Ref. Ares(2018)6154041 - 30/11/2018

MinFuture

D2.2 Challenges, systems and data

Synthesis report

MinFuture is funded by the Horizon 2020 Framework Programme of the European Union under Grant Agreement no. 730330. The contents of this document are the sole responsibility of MinFuture and can in no way be taken to reflect the views of the European Union

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With thanks to:

All MinFuture partners

Manuscript completed in November 2018

Document title	D2.2 Challenges, Systems and data
Work Package	WP2
Document Type	Deliverable
Date	30. November 2018
Document Status	Final version

Acknowledgments & Disclaimer

This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 730330.

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1 Introduction

Material cycles has grown increasingly complex throughout the years, fuelled by globalization, changing demographics, technology, environmental concerns and our political environment. Our supply chains have increased in complexity together with the increased material complexity of our products. This has further led to an increased dependency on mineral raw materials within the European economy.

If we are to be able to solve many of today's large challenges, we need to be able to restructure the physical economy (PE). Enabling this task requires that we are able to systematically monitor the physical economy. Currently, we are focusing on the monitoring of the monetary economy and our understanding physical stocks and flows that constitutes our physical economy is limited.

The MinFuture project has developed a framework that provides a proof of concept for robust monitoring of the physical economy in four dimensions (1) Stages, (2) International trade, (3) Layers and (4) Time. Together with recommendations for the monitoring of the physical economy, see deliverable 5.1 and 5.3.

The framework contains seven components that forms a pyramid, see Figure 1. Systems forms the foundation of this pyramid and together with data these two components provides the necessary basis to go further up the pyramid. As Systems and data forms the foundation, they are particularly important if we aim to have robust models, scenarios, visualisations and indicators that can be used for policy and decision support.

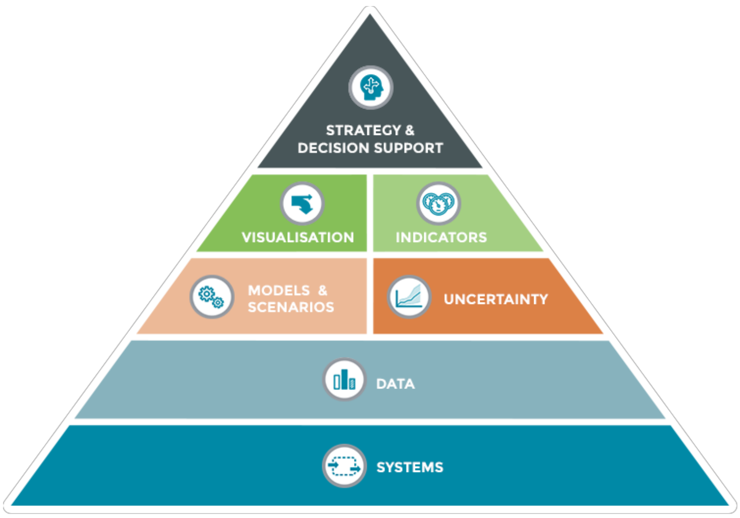

Figure 1: MinFuture Framework of MFA components.

Currently, we are limited by a poor system understanding and limited data availability, this is especially the case for the raw materials on the critical raw materials list (European Commission 2017). The publicly available data is highly fragmented not harmonised and only allows certain areas of the physical economy to be monitored and not the whole system.

The objective of this report is to emphasize the importance of putting raw materials data into a system context and demonstrate how statistical data with a system context adds information. The layout of the report is as follows, we will first go through the challenges, interventions and dimension then we will look more in detail into systems and data. The report finishes with the key monitoring principles that show the importance of providing a system context to the data.

2 Challenges, Interventions & dimensions

2.1 Increasing need for monitoring the physical economy

Raw material related issues have become a focus area of international policy. There is an increasing complexity of global challenges such as climate change adaption and mitigation, coupled with concerns about raw materials criticality, supply chain security, and, among many other problems, increasing waste production, emissions, and ecosystem degradation. Addressing and resolving these challenges requires a good understanding of how, where and when materials are produced and processed, used, and discarded, and how this influences the global physical economy (also called the socioeconomic metabolism or SEM) over time.

The European Union – and many countries in general – have not yet developed the required tools and institutional capacity to anticipate future raw-material related threats, to systematically identify the underlying problems and opportunities, and to develop models and scenarios that analyse the impacts of possible intervention options. To navigate the raw material challenges, it is a necessity to (1) integrate existing data into a systems context, to (2) close relevant knowledge gaps, and (3) to facilitate model building and scenario analysis, which in turn inform strategic policy- and decision-making.

With the **Raw Materials Initiative (RMI)**, the European Commission (EC) has formulated a pan-European EU raw materials policy strategy (European Commission 2008). The RMI is substantiated by the **European Innovation Partnership on Raw Materials (EIP-RM),** under the auspices of the European Commission DG GROW (Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs), as a stakeholder platform that brings together the entire raw materials community to provide high-level guidance to the European Commission, Member States, and private actors (European Commission 2012). To support the implementation of its general objectives the EIP-RM in 2013 adopted a **Strategic Implementation Plan (SIP)** (European Commission 2013) that sets out 95 concrete Actions structured into 24 Action Areas and 7 Priority Areas, which align with 7 common Targets for 2020 (**Error! Reference source not found.**). Further to formulating t he SIP, the EIP-RM launched additional calls for **Raw Materials Commitments** that invite voluntary actions to reach the SIP Objectives.

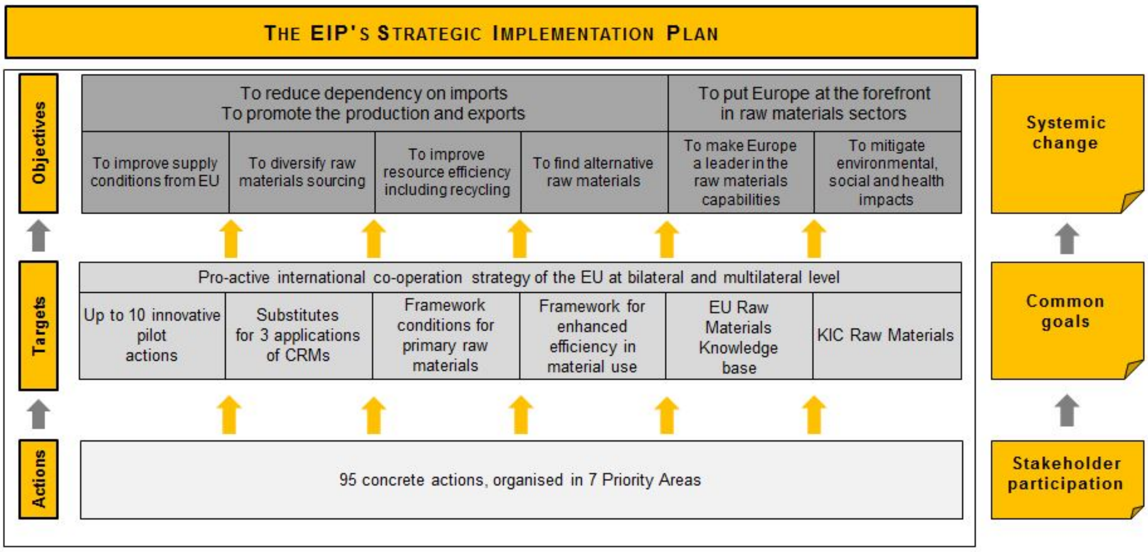

Figure 2: The Strategic Implementation Plan (SIP) outlines the Actions, Targets and Objectives of the European Innovation Partnership on Raw Materials (EIP-RM) for 2020.

