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Circularity within Company Networks

Master Design Project

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Abstract: The global economy faces escalating challenges from increasing resource demands and environmental threats, necessitating a shift to sustainable practices. This urgency has spurred interest in Circular Economy (CE) models, aiming to optimize resource use, reduce waste, and promote recyclable materials. The Dutch government, aligning with a CE vision by 2050, seeks effective policies but lacks industry-level circularity data crucial for policy formulation. To address this, a framework leveraging the Central Bureau of Statistics (CBS) database is proposed. This database, incorporating detailed economic flows by industry, enables robust measurement of circularity indicators essential for supporting CE initiatives and policy development.

1 Introduction

The global population's expansion and the rise of a robust middle class are driving increased demand for natural resources, goods, and services worldwide, Lieder and Rashid (2016). With the increase in competition for finite resources, the current linear economic model of production-consumption-disposal systems is proving insufficient to handle this growing issue, Elia, Gnoni, and Tornese (2017) Geissdoerfer, Savaget, Bocken, and Hultink (2017). The pressing need for a shift toward sustainability in economic production is underscored by the escalating threat of environmental catastrophes. Consequently, governments, NGOs, and businesses are increasingly recognizing this dilemma and directing attention towards solutions, Elia et al. (2017) Kristensen, Kjeldsen, and Thorsøe (2016) Geissdoerfer et al. (2017). To ensure environmental health and sustainable growth, the global economy "must prioritize optimizing natural resource utilization, reducing emissions, minimizing material waste, promoting renewable and recyclable resources, preventing material degradation, and enhancing the value retention of materials and products", Schilkowski, Shukla, and Choudhary (2020). To achieve this the linear economic model needs to change to a CE.

The transition towards a CE has emerged as a goal for the Dutch government, aligning with its vision to achieve a CE by 2050, Hanemaaijer, Delahaye, Hoekstra, Ganzevles, Lijzen, et al. (2018). Therefore, the Dutch government wants to come up with and evaluate an effective policy to stimulate the CE within the Netherlands.

However, with no knowledge of the current level of circularity within the different industries in the Netherlands, the effectiveness of any policy change is unclear. An example of this is the research by Hanemaaijer, Kishna, Koch, Lucas, Rood, Schotten, and van Sluisveld (2023), which discusses the current state of the CE in the Netherlands based on national-level data and highlights the necessity for data at the supply chain and industry levels to formulate effective policies. As an institution responsible for gathering and analyzing socio-economic data, the CBS assumes a crucial role in supporting governmental initiatives aimed at realizing its vision of a CE. However, van Berkel, Schoenaker, van de Steeg, de Jongh, Schovers, Pieters, and Delahaye (2019) underscores the inadequacy of the current CBS method for mapping economic indicators in the CE, thereby not being able to measure the circularity of industries within the Netherlands. To solve this problem, the following management question is stated: *How can the circularity of industries within the Netherlands be determined?*

In order to address this management question we propose a framework to identify and measure different indicators for a given industry within the Netherlands. To be able to use this framework, and to measure the proposed indicators, a database within the CBS is utilized. The CBS is actively engaged in constructing a yearly statistical database that delineates supply chains within the Dutch economy, based on input-output analysis. This dataset contains both product and financial flows at individual company levels of firms with a revenue of 10.000 euros or more.

Interactions among companies are categorized based on the General Company Register (ABR) and further segmented into economic activity categories defined by the Standard Company Grouping (SBI) (or industry code) and Goods and Services Categories (GDC), such as 'shipbuilding' and 'fuel oil', respectively.

When developing a systematic process for analyzing the circularity for a given SBI, the CBS not only enhances its capacity to furnish comprehensive information but also fulfills its mandate to support government initiatives towards a CE.

2 Background

In this chapter, background information is given regarding networks of companies and circularity. The chapter ends by defining and explaining the research questions in Section 2.3.

2.1 Networks and Systems

The previously discussed database contains financial transactions between companies in the Netherlands. Within these transactions, the SBIs of both the user and supplier, their financial weight, and the GDC can be seen. The SBI comprises five levels, with each economic activity represented by up to five digits. An example of this level can be agriculture. Level 01 is Agriculture and related service activities, this is then further divided into multiple sub levels on three digits, of which an example is 011 *Growing of non-perennial crops.* In its turn a lower level is 0113 *Growing of vegetables, roots, and tubers.* Diving into the last level provides 01131 *Growing of vegetables in open fields.* Up until the 3 digit the SBI is universal for all EU countries. Moreover, it is important to note that not all SBI's are divided into 5 digits. The GDC are coded by Eurostat in the combined nomenclature. This combined nomenclature contains the codes prescribed by the European Union for the statistics on International Trade in Goods in all EU countries and is an 8-digit code.

How the Company Network (CN) is formed from the dataset is explained in Section 2.1.1, the Network structures are further explained and analyzed in Section 2.1.2.

2.1.1 Methodology of the CN

The method used for constructing the CN is outlined in Gert, de Jonge, Mooijen, Hooijmaaijers, and Bogaart (2021). However, in this section, a simplified overview is provided to give the reader an insight in the buildup of the network. The methodology comprises the following key steps:

1. Identification of Network Nodes: The nodes within the Dutch inter-company production network represent entities with significant annual intermediate supply and/or usage. Companies with an annual turnover exceeding 10.000 euros are selected, totaling approximately 900.000 companies, while around 800.000 micro companies, primarily self-employed individuals, are excluded. This exclusion streamlines the network dataset significantly with minimal impact on results.

2. Estimation of Intermediary Supply and Usage: The framework involves estimating intermediary supply and usage per company per GDC, and constructing company-to-company input/output tables per GDC. Initially, the intermediate supply/usage structures of some companies are derived from surveys. Subsequently, breakdowns are estimated for companies not covered in these samples by applying industry-wide distribution from supply and usage tables. An iterative proportional fitting technique ensures the estimated supply and usage align with the total supply and usage per GDC per SBI. To clarify, the data in the CN on SBI and GDC levels is exact and known and is aggregated towards the company-to-company level.

3. Estimation of Link Probability: This step entails estimating the likelihood that two given companies will engage in trade. Various scores based on assortativity, distance, industry affiliation, and observed relations inform this matching process.

4. Matching Procedure: Matching supplying and using companies per GDC involves a clearing process that allocates total intermediary transactions per GDC across the most probable company-to-company combinations. Notably, this dataset exclusively captures intermediary transactions among companies, excluding transactions involving final products sold for consumption, exports, and investments.

