not allow monitoring of material flows in economic sectors and in the use stage;
- The use of monetary prices in the models does not necessarily properly reflect the physical material flows. This leads to misleading results particularly when non-metal minerals and secondary materials are tracked.

The activities of other organisations in other countries, are not based on a unified framework and cannot readily be integrated. Better understanding of the whole system of material flows is required to inform robust strategy and policy development. For example, detailed monitoring systems based on empirical data with high quality and resolutions are required to better understand sectoral consumption, material dematerialisation, circular economy, resource dependencies and others.

Recommendations

We recommend developing further current official monitoring systems at the national level through:

- Increasing the resolution of existing models by moving towards detailed material flow analysis, where all materials, including minor-metals are tracked systematically across their cycle;
- Using physical units, for example in hybrid physical-monetary input-output models, to represent the physical dimension of material flows of an economy;
- Ensuring coordination of activities by different national authorities, for example statistic offices, geological surveys and environment agencies, to maximise the benefits of material flows analysis for natural resources management and environmental protection

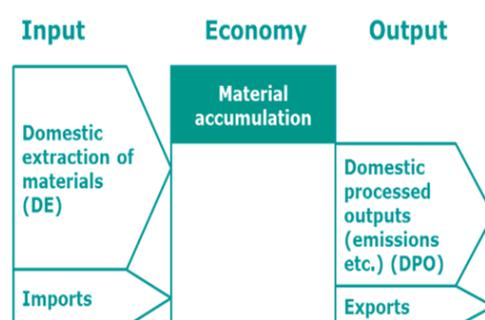


Figure 5: Economy-wide material flow accounts model

⁸ USEPA Sustainable Materials Management Programme Strategic Plan for Fiscal Year 2017-2022.

<https://www.epa.gov/smm/epa-sustainable-materials-management-program-strategic-plan-fiscal-years-2017-2022>

⁹ https://ec.europa.eu/growth/content/study-data-inventory-raw-material-system-analysis-0_en

3 Implementation of physical accounting

3.1 Coordinating efforts for global monitoring of the physical economy

Goal: Global monitoring the physical economy

According to the International Resource Panel, natural resources accounting should become common practice to ensure that the Earth's assets are utilised and valued properly. This in turn can lead to more robust forecasting and assessments of future material supply and demand¹⁰.

Traditionally, governmental agencies monitor different aspects of the physical economy and no single institution has the mandate to monitor the physical economy as a whole. Often, assessments are project and site based and they ignore the cumulative global impact across the entire value chain. At present geological surveys collate mineral reserves and mine production flows, environmental

protection agencies monitor specific waste and emission flows, while tax and statistical offices measure trade flows. These institutions have an overview of their own individual parts of the system, but, they do not see the totality of the system they operate within. In addition, many institutions often only operate on a national level, whilst the problems we are facing are global and therefore require global solutions.

The establishment of a stand-alone institution with a mandate to monitor the physical economy at the global level is an important essential goal. Such an institution, whether a new body or incorporated within an existing institution would have a major role to play in coordinating efforts amongst multiple players. .

Recommendations

We call for the establishment of a high-level working group with the aim of evaluating institutional options to coordinate the monitoring of the global physical economy, including legal frameworks and data infrastructures. Our recommendation is endorsed by the International Resource Panel, which has suggested the need for an international coordinated action to establish a body with a similar role to that of the International Energy Agency¹⁰. Other organisation, such as the OECD, IEA, UNSD IGF, and UNECE could play an important role in establishing such a group.

Other initiatives, including the recommended World Forum on Raw Materials from the EU H2020 FORAM project and the International Raw Materials Observatory may also contribute to the development of the high-level working group.

The working group should also assess the need for linking material use to the use of energy and greenhouse gas emissions and help to coordinate efforts of reporting between the different governments.



Figure 6: Physical economy in the global context [Photo by Slava Bowman on Unsplash]

¹⁰ <https://www.unenvironment.org/news-and-stories/story/mineral-resource-governance-21st-century-conversation-antonio-pedro>

3.2 Legal interventions

Goal: Legal interventions for the development of data infrastructure for physical accounting.

Current legislation and its implementing frameworks for the accounting of stocks and flows is centred on monetary units, or on isolated physical flows and remains highly fragmented. The EU INSPIRE Directive stands out, as a good example of data harmonisation, interoperability and standardization setting a common framework and implementation rules to ensure compatible spatial data across all EU Member States. The key challenges for the implementation of physical accounting at EU and national levels are given below.



Figure 7: The INSPIRE Directive – an infrastructure for spatial information in Europe.

At EU level:

- Lack of sufficient legislation for detailed tracking of physical flows of materials. Different data collection systems like PRODCOM, ITGS, EW-MFA are not linked to each other;
- Lack of European legislation requiring the collection of data in a standard, harmonised and interoperable way with a system-based perspective.

At national level:

- Mineral policy frameworks do not encourage data collection from a systems-based perspective;
- Data collection of primary and secondary raw materials (production, trade, recycling) is not coordinated or centralised.