The RMI and SIP have been instrumental in setting an international EU action plan and mobilising European research and innovation (R&I) for raw materials. Through the **Seventh Framework Programme FP7** (2007-2013) and its follow-up **Framework Programme Horizon 2020** (2014-2020)[1], the EC has dedicated significant research efforts and funds to addressing the raw material challenges[2,3]. In Horizon 2020, the Societal Challenge 5 (SC5): "Climate action, environment, resource efficiency and raw materials" explicitly addresses raw materials; it aims to boost innovation in the EU raw materials sector, and to develop the full potential of primary and secondary raw materials. Further to this, the European Commission's independent **European Institute of Innovation and Technology (EIT)** in 2014 initiated a KIC (Knowledge and Innovation Community) for raw materials, the **EIT Raw Materials**[4]. The EIT Raw Materials brings together the knowledge triangle of business, education, and research centres to ensure the accessibility, availability and sustainable use of raw materials for sustainable European economic growth and global competitiveness.

Overall, EU raw materials efforts have led to a wide array of successful research and innovation projects[5] that have strengthened the raw materials base in Europe. The EIP Strategic Implementation Plan with its three pillars (1) technology, (2) non-technology, and (3) international cooperation, targeted non-energy, non-agricultural raw materials though specific project calls, which helped to unite more than 652 European project partners around more than 56 raw materials projects (see overview over H2020 raw material actions: https://sc5.easme-web.eu/?theme=green, with Topics filter "raw materials").

Albeit having accomplished a major step forward for many issues related to understanding and securing the EU raw materials base (see e.g. EIP High-Level Steering Group 2016b;

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1 http://ec.europa.eu/programmes/horizon2020/en/area/raw-materials
2 https://ec.europa.eu/research/participants/portal/desktop/en/projectresults
3 For critical raw materials, see e.g. review by Løvik *et al.* (2018).
4 https://eit.europa.eu/eit-community/eit-raw-materials
5 https://www.securityresearch-cou.eu/sites/default/files/Theme6-16-00%20EIP%20Raw%20Materials_Milan%20Grohol.pdf

DG Growth 2018), an overall synthesis framework to integrate individual efforts and assist long-term policy development is still lacking.

Because neither the existing raw materials strategy, nor the platforms and research programmes consider raw materials in a holistic system context of interconnected physical stocks and flows, there is a lot of remaining synergy potential across the actions. **Raw materials information is still fragmented** across projects and stakeholders, which means that even though it is easy to understand that an adjustment of any one raw material sector or target indicator will likely change the entire stock and flow balance of the physical economy, there is no institutional capacity to analyse the response of the whole system. In consequence, individual targets and policy efforts may be counterproductive or eliminate each other, thus harming the overall raw material situation in Europe. **Error! Reference s ource not found.** showed how the SIP actions align with targets to support the objectives, but it also reveals that individual objectives are interdependent; efforts to improve supply conditions in Europe, for instance, will decrease the urgency to diversify materials sourcing, and ease the need to search for alternative raw materials. Unless there is a holistic systems monitoring that bridges the isolated silos of knowledge, there is, simply put, no robust way to analyse whether a specific action contributes to or hinders overall progress.

What is needed is an understanding of the whole system of raw material stocks and flows in four MFA dimensions: across all **stages** of the physical material life cycle, integrating **trade** information, resolving **layers** of interacting materials, and covering **time**, both historically and prospective.

Table 1, llustrates that none of the Action Areas outlined by the SIP[6] explicitly and fully integrate all of the four MinFuture dimensions (Stages, Trade, Layers and Time). The results were compiled by analysing the descriptions of the respective Action Areas for keywords and references that relate to the four dimensions, e.g. "value chain", product "life cycle", or production "stages" for the "stages" dimension.

Table 1: Mapping the 24 Action Areas of the Strategic Implementation Plan (SIP) of the European Innovation Partnership on Raw Materials (EIP-RM) and the MinFuture dimensions they target (+ indicating strong, and (+) partial focus).

EU Policy interventions and their integration of MFA System dimensions				
SIP Action Area	**Stages**	**Trade**	**Layers**	**Time**
I.A. Research and innovation coordination				
I.1. Improving research and innovation coordination	+		+	(+)
I.B. Technologies for primary and secondary RM production				
I.2. Exploration				
I.3. Innovative extraction of raw materials			(+)	
I.4. Processing and refining of raw materials	(+)		(+)	(+)
I.5. Recycling of raw materials from products, buildings and infrastructure	(+)		(+)	
I.C. Substitution of raw materials				
I.6. Materials for green energy technologies			(+)	+

[6] Table with hyperlinks; see also https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/content/strategic-implementation-plan-part-ii#I.A.%20Research

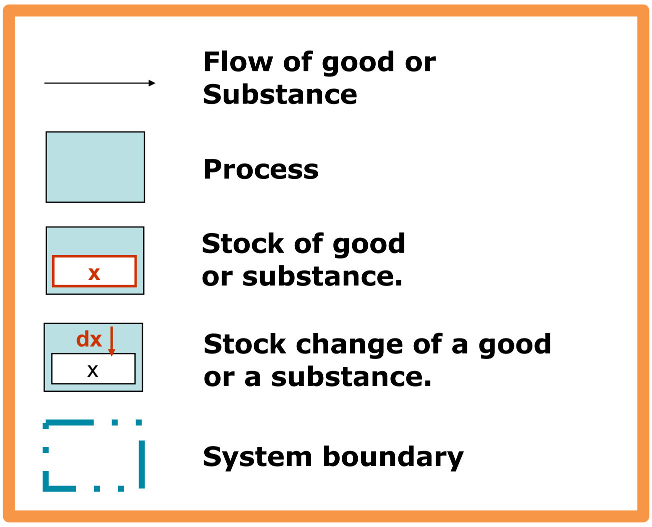
I.7. Materials for electronic devices			(+)	+
I.8. Materials under extreme conditions			(+)	
I.9. Applications using materials in large quantities				
II.A. Improving Europe's raw materials framework conditions				
II.1. Minerals policy framework		+		+
II.2. Access to minerals potential in the EU				+
II.3. Public awareness, acceptance and trust				
II.B. Improving Europe's waste management framework conditions and excellence				
II.4. Product design for optimised use of (critical) raw materials and increased quality recycling	(+)			(+)
II.5. Optimised waste flows for increased recycling	(+)	(+)	+	+
II.6. Prevention of illegal waste shipments		+		
II.7. Optimised material recovery				
II.C. Knowledge, skills and raw materials flows				
II.8. EU raw materials knowledge base	+	+		+
II.9. Possible EIT knowledge and innovation community	+			
II.10. Optimised raw material flows along val. chains	+		(+)	
III. International cooperation				
III.1. Technology	+		+	+
III.2. Global raw materials governance and dialogues	+	+		
III.3. Health, safety and environment		+		
III.4. Skills, education and knowledge		+		+
III.5. Investment activities		+		+
	9/24	8/24	10/24	12/24

In collaboration with the EC's Science and Knowledge service (the Joint Research Centre JRC) the EIP-RM in 2016 launched a biannual publication to provide quantitative data on SIP progress in the **Raw Materials Scoreboard**. Both the Raw Materials Scoreboard and the **EIP's Strategic Implementation Document (SIPID)**(EIP High-Level Steering Group 2016a) show the progress towards EIP Objectives, but also indicate that a robust monitoring is still lacking. The EIP's High-Level Steering group recognises the need for further work on an integrated raw materials policy framework in its **Strategic Evaluation Report 2016** (EIP High-Level Steering Group 2016b), and in the recently published **Position Paper on Future Orientations** (EIP High-Level Steering Group 2017). Particularly noteworthy is the SIP action area III.4 explicitly calling to "Establish a monitoring system for material flows (including end of life products) possibly through an international agency on material flow analysis or depositing this task with an existing body", which reflects the observations and recommendations of MinFuture.