The economic system of the Netherlands is intricately connected to the global economy, functioning as a significant importer and exporter. However, the focus of this network analysis is confined to national companies, excluding transactions between Dutch firms and international entities. This ensures the network operates as a closed system, consistent with data from National Account registers. Although, besides the CN both data on the import and export of the CN is available as well. It's essential to recognize that the entire study hinges on data collected and constructed through a specific reconstruction method, introducing a level of uncertainty due to potential errors in the methodology.

2.1.2 Networks and graphs

From the transaction between companies, a network can be formed. This network contains N amount of nodes n, which are companies. Each of these nodes is connected to different nodes, called links l, where the total number of links is L. While networks often relate to real systems, graphs often relate to mathematical representations of the network. A graph is defined as,

$$G = (V, E), \tag{2.1}$$

where V is the set of vertices (nodes) and E is the set of edges (links) of the graph.

In the CN two vertices can have incoming transactions and/or outgoing transaction based on them acting as suppliers or users (purchasers). Figure 2.1 shows a possible orientation of how these vertices look with respect to incoming and outgoing transactions.

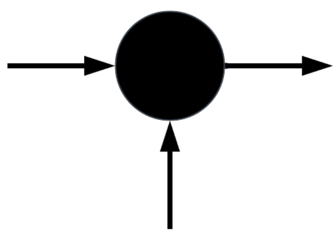

Figure 2.1: Vertex with three edges. Two of the edges are incoming and one is outgoing.

Different types of networks can have systematically different structural properties. A recent research by Mattsson, Takes, Heemskerk, Diks, Buiten, Faber, and Sloot (2021) on the CN, used spectral bipartivity, to denoted the network topology of the CN. Spectral bipartivity quantifies the abundance of even versus odd cycles in a network's local connectivity structure, Estrada and Gómez-Gardeñes (2016). Mattsson et al. (2021) found that the CN is a functional network, meaning that edges are likely to form when a node is similar to already existing connections. This indicates that two comparable nodes based on connections are not likely to be connected, while it is likely for them to be connected with the same node. To give a practical example of this, we can think of two bicycle producers who are likely to sell to the same bicycle retailers and buy from the same tire producer. However, it is not likely that they will have financial transactions between them as they are competitors.

Based on this result it would be possible to cluster nodes into sets according to their SBI. These sets of nodes contain then all companies with the same SBI. An example of such a cluster is SBI 3830 which is identified as a cluster in which companies have as their main activity recycling materials.

2.2 Circular economy

The CE, while gaining traction among scholars and practitioners, faces challenges due to its diverse interpretations, as highlighted in Kirchherr, Reike, and Hekkert (2017), analyzing 114 definitions of CE. According to Conference of European Statisticians (2023), *A CE is an economy where:*

- *The value of materials in the economy is maximized and maintained for as long as possible.*
- *The input of materials and their consumption is minimized.*
- *The generation of waste is prevented and negative environmental impacts reduced throughout the life-cycle of materials.*

The publication referenced (Conference of European Statisticians (2023)) emanates from the United Nations and was co-authored by the CBS. Its intended recipients predominantly include specialists affiliated with National Statistical Offices and governmental bodies tasked with quantifying the CE. Additionally, it targets policy advisors and decision-makers involved in facilitating the shift towards a circular economy paradigm, justifying the selected definition's pertinence. Besides the definition, Conference of European Statisticians (2023) names the R-strategies defined by Potting, Hekkert, Worrell, Hanemaaijer, et al. (2017) as well. The R-strategies consist of ten strategies ranging from refuse to recover and can be seen in Figure 2.2. These strategies aim to close, slow, and narrow resource loops, contributing to maintaining material value, preserving natural capital, and safeguarding human health. This framework provides a common reference for international efforts towards a more CE.

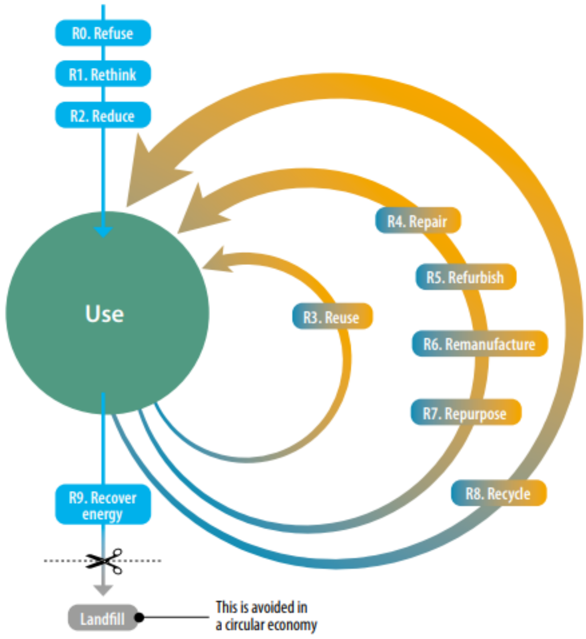

Figure 2.2: R-strategies for a circular economy. ***Retrieved from Conference of European Statisticians (2023)***

Based on these R-strategies, circularity can be divided into more approachable business models. Below, a few of these business models are named.

The first discussed is leasing. Despite being a longstanding financial practice, leasing's specific contributions to circular business models and their environmental implications have received limited attention, Agrawal, Atasu, and Ülkü (2021). Within the CE, leasing represents a transformative approach to resource management, emphasizing access over ownership and facilitating the continuous circulation of goods and materials Guldmann (2016). This transition aligns with principles of sustainable consumption and production, aiming to extend product life cycles and minimize waste generation Rogers and Rodrigues (2015). However, empirical evidence on the economic and environmental impacts of leasing within the CE context remains scarce, highlighting the need for further research to elucidate its potential benefits and challenges Koh and Jang (2009). As organizations increasingly embrace circular business models, understanding the role of leasing in fostering economic prosperity and environmental stewardship becomes imperative for advancing the principles of sustainability and resource efficiency.