Recommendations

At EU level:

- Eurostat through the European Statistical System Committee (ESSC) should initiate discussions on how to improve the physical accounting at EU level, using the MINFUTURE findings and recommendations, and involving its global network of partners.
- The EC should consider preparing a Communication (COM) on the importance of improving the accounting of the physical economy for better informing policy formulation and monitoring, according to the gaps identified by the MINFUTURE project.
- The EC should evaluate the possibility of either amending the existing INSPIRE Directive, or preparing a new Directive that requires monitoring of the physical economy of each EU Member State. The focus should be on the monitoring of whole material cycles from cradle to cradle rather than individual physical flows. Open access to data and incentives for data sharing should be an inherent component of any option taken forward.

At national level:

- National policies and strategies should clearly require and/or provide incentives to Member States to collect data from a systems-based perspective and in a harmonised way.

3.4 Financial investment

Goal: Attract financial investment to implement physical accounting

Governments invest considerable amounts of money for compiling, analysing and maintaining statistical data. Some governments that place particular importance on statistical research and make use of statistics in policy development and decision-making, continually invest in enhancing them. The financial budget provided to physical accounting is currently directed towards economy-wide material flow accounts (EW-MFA) only, which serve a different role to the physical accounting proposed by MinFuture.

Additional budgets are required to enable the monitoring of the physical economy, beyond the EW-MFA scope. Without such investment, we will remain unable to understand and resolve problems that relate to the physical economy/socio-economic metabolism. National accounts, EW-MFA and existing statistical datasets today are not explicit enough to provide the level of detail needed for mass-balance consistent physical accounting. Several individual projects, funded by national, EU or global sources have explored material flows in detail and have produced important findings. However, their approaches are not consistent or systematic and any benefits delivered largely cease when the project is completed. This undermines the value of the research undertaken and ultimately results in financial loss. At the company level, monetary accounting is common practice. Systems to monitor physical flows and stocks of materials, may be available, but are rarely in the public domain.

The main challenge is the provision of funding for the development of procedures to monitor the physical economy all the way from the company level up to the country and global levels. This will require funding from companies and governments towards the development of systems, data, databases, and training, in addition to legal or motivational incentives to ensure implementation. The investment should aim for a 'structural' transformation of the way national accounts are developed, rather than being project specific and therefore of limited scope. Financial provisions to all linked data providers should be made to allow adjustments to existing procedures, datasets, database tools etc.

Recommendations

The financial investment needed to accommodate a move towards physical accounting is anticipated to be substantial at the beginning of the process. This will ensure that all key players involved have developed capabilities, systems, tools and data, such that adequately trained staff can collect and report data with a system context. Once procedures are in place, the physical accounting becomes straight forward and the maintenance cost is expected to drop substantially. Some base funding will be required in the longer term for maintaining and adapting the system and data, for updates, enhancements, and the development of scenario models and other derivative products from physical accounting.

As a first step, it is important to undertake an analysis to prove the hypothetical investment curve and to provide evidence that the overall benefits that, in the longer term, the overall benefits will outweigh the initial investment made. This analysis can take place through the development of case studies at the company, national and global levels.

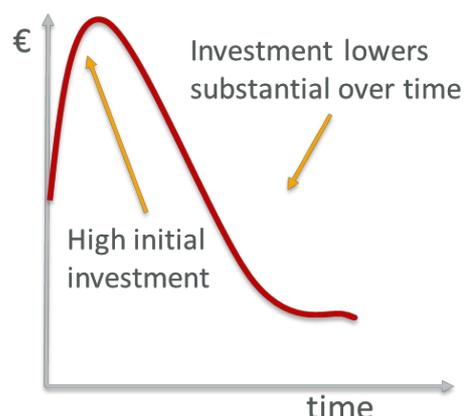


Figure 9: The hypothetical trajectory of financial investment needed over time to move towards physical accounting.

3.5 Education and training

Goal: Skilled personnel that can deliver physical accounts in a systematic manner

It is not common practice for data providers to report physical data with a system context. Their understanding of material flow analysis, the development of systems and the mapping of data in a system is often alien to them.

Economy-wide material flow analysis (EW-MFA) includes the only systematic action taken for reporting data with a system context. However the systems and data used in EW-MFA are highly aggregated and do not provide detail on individual commodities that require expert knowledge.

Training in MFA is available through a few academic courses for undergraduate and postgraduate studies only.

There are no professional training courses currently available to assist government authorities and industry to develop systems and support the reporting of data in system context.

The use of MFA to investigate issues with societal metabolism is currently undertaken by the research community only, with limited interactions with data providers and industry to test and validate their models.

Adequate training will be required to become for all bodies, whether industry or government authorities, involved in the reporting and provision of data to enable the development of systems and data with system context. This includes a substantial number of organisations, which will require tailored training and support to facilitate the transition to physical accounting. Sufficient financial support, technical tools, revised data collection and reporting frameworks will be essential to support training needs.

Recommendations

- Tailored training will be required to support public authorities, statistic offices and the industry for the development of systems and data with system context.
- The MFA academic community will need to play an important role in the development of tailored training courses and tools.
- National governments should invest in the development of 'in house' training to assist with day-to-day issues and practical queries.

At the EU level, the European Commission should make funds available for projects that deliver training to Member States and industry.