MinFuture is designed to facilitate a better systems understanding and monitoring of the global physical economy and its material stocks and flows to support development of better decision-making tools for raw material demand and supply forecasting. In addition, the MinFuture framework provides methodological guidance for the development of the European Commission's **Raw Materials Information System (RMIS)** with its **Raw Materials Knowledge Gateway (RMKG)**. The European Commission designates the RMIS as the central reference knowledge platform and information gateway for non-fuel, non-agriculture raw materials from primary (extraction/harvesting) and secondary (recycled/recovered) sources. Although the RMIS has a strong material flow analysis component, it is not yet capable of monitoring the physical economy. Additional cross-cutting efforts are required to create an internationally accepted framework and infrastructure to facilitate this.

3 Systems

Defining systems is one of the core concepts of MFA and are one of the first tasks performed in an analysis. Systems represents maps of the stocks and flows that constitutes our economy. System definitions connects the sources, transformation and the sinks (processes and stocks) through the routes travelled by a material (flows) and allows, depending on the purpose of the system, for the ability to have an overview of the entire material cycle. MFA systems are always defined for a given temporal and spatial boundary and all systems should obey the law of conservation of matter (Baccini and Brunner 2012). The main symbols used in MFA are shown in Box 1.



Box 1: Main symbols used in MFA.

MFA systems are always defined for a purpose. This can be to understand the trade linked cycle of aluminum (Liu and Müller 2013b), the building stock (Brattebø et al. 2009), investigating the recycling potential of aluminum in the vehicle stock (Løvik, Modaresi, and Müller 2014) or to quantify the use of cobalt in our economy (Harper, Kavlak, and Graedel 2012).

Systems can be aggregated and disaggregated based on the purpose, however, when using highly aggregated systems such as Economy-wide Material Flow Accounts (EW-MFA) (EUROSTAT 2013), it is not possible to understand what occurs inside the economy itself. EW-MFA essentially models the economy as a "black box", only regarding the inputs and outputs, imports and exports and not the transformation processes within, see Figure 3.

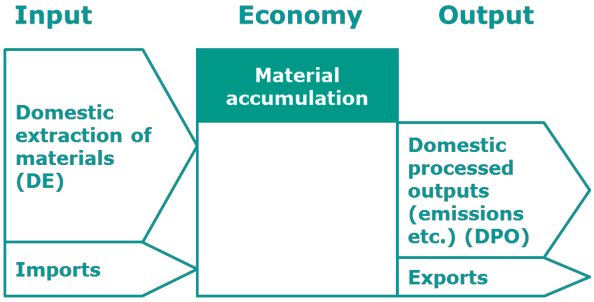


Figure 3: Example of EW-MFA, figure from (Eurostat n.d.)

With the challenges that we are currently facing we need more disaggregated models are needed, especially if we want to enable a robust monitoring of the physical economy. A higher level of disaggregation allows us to monitor aspects of the economy that are especially important. In the example below the global cycle of aluminium is shown (Liu and Müller 2013a). By using more aggregated systems we are able to have an overview of the entire value chain of aluminium. When such a system is quantified, we can further gain an understanding of the material efficiency, the amount of scrap that is available for recycling and we can find avoidable losses throughout the value chain. Such systems can be used for early recognitions of future stocks and flows, and priority setting.

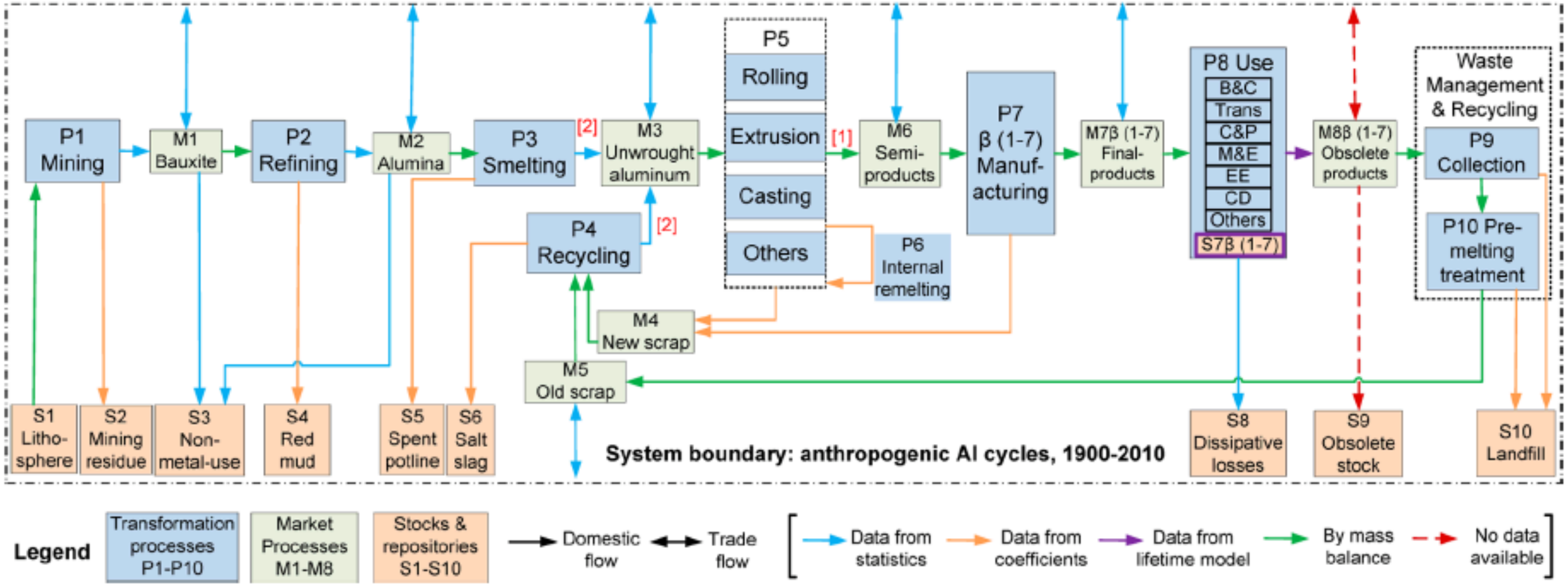
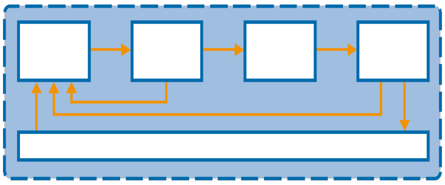
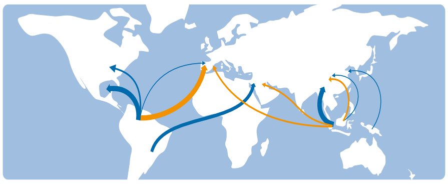


Figure 4: The global cycle of Aluminium (Liu and Müller 2013a)

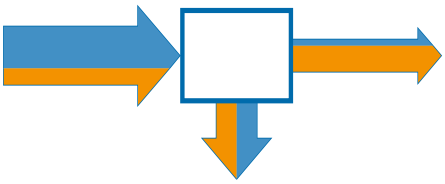
Within the MinFuture project we focus on four dimensions (1) Stages, (2) Trade, (3) Layers and (4) Time. For the development of systems three of the dimensions apply, (1) Stages which represents the various transformation and use stages that occur through the materials cycle. (2) International trade, which allows us to understand raw material dependencies and how countries are linked through the supply chain of the materials. And (3) Layers, that explores the interactions and changing characteristics of materials throughout their life. Systems do not have a time dimension as our system understanding does not depend on time.