Repair, seen as R-4 in Figure 2.2, is a pivotal element in the transition toward a CE, aiming to mitigate the environmental impact of linear production-consumption-disposal systems. This strategy extends product lifespans, diverts items from the waste stream, and reduces the need for primary production, thereby curbing greenhouse gas emissions, Hobson (2020). Additionally, repair cultivates sustainable consumer behavior, heightening awareness of product value and environmental implications Bridgens, Hobson, Lilley, Lee, Scott, and Wilson (2019). Despite its significance, mainstream CE discussions often overlook repair, necessitating its greater recognition and promotion within the CE discourse Hobson and Lynch (2016).

A different aspect in CE is looking at the material flows. An article written by Haas et al. (2015) focuses on these material flows and states that the CE aims at reducing both the input of virgin materials and the output of wastes by closing economic and ecological loops of resource flows. The escalating resource use, particularly in industrialized nations, is placing immense pressure on ecosystems and resource availability, Schaffartzik, Mayer, Gingrich, Eisenmenger, Loy, and Krausmann (2014). Haas et al. (2015) states that the CE advocates for two main material pathways: biological materials that can re-enter ecological cycles, and materials designed for reuse and recycling within the social economic system, Programme (2012).

In Figure 2.3 a schematic approach to material flows in a national economy is displayed. This approach is close to a system dynamic methodology when looking at a CE, such as done by Vegter, van Hillegersberg, and Olthaar (2023) and Pinto, Sverdrup, and Diemer (2019). They integrate life cycle assessment and system dynamics as a methodology for CE. System dynamics is a methodology for studying complex nonlinear behavior within systems, often used for simulating new potential behaviors by adding, removing, or changing variables, triggers, and delays Sterman (2000). By mapping the flows of a supply chain on a system dynamic level possible circles in the CN can be identified, which can be indicators of a CE. An example of this approach is a very recent article where a case study on PET bottle resin is studied by Ghosh, Avery, Bhatt, Uekert, Walzberg, and Carpenter (2023). They develop a material flow-system dynamics framework to model the life cycle of plastic material flows within the current and future economy.

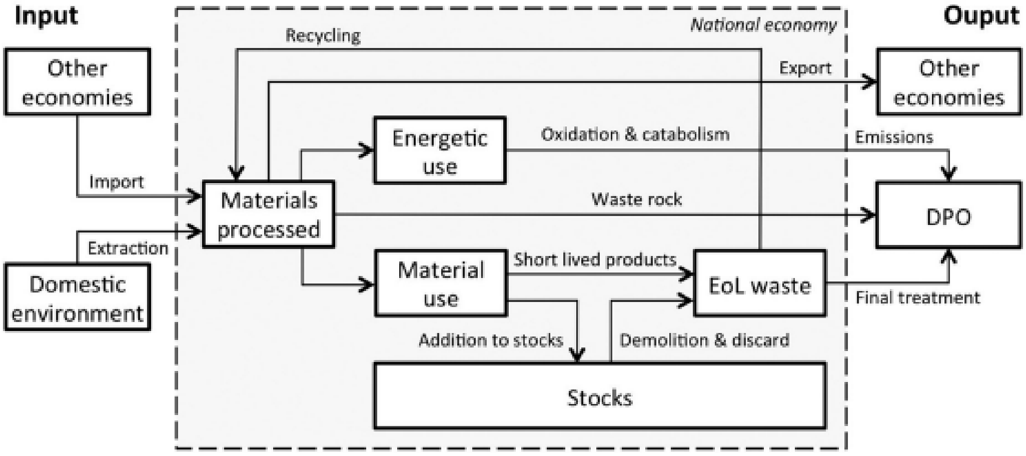

Figure 2.3: General model of economy-wide material flows from resource inputs imports and extraction to outputs of wastes and emissions and exports. All flows shown in the model have been quantified to assess the key characteristics of the circular economy. EoL waste = end-of-life waste; DPO = domestic processed output. *Retrieved from Haas et al. (2015).*

Recycling of materials, R-8, can be done according to different techniques. The quality of the produced recycled material indicates if this material can be used for the same product, a product of a higher quality or a lower quality. The last one is denoted as downcycling while recycling a material to let it be used for the same product or of higher quality is known as upcycling. Helbig, Huether, Joachimsthaler, Lehmann, Raatz, Thorenz, Faulstich, and Tuma (2022) gives a definition of downcycling as, "the phenomenon of the quality reduction occurring during or because of recycling, expressing itself in a thermodynamic, functional, or economic way". Four primary factors of downcycling are identified by Helbig et al. (2022). Firstly, downcycling may occur due to the mixing of different scrap types during collection, leading to the dilution of high-quality materials and their relegation to less demanding applications. Secondly, contamination with undesirable substances can prompt downcycling, necessitating additional purification efforts. Thirdly, downcycling can result from a lack of demand for recycled materials or the obsolescence of closed-loop recycling systems due to market changes. Lastly, the complexity of composite materials exacerbates downcycling challenges. These causes are illustrated in Figure 2.4.

The last R-strategies that is named is recover energy. The transition towards a CE within the electricity sector demands innovative solutions to address waste and emissions, pivotal in mitigating environmental impact and fostering sustainability, Bogdanov, Ram, Aghahosseini, Gulagi, Oyewo, Child, Caldera, Sadovskaia, Farfan, Barbosa, et al. (2021) and Osman, Hefny, Abdel Maksoud, Elgarahy, and Rooney (2021). By leveraging waste-to-energy technologies, such as converting municipal and industrial waste into composite fuel Lausselet, Cherubini, Oreggioni, del Alamo Serrano, Becidan, Hu, Rørstad, and Strømman (2017), it becomes possible to not only mitigate environmental impacts but also contribute to the efficient management of waste, Glushkov, Kuznetsov, and Paushkina (2020). Waste-to-energy technologies offer a promising avenue, converting waste from non-renewable power generation into usable energy, thereby promoting efficient waste management while bolstering circularity, Glushkov et al. (2020). This approach, coupled with smart grid management systems, facilitates dynamic energy optimization and integration of renewable sources, such as solar and wind power, enhancing grid resilience and minimizing environmental footprint, Ullah, Hafeez, Khan, Jan, and Javaid (2021). By leveraging waste as a valuable resource and optimizing energy utilization, the electricity supply chain moves towards a circular model, aligning with global sustainability goals and ensuring a greener future.

2.3 Research questions

Based on the last two sections research questions are presented. The research questions start with the main research question. Below the list of research questions, the motivation and identifications of these equations are explained in Subsection 2.3.1.

For the research question, the main research question is stated as: *How can the circular activities of an SBI be identified?* Based on this main research question, the following sub-questions are stated:

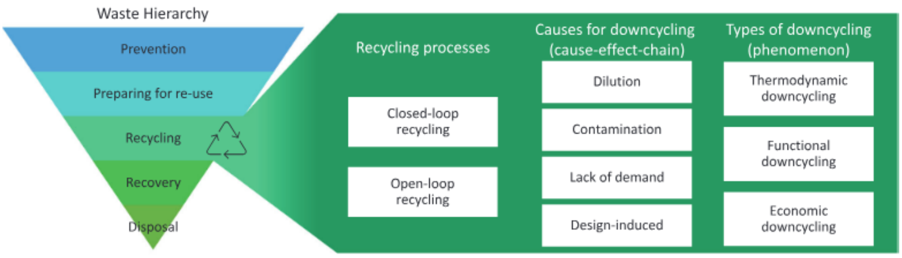

Figure 2.4: Diagram showing recycling processes as part of the waste hierarchy and the causes of recycling processes that lead to various types of downcycling. ***Retrieved from Helbig et al. (2022).***

RQ 1 *Which R-strategies can be seen in the CN?*

RQ 2 *Is there a relation between the monetary flows of the recycling industry to other SBI's and circularity?*

RQ 2.1 *Do monetary outflows from the recycling industry to a given industry indicate circularity of this given industry?*

RQ 2.2 *Can the monetary inflow of non-recycled material to landfills be identified and related to circularity?*

RQ 2.3 *How can upcycled and downcycled material be identified in the CN and what is its connection to circularity?*

RQ 3 *What is the relation between leasing industries and circular activities of an SBI and how can its impact be identified?*

RQ 4 *What is the relation between repair industries and circular activities of an SBI and how can its impact be identified?*

RQ 5 *What are the critical aspects of designing and implementing a framework that can be used for all industries?*

2.3.1 Research questions identification

RQ 1 is identified following the ideas of Potting et al. (2017) and Morseletto (2020). They state a list of nine R-strategies that contribute to the transition towards a CE. Therefore, as a start of looking for circularity within the CN, it is important to identify which of these strategies can be seen in the CN.

The purpose of RQ 2 is to explore the potential for determining a degree of circularity within various SBI entities through analysis of their financial transactions with the recycling industry. This question is specified further in the following three sub-questions.

RQ 2.1 is identified to look for the inflow of industries from recycling centers. It aligns with findings from the report authored by Conference of European Statisticians (2023), which introduces the concept of a *circular material use rate* as an indicator of the circularity observed in material flows and the efficiency of materials and garbage management practices. Notably, examining financial flows, where SBIs from the recycling industry serve as the supplier, may provide insights into its utilization of recycled materials.

RQ 2.2, of whether the inflow of material to landfills in the CN can be identified and related to circularity is of importance for the understanding of assessing changing consumption patterns, waste prevention efforts, and the effectiveness of waste management strategies, Commission (2018). Understanding the inflow of landfills, where the material will eventually be dumped if it is not recycled, and its connection to circularity is essential for developing effective waste management models at the national level. By integrating CE principles into waste management strategies, countries can improve resource efficiency, reduce environmental impacts, and comply with EU regulations and sustainability requirements, Luttenberger (2020). To identify the circular activities of an SBI, it could be researched how much of its waste will end up in a landfill.

RQ 2.3 is identified by following the ideas of Teigiserova, Hamelin, and Thomsen (2020) and Lombardi and Costantino (2021). They identify the different categories of reusing food, higher quality can be used for humans, lower for animals and the least quality should be burned to create energy. Moreover, they stated that this should be done for all materials, such as proposed by Bos, van den Oever, and Meesters (2014), who came up with a value pyramid, as can be seen in Figure 2.5. Besides the use within society, it is also important to look at the quality of recycling for upcycling and downcycling, such as done by Horodytska, Kiritsis, and Fullana (2020) and Helbig et al. (2022).

Furthermore, it is valuable to identify what happens with the value of recycled material, since within a CE the value of materials in the economy is maximized and maintained for as long as possible, as stated in Section 2.2. Based on these defections it is important to identify the amount of the material in the recycling industry either upcycles or downcycles.

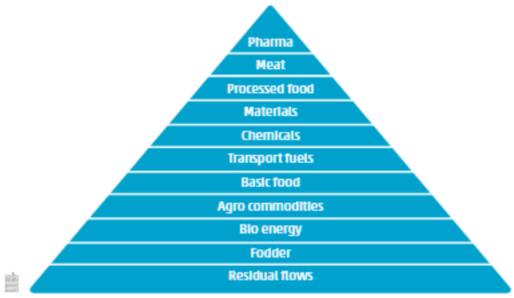

Figure 2.5: Value pyramid. ***Retrieved from Bos et al. (2014).***

RQ 3 is identified by following the ideas of Bal and Badurdeen (2022) and Van Loon, Delagarde, and Van Wassenhove (2018). They state that by offering products on a lease basis, companies can extend the lifespan of goods, promote resource efficiency, and reduce waste generation. The leasing model encourages the manufacturer to design products for durability, repairability, and upgradability, thereby fostering a closed-loop system where materials are continuously circulated within the economy. However, limited literature exists that couples the amount of leasing to a metric for circularity. The objective of RQ 3 is to design an indicator for leasing that can link it to the circularity of a given SBI.

As stated in Section 2.2, repair plays a crucial role in the CE by extending product lifespans, reducing waste, and curbing greenhouse gas emissions. Despite its significance, repair is often overlooked in CE discussions, highlighting the need for its greater recognition in the literature. Although it is unclear what the exact impact is on circularity, due to a large literature gap, RQ 4 is asked to identify the role of repair within the circularity of the CN.

The last research question is asked is RQ 5. The goal of this research question is to help define a framework, that can be used to identify the circularities of all industries within CNs. Addressing RQ1-4 will provide the initial insights necessary to outline this framework. Subsequently, answering RQ 5 will allow us to refine these insights and design specific constraints and guidelines.

3 Research methodology

The research questions in Section 2.3 can be divided into knowledge questions and design questions. RQ 1 till RQ 4, are knowledge questions and have the goal of understanding, explaining, or exploring existing information, concepts, theories, or phenomena. It seeks to generate insights, expand understanding, and provide explanations based on available evidence or research. RQ 5 is a design question and has the primary goal to create a framework. It seeks practical solutions and formulates design constraints and guidelines.