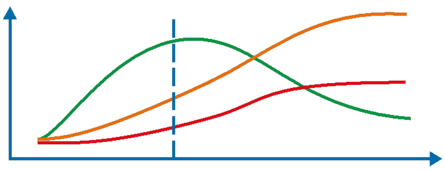
Stages
Track material stocks and flows along the supply chain



Trade
Track material stocks and flows in international trade of goods along the supply chain



Layers
Track individual components of goods and their linkages (materials, energy, value)



Time
Historical development and future scenarios

Box 2: MinFuture dimensions

It needs to be acknowledged that these dimensions do not exist in isolation and are interdependent. In the trade dimension we acknowledge the fact that material cycles have globalized value chains and connects this to the stages dimension through the use of markets. Whilst for layers we explore the fact that no material exists in isolation, either in the mineralogy of the ore, the products they are embedded as some examples. With the use of layers we can further explore these linkages throughout the stages and better understand how materials are linked which specifically are useful for the case of recycling in which the materials needs to be separated again. Improvement in our systems needs to occur along all of the above-mentioned dimensions related to systems.

As the purpose of the current monitoring and reporting does not encompass the physical economy, the focus lies on the monetary economy. For the physical economy, governments tend to focus on the monitoring of isolated flows such as production, apparent consumption and so on, not on the system itself. The current monitoring is inefficient and does not fit the purpose of being able to monitor the physical economy.

Systems can be seen as maps of the physical economy that can provide a coordinate system in which we can more accurately place the reference points for measurements (data). In the following sections, we will look at how data placed in system context can add information and how the development of robust systems can enable the monitoring of the physical economy.

4 Data

Data represent observations of either stocks (at a given point in time) or flows (over a given time period). Enabling an efficient monitoring of the physical economy is a data intensive task and requires data along the entire supply chain across regions and across nations. However, the data currently needed for compiling material cycles are often fragmented, inconsistent and it is not harmonized. In the MinFuture framework, data comes after systems since a system can be developed without the use of data. However, data without a system context does not add any information.

Rather than designing the systems to fit the data, we need to do this the other way around. Systems needs to be designed first, then the available data needs to be placed correctly within the system. Nevertheless, data currently represent a challenge for MFA practitioners due to the lack of system context, fragmentation, lack of harmonization and the lack of digital infrastructures.

4.1 Data within a system context

The collection of data is done by several governmental agencies and for a variety of purposes. As an example, trade data is collected for taxation purposes and production data is often collected for a countries national accounting. To compile material cycles data is collected from national statistical offices, international trade statistics databases, geological surveys, industry associations and industry. None of the data needed in the monitoring of the physical economy is currently collected for the purpose of monitoring the physical economy.

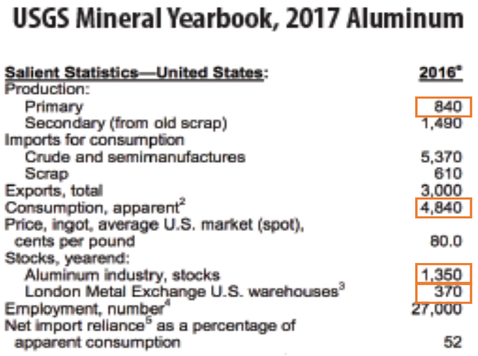
As a consequence of this, the data used often have different reference points since the data points are not collected with a system context. By system context we mean that we do not exactly know where in the system the measurement has taken place, which flow or which stock that has been measured. Consequentially, MFA practitioners need to gather data from a variety of sources, interpret the data and place them to the best of their abilities within a system. The implication of this is ambiguous datasets that cannot properly represent the "real" system and cannot be used to their full potential in MFA without introducing assumptions on their definition.

Wrongly interpreted data is a challenge for MFA practitioners. An example of challenge is illustrated in Box 3, in which two systems are shown for aluminum. The first system is on a very aggregated level and the second system is on a more refined level. Here we have taken data on aluminum from United States Geological Survey (USGS) with the aim of placing the measurements onto the different systems. Due to the first system being on such an aggregated level it is not clear which measurement that should be placed on the flow between production and manufacturing. This could either be production or apparent consumption which differ in their magnitude. However, in the refined system, several of the reported measurements can be placed. In addition, in the refined system we are able to show our data gaps explicitly in addition to showing what we do know.

To be able to monitor the physical economy in a consistent matter data needs to be collected and provided with a system context in mind. Reporting data within a systems context adds information and increases the robustness as it provides coordinates to the measurement.

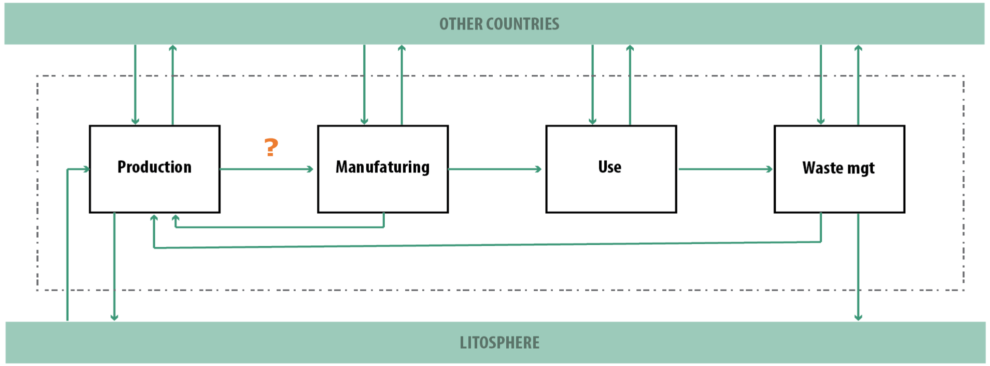
From “crude maps with hidden gaps” to “refined maps with explicit gaps”

Systems often don’t reflect reality of data collection. Aggregated systems can nevertheless be useful for providing a crude overview, but relevant information is lost.