To answer the knowledge questions, three steps are taken: The first step is a manual observation of the data for the specific question and a literature study into the related field. In the second step, multiple methods are identified based on the available data and related literature. In the last steps the data is applied, and the results are analyzed and validated. For this step, an empirical test study is developed to test the proposed indicators by utilizing the database of the CBS. The industry of choice for this empirical test study is the metal industry. This part will be discussed further in Section 4.2. At last, the analyzed data will be validated with the help of Metaal Nederland, the advocacy organization of the metal industry within the Netherlands, the CBS, and TATA steel.

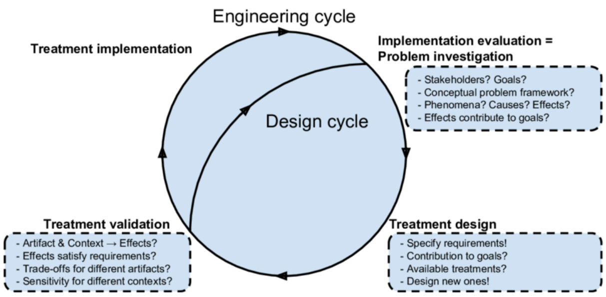

Figure 3.1: Engineering cycle. ***Retrieved from Wieringa (2014).***

The design question is answered using the engineering cycle of design science, as presented in Figure 3.1, incorporating stages of treatment design, treatment validation, treatment implementation, and implementation evaluation. Each stage contributes to building a robust foundation for developing a comprehensive framework for identifying circular activities in various industries. To concertize the framework, a Business Process Model and Notation (BPMN) diagram will be developed.

This BPMN diagram visually represents the workflows and interactions necessary for identifying circular activities. The BPMN diagram provides a clear and standardized method for depicting the processes, making it easier for stakeholders to understand and implement the framework. For validation, a validation workshop with the data science community of the CBS will be conducted. They are the user of the framework, and therefore it will provide critical insights into the practicality and relevance of the BPMN diagram and the overall framework. The feedback from this session will be instrumental in making final adjustments to ensure the framework meets the needs and expectations of industry stakeholders.

4 Design

Within this chapter, the research questions are analyzed with the goal of developing indicators to identify circularity within the CN and finally coming to a framework to analyze the circularity of an industry. Within Section 4.1 the analysis is done of the research questions and Section 4.2 provides the empirical test study on the Dutch steel industry. Section4.3, finally concludes this chapter with the schematic framework and a description of it.

4.1 Analysis

In this section, the research questions are analyzed with the goal of developing indicators to identify circularity within the CN. Then a model is developed to analyze the indicator for an industry.

4.1.1 R-strategies and circular activities

RQ 1 investigates the presence of various R strategies named in Figure 2.2 within the CN. Strategies R-0, R-1, and R-2 are discerned by analyzing the leasing and renting sectors within the CN. Specifically, we focus on two SBIs engaged in leasing activities: SBI 7710, encompassing the *renting and leasing of motor vehicles*, and SBI 7723, involving the *renting and leasing of other products*. Leasing and renting practices inherently entail actions of refusal, reevaluation, and reduction in material utilization.

Unfortunately, strategy R-3 remains elusive due to the absence of discernible internal reuse practices within individual companies. The visibility in the CN is limited to transactions between companies, precluding the identification of R-3. Strategies R-4, R-5, R-6, and R-7 are identifiable through direct associations with repair activities evident in certain SBIs within the CN.

We identify SBI 33, specialized in the *repair and installation of machines and devices*, as a metric for assessing repair-related endeavors. Additionally, SBIs 4512 *sale of motor vehicles and trailers, including repair* and 4543 *sale and repair of motorcycles and related parts* are pertinent, alongside SBI 9500 *repair of computers and consumer goods*, all predominantly focused on repair services.

Strategy R-8 is observable through several SBIs operating within the recycling sector. Notably, SBI 4677 specializes in the *wholesale of garbage and scrap*, while SBI 3830 engages in *recycling and demolition*. Furthermore, SBI 3789 is involved in *wastewater collection and treatment*, all centrally oriented around recycling activities. At last, a less directly linked SBI with the recycling industry is SBI 8400 *public administration, public services, and compulsory social security*. However, this SBI provides services such as the collection, processing, and incineration of low-grade garbage.

Finally, strategy R-9 is discerned through an examination of the energy production sector, particularly by scrutinizing inputs and identifying garbage components. The energy producers industry encompasses SBI 3510, encompassing *electric power generation; transmission and distribution of gas and electricity*, where garbage fractions can be delineated. However, typically no metal is used to be burned for energy. Therefore, not continuation question is sated regarding this R-strategy.

Out of these strategies, it can be concluded that for RQ 2 we need to investigate the SBIs within the recycling industry, to observe R-8. In the following three subsections, the subquestions of RQ 2 are analyzed.

4.1.2 Circular material inflow

In addressing RQ 2.1, we investigate the correlation between the financial magnitude of transactions from the recycling industry to a given industry and its link to circularity. Firstly, two specific SBIs are identified as representatives of the recycling industry. Firstly, SBI 4677 primarily engages in the *wholesale of garbage and scrap*. Another significant SBI in recycling is SBI 3830, focusing on *recycling and demolition* activities. The delineation between SBI codes 3830 and 4667 hinges on the degree of garbage processing. SBI 4667 primarily involves wholesale activities related to garbage and scrap, including collection, sorting, packaging, and trading, without substantive processing.

According to SBI definitions, the pivotal factor lies in the application of mechanical (e.g., shredding) or chemical processes. Conversely, a substantial distinction in processing methodologies exists between SBI 3830 and 4667 within the supply and use tables classification. SBI 3830 encompasses the production of goods through processing and the acquisition of raw materials and ancillary substances. In contrast, SBI 4667 predominantly provides trading services under wholesale.

Two other SBIs from the recycling industry are SBI 3789, *environmental services* and SBI 8400 *public administration, public services, and compulsory social security*. They provide environmental services, such as GDC 3789010 *privately financed environmental services* and GDC 3789020 *publicly financed environmental services* with services such as the collection, processing, and incineration of low-grade garbage. The difference between the two is that SBI 8400 includes governments who collect the garbage, while SBI 3789 is private companies who provide environmental services. What makes them different from 3830 and 4667 is that they do not solely process garbage but also have different activities.

Based on the different SBIs in the recycling industry we can assess the financial significance that other sectors of the economy derive from this industry. This assessment is facilitated by using the concept of *circular material use rate* as a metric. To gauge the circular material use rate within a particular industry, percentages are computed representing the proportion of the total financial input that flows into that industry. By analyzing these percentages, we can compare the total financial transactions over a year of the recycling industry to a given industry with the financial inputs of other industries. A schematic representation of this input-output of an SBI is presented in Figure 4.1.

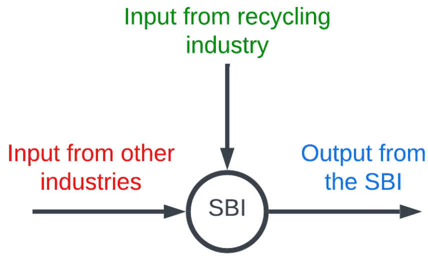

Figure 4.1: A schematic representation of the inputs-outputs of an SBI.

Although this metric will result in a percentage of monetary inflow from the recycling industry, it does not take into account imports from abroad, since the CN only included business-to-business transactions of companies within the Netherlands, as stated in Section 2.1.1. Therefore, an additional step is added by looking at the imports of the specific SBI and their GDC. GDCs that are recycled materials are listed internally within CBS.

4.1.3 Landfills

In addressing RQ 2.2, we first tried to identify the monetary inflow of landfills, where the waste will not be recycled. This proved to be not possible due to no possible identification of transactions of non-recyclable waste within the CN.

4.1.4 Upcycling and downcycling

In addressing RQ 2.3, the end-use of the recycled metal needs to be identified in order to monitor upcycling or downcycling of material. Downcycling involves the recovery of waste, resulting in a deterioration of material quality, such as diminished physical properties, darker hues, and unpleasant odors Horodytska et al. (2020). This degradation diminishes the potential for circularity, specifically, the ability to reintegrate the material into a closed-loop system Eriksen, Damgaard, Boldrin, and Astrup (2019). Conversely, upcycling enhances material quality, rendering it suitable for reuse in the same capacity as the original product Sung and Sung (2015). Consequently, prioritizing upcycling over alternative treatment methods is imperative to uphold material quality and maximize the number of material cycles. As previously stated, to be able to define upcycling and downcycling the end-use industries of the recycled metal needs to be identified. An example is presented in Figure 4.2, where the plastic recycling end-use options are presented in a schematic representation.

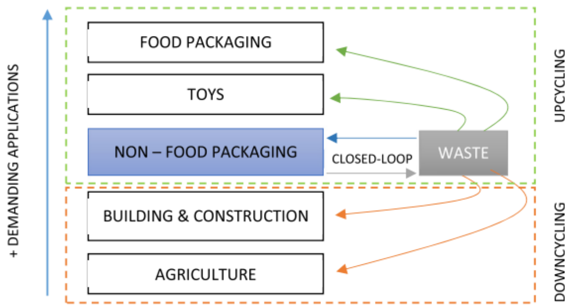

Figure 4.2: Schematic representation of possible recycling options for post-industrial plastic waste. ***Retrieved from Horodytska et al. (2020).***

4.1.5 Leasing industry

In RQ 3 the question is asked what is the relation between leasing industries and circular activities of an SBI and how its impact be identified. Within the CN there are two 4*d* codes of leasing industries. 7710 is *leasing of vehicles* and 7723 is *leasing of non-vehicles*. A possible way to measure the leasing activities within a specific SBI, we can look at the financial transactions between them. Comparing these transactions in percentages of the total input of an SBI over different years can result in an indicator of circular activities of an SBI compared to different years.

4.1.6 Repair industry

In RQ 4 the question is asked what is the relation between repair industries and circular activities of a SBI and how its impact be identified. Within the CN there are four 4*d* codes of repair industries. 3300 is *repair and installation of machinery and equipment*, 4512 is *sale and repair of motor vehicles and trailers*, 4543 is *sale and repair of motorcycles and related parts*, and at last 9500 is *repair of computers and consumer goods*. To measure the repair activities within a specific SBI, we can look at the financial transactions between them. Comparing these transactions in percentages of the total input of an SBI over different years can result in an indicator of circular activities of an SBI compared to different years.

4.2 Emperical test study

In order to answer the research questions, the dataset is analyzed using Python. At first, the dataset is trimmed by excluding generic GDCs. Generic GDCs are transactions that do not belong to the core business of a company. By excluding transactions that are not sufficiently distinctive within a company, a sharper image can be achieved.

The case study is focused on the Dutch Metal Industry (DMI). One of the reasons for this pick is that the "steel production accounts for approximately 8% of all global CO_2 emissions, with the primary steel making route using iron ores accounting for about 80% of those emissions", Raabe, Jovičević-Klug, Ponge, Gramlich, da Silva, Grundy, Springer, Filho, and Ma (2024). Moreover, Raabe et al. (2024) states as well that, "given the huge size of this sector (1.9 billion t of steel produced per year), the fastest way to decarbonize it is to produce more steel from scrap". As the steel-making process involves the combustion of fossil fuel to generate high temperatures, making it one of the most difficult sectors to decarbonize, Guzzo, Pigosso, Videira, and Mascarenhas (2022). A second motivation for the metal industry is resource scarcity. With the rising costs and environmental impacts associated with extracting lower-grade ores, there is a critical need to increase recycling and material efficiency to maintain the industry's viability while minimizing resource depletion, Henckens, Driessen, and Worrell (2014). Within the CN, the DMI exists out of the following four SBIs: SBI 2415 *iron steel ferro alloy*, 2445 *non-ferrous metals*, 2510 *metal building construction*, and 2529 *other metal production*.

4.2.1 Circular material inflow

For RQ 2.1 the inflow of the DMI is analyzed. As noted in Section 4 the inflow of the DMI exists out of import from outside of the Netherlands and the inflow of other SBIs within the CN. To get a better idea of which parts of the monetary inflow of the DMI come from importing outside the Netherlands and what comes from the CN Table 4.1 is made.