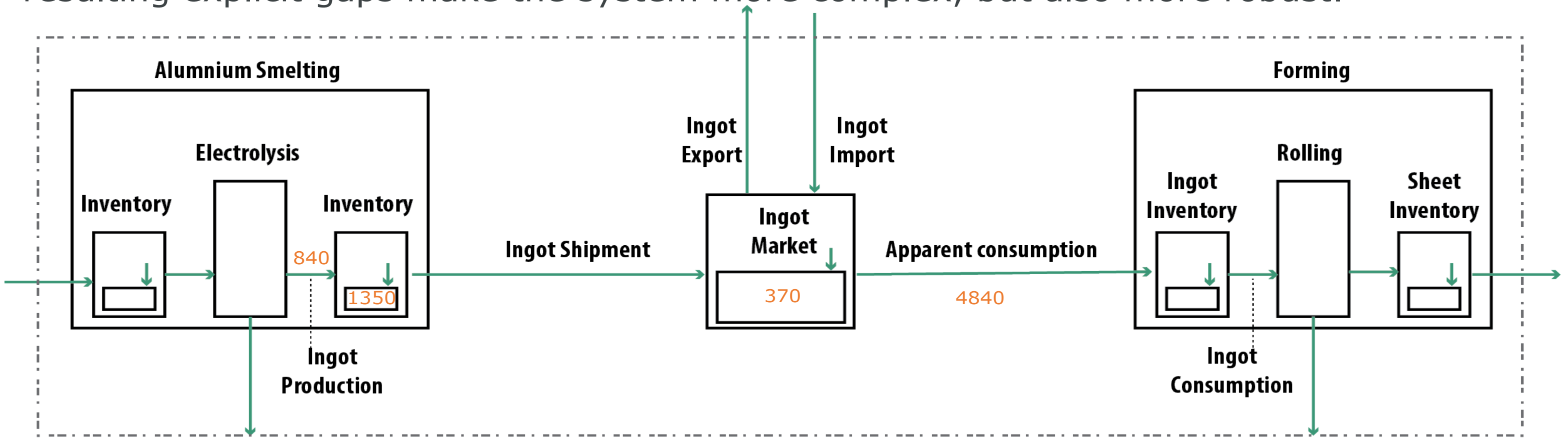


USGS Mineral Yearbook, 2017 Aluminum

Salient Statistics—United States:	2016[e]
Production:	
Primary	840
Secondary (from old scrap)	1,490
Imports for consumption	
Crude and semimanufactures	5,370
Scrap	610
Exports, total	3,000
Consumption, apparent[2]	4,840
Price, ingot, average U.S. market (spot), cents per pound	80.0
Stocks, yearend:	
Aluminum industry, stocks	1,350
London Metal Exchange U.S. warehouses[3]	370
Employment, number[4]	27,000
Net import reliance[5] as a percentage of apparent consumption	52



Refined system definitions can be made to reflect the exact location of the measurements. The resulting explicit gaps make the system more complex, but also more robust.



Box 3: Issues with data use in crude systems vs the benefits of a refined system.

4.2 Fragmentation and harmonization of data

When data is not collected or reported with a system context in mind it is challenging to interpret and place data within a system. Data used for MFAs are currently highly fragmented. In Figure 5 below, this is illustrated by the different colored flows. Data for extraction and production can be found using national statistics, statistics from geological surveys or through trade statistics. Some numbers regarding end-of-life recycling can be found through national statistics and geological surveys, but the data availability here can depend on the material in question. However, it is important to notice that for the majority of the data from national statistics the metal content needs to be estimated in order to provide a consistent substance or material layer. E.g. the aluminum content in a car needs to be estimated from the number of cars produced or traded.

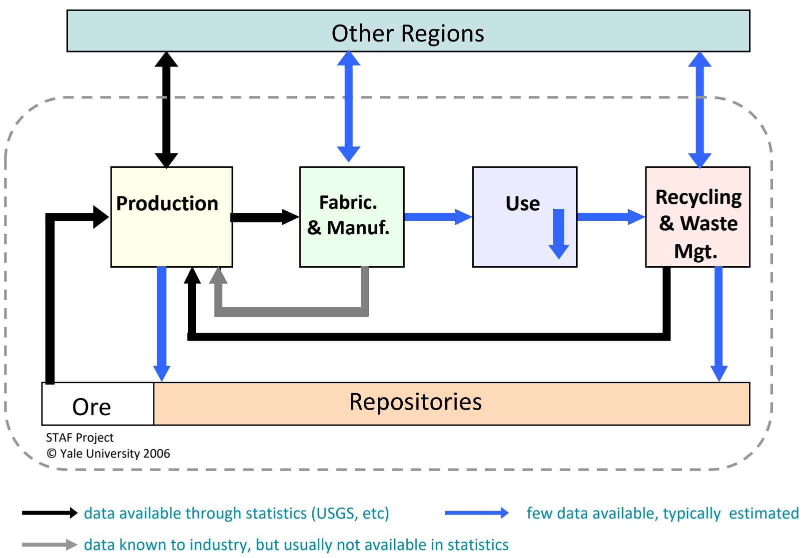


Figure 5: Data sources used for MFA related to their value chain coverage.

For the grey flow from fabrication and manufacturing to production, this is data that is known by the industries themselves, but this is often not available to MFA practitioners.

The blue flows represent where the MFA practitioner needs to estimate either through mass-balance or by using other publications or industry reports. For the blue flow from production to repositories, this can represent tailing and slag which still have a metal content, even though this might be quite low. It might be necessary in the future to recover the metal from these sources, therefore it is important to know the potential recourse that these represents today.

From manufacturing until use, for the most part estimates are needed, in any case this is needed to get to the metal content in the different products as described above. This is also the case for the in-use stock of materials. This needs to be estimated often through the use of the lifetime of the different products which can further lead to large uncertainties. For the flows going out of the in-use stocks, estimates are often done on the basis of the lifetime since it is very challenging to find statistics on this. As an example, in trade statistics, the discarded products may be seen to have no value, if this is the case they are not further tracked. This can be the case for old discarded electronics which then are further not tracked in statistics although their metal content can be quite high.

The system described in Figure 5 is on a rather aggregated level, when monitoring the physical economy, more detailed systems might be needed. And the fragmentation in data becomes even more evident. In Figure 6 below, the first stages of mining and refining of cobalt is presented. Here we attempted to place data from geological surveys and trade statistics onto their respective places in the system. For the data from geological surveys, this was tested through a case study at BGS and the results are presented in Deliverable 5.2 Testing of the framework. A similar testing was also done for aluminium. The aim of this testing was to check the applicability of the system itself as well as to explore if the existing data from BGS are developed with a right system context in mind. From the outcome of this testing it was found that the uncertainty regarding the reported figures can be quite high even from a data provider perspective. Especially when trying to match the description specified by the HS codes for trade data. Uncertainties also emerge from the data for cobalt production due to the fact that different sources report different production figures and the fact it was not currently possible to disaggregate the production numbers to the various markets for cobalt. Several other challenges were found and are further discussed in detail in Deliverable 5.2.