Combining Table 4.1 with the results of the inflow of the DMI in Table B.1 and the inflow from abroad for the DMI, given in Table B.2, a percentage can be calculated of what part of the input is recycled material. For the inflow from the CN, in Table B.1 all inflows from SBI 3789, 3830, 4677, and 8400 are considered as recycled material. This is not only indicated by their SBI code but also by the GDC code of the transaction. For the import, shown in Table B.2, only the transactions with GDC 3811580 are stated as recycled material. However, this assertion is not necessarily accurate. Within the CN, certain recycled materials sourced from the recycling industry may possess GDC codes other than 3811580. Consequently, some transactions that do not bear the GDC code 3811580 may also involve recycled materials.

Out of the resulting analysis in the tables, Figure A.1 is made. This figure shows in graph form the inflows of the DMI. Based on this figure and Table 4.1 it can be concluded that out of the total inflow of the DMI, $16,79\%$ of the total monetary value comes from recycled material.

However, what is not included in the circular material rate of the inflow is the fact that when part of the output of an SBI in the DMI is an input for a different SBI in the DMI. This inflow from the DMI contains recycled material as well. However, as stated in Section 2.1 the CN only contains data on transactions between companies and the GDC of this transaction. Therefore, no information is available in the CN, to know to how much of the recycled metal is present in a specific transaction. To be able to analyze without this data the following assumption is made:

SBI codes	2415	2445	2510	2529
Total monetary input	2.75×10^9	8.85×10^8	1.24×10^9	3.58×10^9
Import	73.42%	37.90%	44.58%	53.81%
CN	26.58%	62.10%	55.42%	46.19%

Table 4.1: Total inflow of the DMI divided into import from outside of the Netherlands (Import) and B2B transactions within the Netherlands (CN).

Assumption 1 *All the outflows of the SBIs within DMI have an equal percentage of recycled metal, which is in turn equal to the percentage of the total inflow of recycled material transactions out of the total inflow of transactions.*

With this assumption applied to the SBIs within the DMI the percentage of recycled material inflow increases for some SBIs as can be seen in Figure A.2. Consequently, it can be concluded that out of the total inflow of the DMI increases from 16.79% to 17.68% of the total monetary value comes from recycled material.

4.2.2 Upcycling and downcycling of metal

For the analysis of RQ 2.3, first, some theory is provided of upcycling and downcycling of metal. Later on in this subsection, an analysis of the outflows of the DMI is presented.

Utilizing scrap metal in manufacturing poses distinct challenges, particularly when producing long products and high-performance sheet steel grades, Raabe et al. (2024). Long products are steel rolled products derived from billets, which include blooms, rebars, wire rods, rails, steel wire, and others, Usamentiaga, Garcia, and de la Calle Herrero (2018). Long products, commonly used in construction, are less sensitive to steel chemistry and microstructure compared to high-performance grades, which require precise control over these factors. Meeting the stringent quality requirements of high-performance grades demands well-sorted scrap and innovative alloy designs to mitigate impurity effects, Raabe et al. (2024).

According to Raabe et al. (2024), there is a need to shift from the prevalent downcycling approach, where much of the carbon-steel scrap is currently utilized in construction steel production, towards upcycling scrap into high-performance sheet steels. The process of using steel scrap for long products is often considered downcycling, as the resulting products typically exhibit inferior quality and value relative to the original steel. This decline in quality is primarily attributed to impurity contamination from mixed scrap and the gradual accumulation of difficult-to-remove elements with each recycling cycle. Examples of this are tramp elements (copper and tin) mixed in scrap, which are difficult to remove into liquid steel during arc melting, Reck and Graedel (2012). These impurities can make it challenging to produce high-grade steel with scrap and an electric arc furnace, Harvey (2021).

Based on the paper of Watari, Hata, Nakajima, and Nansai (2023), which presented an analysis of the downcycling of steel scrap in Japan's steel industry, a similar approach is taken to analyze the outflows of the DMI. The major difference between the analysis within Watari et al. (2023) is that they have data on recycled material rate within the different outflows of the steel industry in Japan. However, under Assumption 1, it can be assumed that the percentage of recycled metal in the outflow of SBIs is equal to the percentage of metal scrap in the inflow of this SBI.

The starting point of steel flows is the procurement of raw materials: iron ore and scrap. Based on the analysis in Subsection 4.2.1, we know the percentages of scrap as inflow of each SBI in the DMI, Figure A.2. To identify where the produced metal ends up and detect in what industry the highest percentage of recycled material ends up, the outflows of the DMI are analyzed. First, the difference between outflow to the CN and export is analyzed and shown in Figure 4.3. From this figure, it can be concluded that the largest part of the outflow of the DMI goes to countries outside of the Netherlands. Especially for SBI 2415, 2445 and 2529, for which 79,31%, 62,72% and 81,82% respectively of the outflow is export. Of the total DMI, the percentage of exports from the outflow is 73,40%. Data were examined to analyze the distribution of exports from the DMI by country. The total export value from this sector amounts to 7.11 billion (10^9). Of this, 6.33% is exported by wholesalers, but data on the destinations for this portion are unavailable. For the remaining 93.67%, the destinations are detailed in Figure 4.4. From the figure, it can be concluded that the majority of exports are directed to the Netherlands' neighboring countries and the USA.

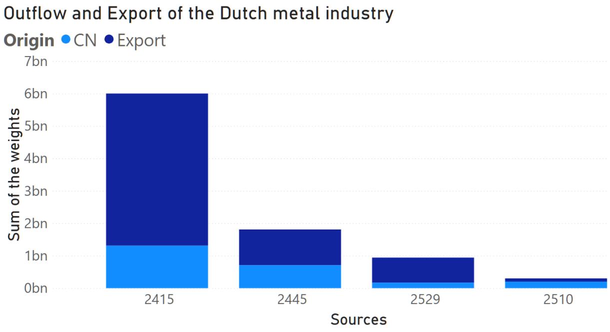

Figure 4.3: Outflow and Export of the DMI.

Besides the export, the outflow of the metal industry ends up largely in the metal industry itself, *other metal production*, SBI 2529 with 10, 15%, *metal building construction*, SBI 2510 with 4.66% and *iron steel ferro alloy*, SBI 2415 with 0.14%. This can be seen graphically in a Sankey diagram in Figure A.3, which is inspired by the analysis in Watari et al. (2023). However, these are flows from within the DMI and the goal is to analyze the flows to the end-use industries. Therefore, the export and the internal flows of the DMI are excluded from our analysis. The remaining percentage of outflow in this analysis is 11, 65% of the total outflow of the SBIs within the DMI. To which industries this outflow goes is presented in Figure A.4.