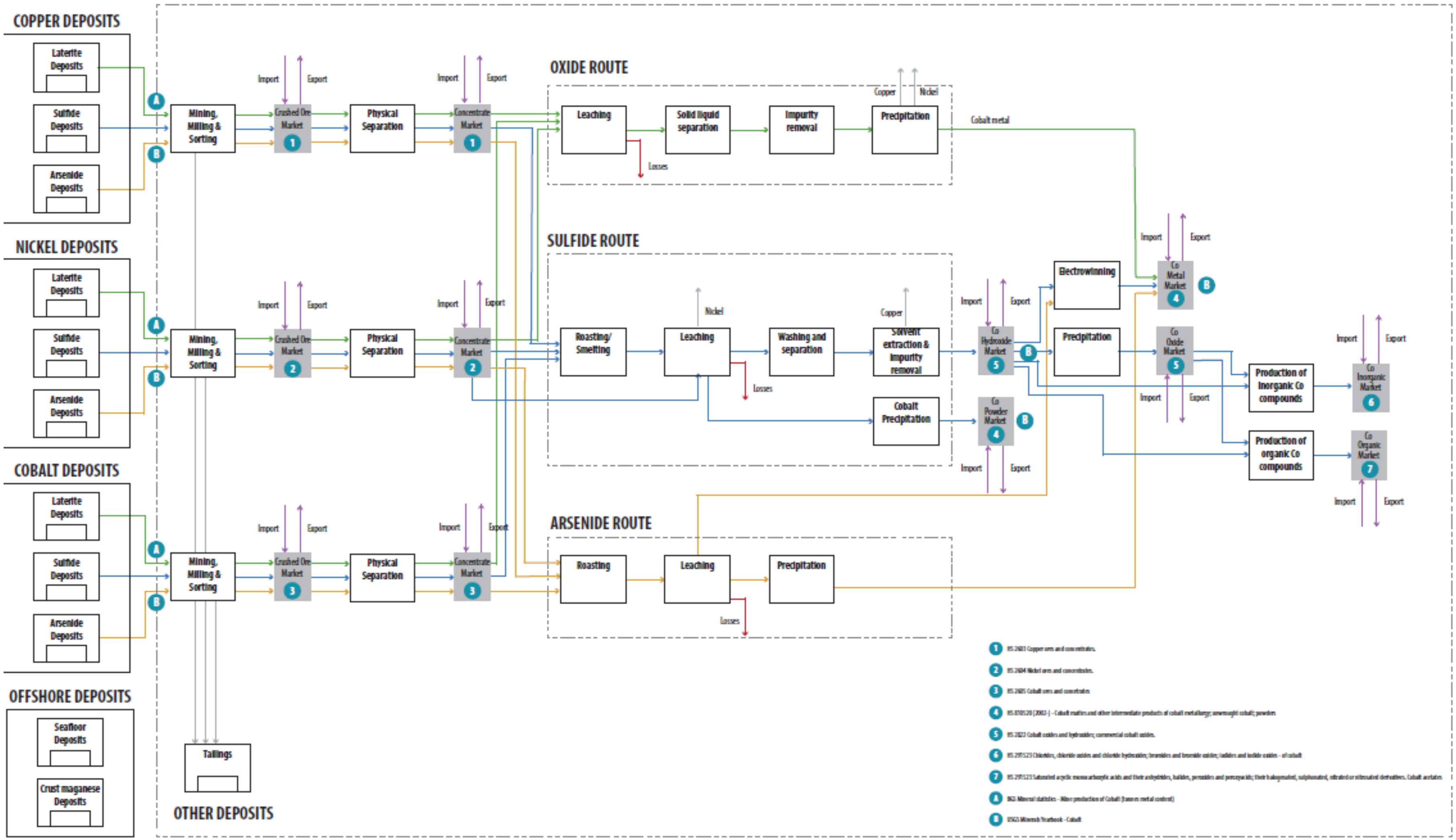


Figure 6: The cobalt system

When it comes to trade data, and the case of cobalt, we find that the HS codes which explicitly mentions cobalt groups together several stages of the supply chain with no possibility for further disaggregation. The HS code 260500 includes both ores and concentrates which are in different places in the value chain, while the ore is what is extracted from the ground, the concentrate is the remainder of the ore after an initial separation in which the tailings and slags are discarded. The weight and the value of these differs significantly and in the trade statistics. But just the total weight and value is reported for both. Cobalt oxides and hydroxides which are reported together in HS code 282200, cobalt hydroxides are often used to produce cobalt oxide and both can be used directly in the manufacturing and in the production of products making the tracking of these compounds further on in the vale chain quite challenging.

It should also be mentioned that since cobalt mainly are produced as by-product of copper and nickel for the production these codes also needs to be used to estimate cobalt content of nickel and copper ores. The fragmentation becomes even more evident in HS code 810510, here the remainder of the value chain are grouped together in one code that also includes wastes and scraps. As we have no possibility to further disaggregate this code, it is not possible to further track the cycle of cobalt without introducing large uncertainties and make use of estimates decreasing the robustness further up the pyramid.

Table 2: HS codes explicitly mentioning cobalt

HS CODE	DESCRIPTION
260500	Cobalt ores and concentrates
282200	Cobalt oxides and hydroxides; commercial cobalt oxides
282734	Cobalt chloride
810510	Cobalt, unwrought, matte & other intermediate products, waste, scrap & powders
810590	Cobalt and articles thereof, nes

The harmonization of production and trade data also represents an issue for MFA practitioners. As they report their data in different classification systems. Whilst trade can be reported in the Harmonized Commodity Description and Coding System (HS), International Trade Classification (SITC), Combined Nomenclature (CN) and the Broad Economic Categories (BEC). Whilst for production statistics the International Standard Industrial Classifications of All Economic Activities (ISIC), the Central Product Classification (CPC) and PRODCOM are used in additional to national variations of the classification systems.[7]

Due to the different purposes for the collection of trade and production statistics, the codes seldom compare although there exist correlation tables between SITC to ISIC and

[7] https://unstats.un.org/unsd/classifications/nationalclassifications/National_classifications_by_country_180413.pdf

from HS to CPC and from CN to CPA and PRODCOM[8]. The codes also differ in their level of aggregation as shown in table 3 below, and although there exist correlation tables. Due the different levels of aggregation they will not match completely. And the classification with the lowest amount of entries will count.

Table 3: Entries in classification systems

	Trade classifications				Production classifications			
Classification System	SITC (rev 4)	HS 2012	CN	BEC	ISIC Rev 4	CPC	PRODCOM (NACE Rev 2)	CPA
Number of entries	2970	Approx. 5300	Approx. 12200	Level 1: 7 main categories, Level 2: 14 categories Level 3: 8 sub-categories	Approx. 3700	1617 CPC subheadings based on HS	Approx. 3800	Approx. 5300
Correlation tables	ISIC	CPC	CPA, PRODCOM					

4.3 Digital infrastructures

Mapping material cycles is a highly data intensive task and requires data points from the entire supply chain. The collection is time consuming and can require larger amounts of storing capacity. MFA datasets can be stored in excel sheets or in databases developed by the individual practitioner with very limited possibility for sharing or merging of different datasets.

The current trend is moving towards storing such raw material data in generic databases and several initiatives within the field of industrial ecology is currently ongoing. Such as the Unified Materials Information System (UMIS) initiative from Yale and USGS which aims to store the stocks and flow data developed through the STAF project[9]. And the Industrial Ecology group at Freiburg has also developed an Industrial Ecology related database consisting of over 100 datasets that also includes datasets for MFA[10]. However, even though data on stock and flows are collected and stored in such databases, they do not show the system definition. Meaning, that even though we might have access to more data, we still need to interpret them and place them within a system.

If we are to enable the move towards monitoring the physical economy. Statistical data from different governments needs to be stored in way that their system context is explicit. From this follows the fact that it is required that also individual companies perform physical accounting alongside their financial accounting. Since the data collected by statistical agencies originates from the companies. This would allow for a transfer of the system context and reducing the need for interpretation.

Digital infrastructures encompass more than just databases, it is the metadata following the measurement, the collection and reporting scheme and it includes the legislation for sharing and the exchanging of data. Digital infrastructures must be in place already at the company level with legislation for reporting data and the corresponding metadata that

[8] https://ec.europa.eu/eurostat/cache/metadata/en/prom_esms.htm
[9] https://cie.research.yale.edu/project_main/stocks-and-flows-project-staf
[10] http://www.database.industrialecology.uni-freiburg.de/

would allow for a transfer of the system context up statistical agencies and governmental data collectors and in the end up towards an institution that has the mandate to monitor the physical economy. Institutions like these exists (IEA, OECD etc.), but no institution monitor the physical economy on the scale that is currently required. Only parts of the system is monitored. This transfer data in a system context would enable more robust models and scenarios together with a reduction of the uncertainty inherent in that data on all levels from the individual company and on the global level.

The aim of such an infrastructure is to enable a data exchange that allows the receiver of the data to understand what the data actually mean. To enable this a set of standardized metadata needs to follow each data point, that provides and accurate description of the system context of the data. This will need to be implemented already on the company level. Legal incentives needs to be in place avoiding a prisoners dilemma situation in which each company would like the data from all other companies, but not be willing to give their own data. To be able to overcome legal barriers the MFA community can take learning from the INSPIRE directive that develop a set of common implementing rules that are binding for all Member States. This includes metadata for which specific guidelines and rules apply to ensure the ability to share data between Member States.

5 Key monitoring principles for systems and data

Systems form the foundation of any given MFA, they represent the coordinate system of the physical economy being examined. Without a coordinate system, the measurements provided by data cannot accurately be placed to flows or stocks. The key principles below aim to illustrate how systems can be developed in order to provide better coordinate systems for some known challenges. Systems are very much linked to data and without proper systems in which the data can be placed within robust interpretation can become a challenge.

Through the MinFuture project, key monitoring principles were developed with the aim of helping MFA practitioners to place numbers more correctly and explicitly show the data or knowledge gaps that we currently have. Below, some of these design principles are shown and explained that can lead to double counting or incorrectly placing of numbers du to confusion regarding terminology. The key monitoring principles presented in section 5, aim to assist practitioners to make informed decisions when conducting MFAs of any given material. They represent guidelines rather than determining what is right or wrong in an MFA. They aim to provide recommendations on how to conduct MFAs or issues that MFA practitioners should pay extra attention to.

5.1.1 Crude ore versus beneficiated ore

Some geological surveys report the crude ore in their statistics, whilst the majority report the beneficiated ore, namely the valuable part of the ore. The difference between the two represents the waste rock, Figure 8. Let us assume now that the aim of a study is to understand global production of a mineral commodity. When compiling data from different sources that report at different points in the system and do not provide sufficient metadata information, for example, the metal content of the crude ore, then it is highly likely that errors are introduced during the calculation process.

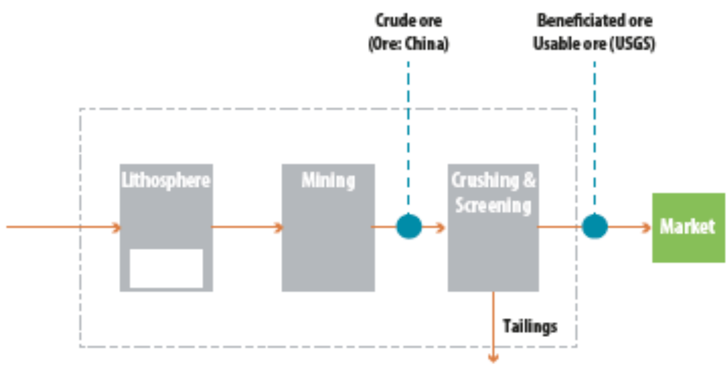


Figure 7: An illustration of the measurement points for crude and beneficiated ore

5.1.2 Production versus sold production

Most statistical agencies and geological surveys report data on production, sold production, or shipment, Figure 9. However, these terms represent different parts of the value chain. Production is the quantity of a material produced directly from a mine in a given year. Shipment and sold production represent the quantity of a material that has been sold in a given year. Often companies have inventories where material is stored after production. Sold production or shipmen may represent a quantity of a material that originates from an inventory. Therefore, the terms production and sold production or shipment do not mean the same thing and should not be used interchangeably as they may introduce errors to MFA. Equally, data providers should try to remove any inconsistencies associated with these terms by providing additional information on the measurement point they represent

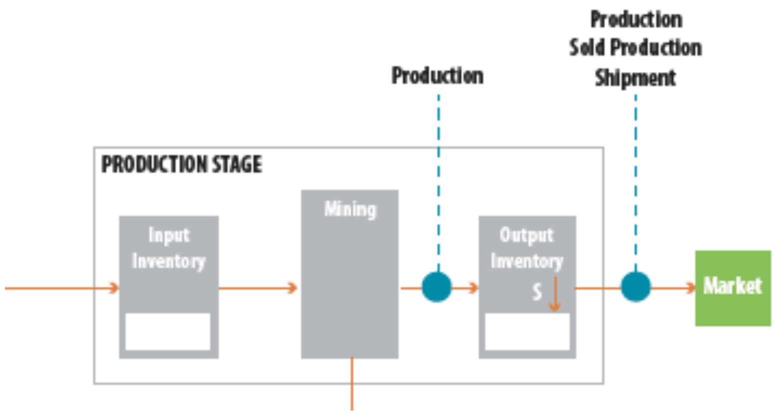


Figure 8: An illustration of the measurement points for production and production sold / shipment

5.1.3 Finished products (steel)

The term finished steel or finished products may correspond to various different production stages, Figure 10. It can be interpreted as the sum of the production of all steel companies, or as the sum of finished steel production by a country. Interpreting the numbers wrongly, for example due to product from company A feeding into company B, may results in double counting especially when attempting to calculation production at country level.

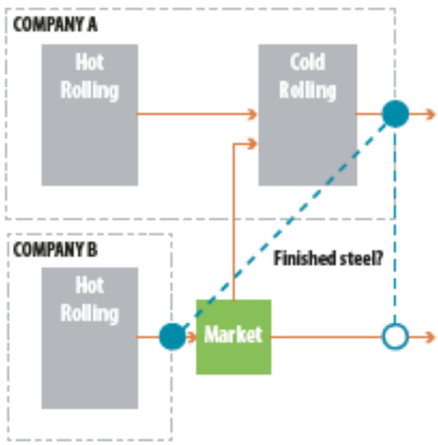


Figure 9: An illustration of the different measurement points that may be accounted for when quantifying 'finished steel' products from different companies

5.1.4 End Use

The term end use is relative and has different meanings for different sectors, Figure 11. Wrongly interpreting the end use statistics can result in inconsistencies throughout the material cycles.

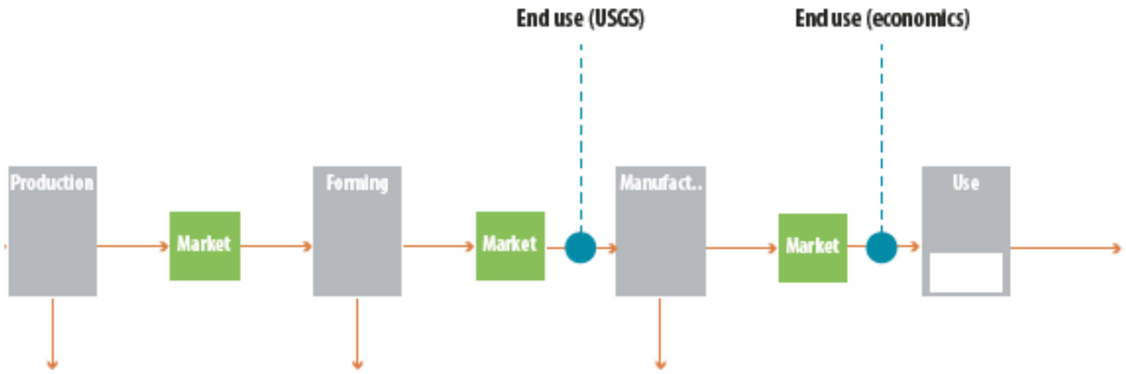


Figure 10: An illustration of different measurement points for end use products

5.1.5 Domestic shipment

Domestic shipment (DS) the "trade" within a single country, cannot be visualized directly when using markets. However, it can be visualized if trade is visualized without markets (Figure 12). To be able to understand the relationship between what a single country produces for own use and their import reliance, it is important that these concepts are properly understood. Production and apparent consumption (AC) can be calculated if DS, import (I) and export (E) are known (see formula), provided that there are no significant stock delays in the market.

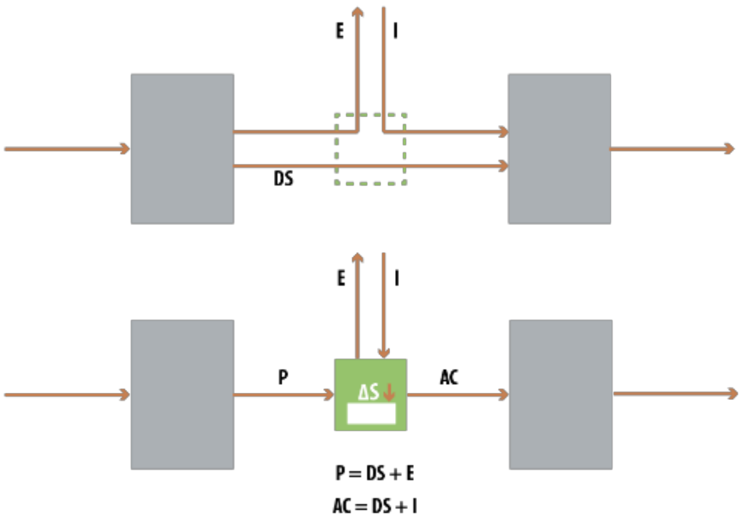


Figure 11: An illustration of how domestic shipment may be accounted for in MFA

5.1.6 International trade

Trade is visualised using markets, however, trade between countries does not happen instantly and can occur in a variety of forms. Markets consists of several sub-processes such as transit, boarder control, customs and warehouses that all can contain stocks which can further lead to delays in the system and to inconsistencies between the measurement (statistics) of import and export. In addition, trade can happen illegally (smuggling), in which the materials are not tracked at all. As an example of possible delays in the system, it is possible to export materials for storage in a bonded warehouse where the material can be stored for some time (possibility to speculate in material prices) before being imported to another country (Figure 13).

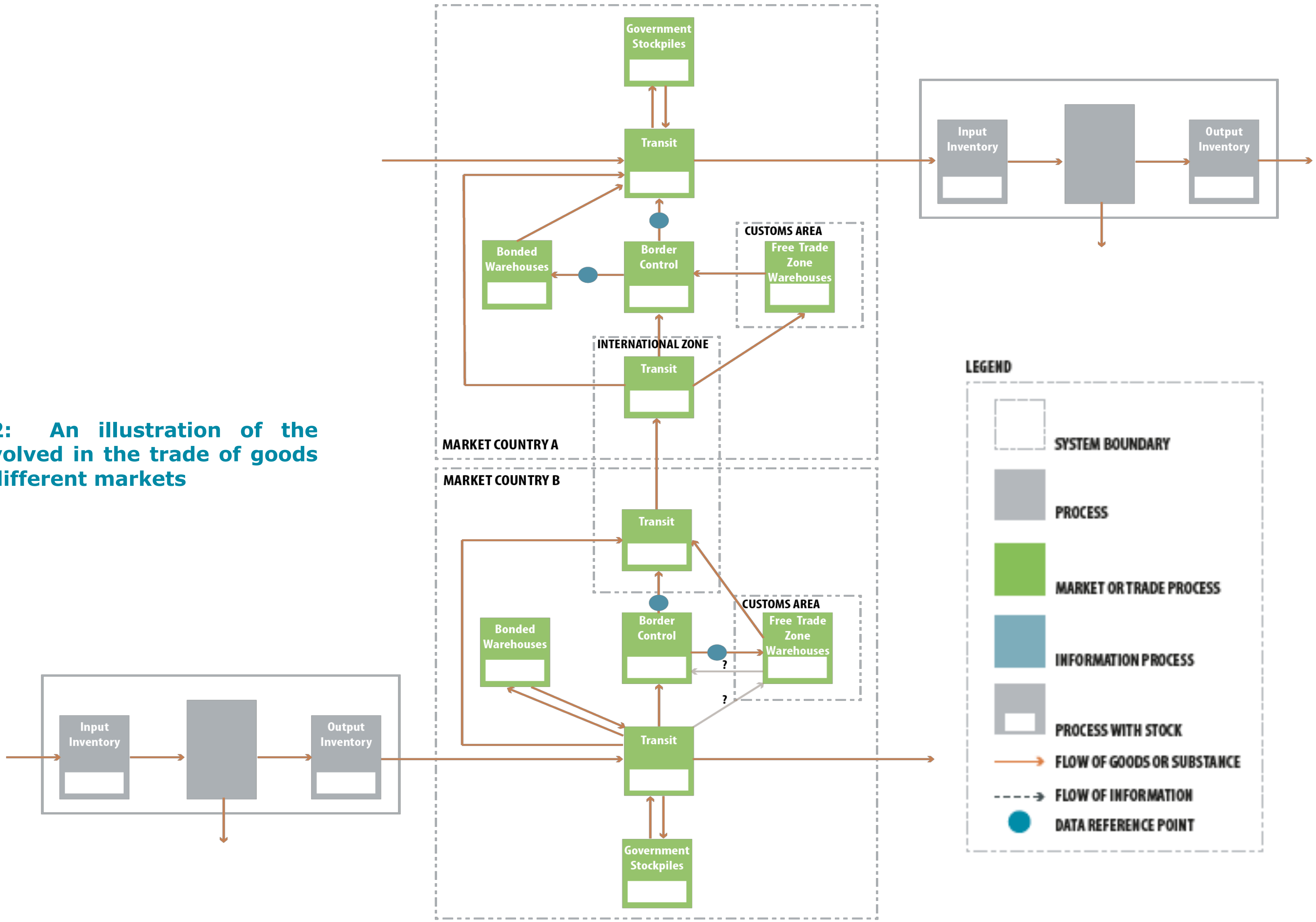


Figure 12: An illustration of the stages involved in the trade of goods between different markets

6 Conclusions

Systems and data form the foundation for further use of data for modelling and for informing decision making. How we currently monitor the physical economy is not efficient and they are not suitable to inform robust policies and strategies that are required to face the challenges our society are facing. To face these challenges robust systems and data are quintessential for RM strategies.

Currently, we have a lack of system understanding, fragmentation and gaps in the data and unclear reference points which can lead to wrong interpretation, the use of assumptions and further wrong conclusions.

Here we show the importance of adding system context to data to enable more robust decision making. Adding system context to the data can help to clarify the meaning of data, this system context can be enabled through the use of a consistent set of metadata following each data point. Adding a system context can also make the data gaps transparent and facilitate the harmonization of data. It would also enable us to refine our overall understanding of the systems in question.

Data with a system context is key in the development of a data infrastructure which further can enable the sharing and exchange of data and the legislative measures that needs to follow. As we have shown with the key monitoring principles, adding a system context to the data helps reduce misunderstanding and misinterpretation of data. The continued development of such monitoring principles are key in work towards a more robust monitoring of the physical economy.

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