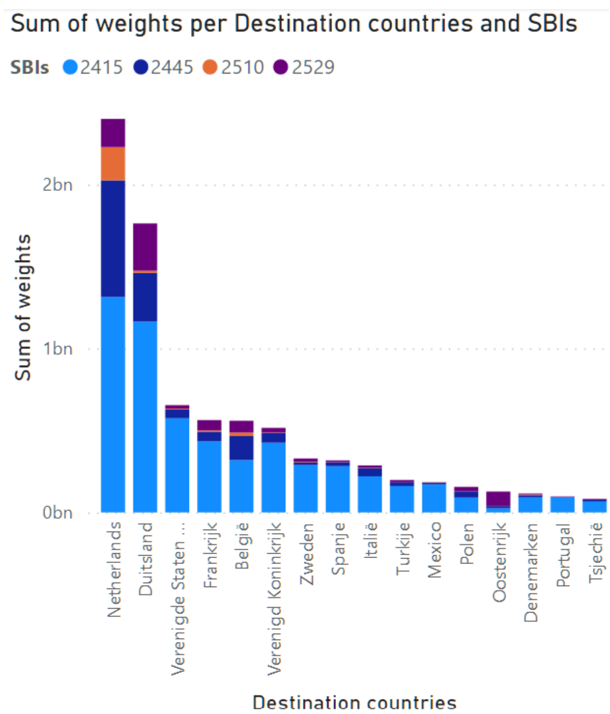

Figure 4.4: Outflow and Export of the DMI by the 16 largest consumer countries.

Combining Figure A.4, with Figure A.2, will give an idea of in which industry the metal that consists of recycled metal ends up. This is shown in Figure A.5, where the percentage of new metal and recycled metal to end-use industries are given, under the Assumption 1.

4.2.3 Leasing

Analyzing the leasing activities of the DMI by identifying transactions between the two resulted in Table B.3. Within this table, the size of *Other* is due is mainly due to 3300 *repair and installation of machinery and equipment* and SBI 4512 *Car retailer*, as can be seen in more detail in Table B.4. Although SBI 2529 *other metal production*, has more value in total transactions with the leasing industry than the other SBIs of the DMI, it is difficult to say that this SBI is more circular. This is primarily due to the difficulty in determining whether relatively higher transaction values, when compared to the total monetary volume of transactions, directly correlate with increased circularity. The leasing of vehicles, for instance, does not have a direct relationship with the total monetary volume of transactions within a given industry.

4.2.4 Repair

The results of analyzing the transactions of the DMI with the four SBIs named in Section 4.1.6 and SBIs that supply repair-related services to the DMI, are stated in Table B.4. The SBI supplier *other* consists of SBI 4719 *retail business* and SBI 6200, *computer services*. Besides the SBIs, the following GDC was selected as well in the search due to repair-related services: 3300000, 3311900, 3312900, 3313900, 3315000, 3316000, 3317000, 4511007, 4519407, 4520000, 9500000, 9511000, 9524000, 9590000. Within this analysis, SBI 4512 only supplied leasing services and is therefore disregarded. SBI 3300 is disregarded as well in this analysis since it also does not supply repair-related services. What is left is GDC 9500000. This GDC can be seen as a circular service. Again, comparing transaction values between industries can not directly relate to a higher level of circularity. What can be stated is that SBI 2510 does not use repair-related services from companies within the CN.

4.3 Framework

In this section, the designed framework for determining circularity of industries within the Netherlands is discussed. The framework itself can be seen in Figure A.6. The BPMN is a graphical representation for specifying business processes in a business process model. It was developed to be a standard, easily understandable method for designing and implementing business processes. BPMN bridges the gap between the business process design and the technical implementation of those processes, making it ideal for communication among business stakeholders, analysts, and developers, Chinosi and Trombetta (2012). Therefore, the BPMN is chosen as the model method for the framework.

Within the BPMN three participants take a role. The *Researcher*, who is responsible for designing the study, analyzing data, and developing recommendations. The *Client*, who provides necessary data and implements the recommendations, and *Experts in the field*, who provide insights, validate the research methodology, and assist in interpreting the results. The expected outcome of following the BPMN is to be able to construct dashboards showing the indicators of circularity of a given industry.

5 Validation

In this chapter the validation of both the empirical test study, Section 5.1, and the designed framework in Section 5.2 is presented.

5.1 Validation empirical test study

In this section, the validation of the empirical test study is discussed. At first, an interview with TATA steel was conducted, while the results were compared as well with the Material Flow Monitor (MFM) in, Section 5.1.2.

5.1.1 Meeting TATA Steel

In a recent discussion with TATA Steel, represented by Robbert Stemmer, several key insights were gathered regarding the inflow and utilization of steel scrap in their operations. TATA steel is within SBI 2415, by far the biggest player. Therefore, the CBS holds in their research the result of TATA equal to the result of the entire SBI 2415. The proportion of steel scrap inflow at TATA Steel has varied between 17% and 20% of the total inflow in tons over the past few years.

This data aligns with existing information on waste and environmental impact available at CBS within the MFM. However, besides that this percentage is in physical weight, TATA also included their internal recycling of steel in this percentage. This part is according to their sources around 45% of the total weight of recycled steel. Therefore, in weight 55% of their total use, which varies between 17% and 20%, can actually be seen in the transactions of the CN.

From an economic perspective, it is important to note that steel scrap is significantly more expensive per kilogram, $\sim$ 0.21 $euro/kilo$ than iron ore, $\sim$ 0.075 $euro/kilo$ or coal, $\sim$ 0.1 $euro/kilo$ in 2018 (Source: tradingeconomics.com). This cost difference is a critical factor when analyzing the monetary flows within the DMI and comparing them with percentages in kilos of inflows.

TATA states that in 2018 it used in total around 640 tons of externally imported recycled steel and 511 tons of internal recycled steel. This makes the percentage of external steel in recycling $\sim$ 45%. From the stated percentage of recycled steel in the steel of TATA over 2018 of 17% in mass, the percentage in mass of external recycled steel is 7.5% out of the total inflow of the steel production. Calculating the percentage of the monetary value of external recycled steel results in a percentage between 19.5% and 17.5% for a price of the needed coal and iron ore between 0.07 and 0.08 $euro/kilo$. Since TATA does not publish data on the prices and amounts bought of both coal and iron ore, this calculation is more of an estimate. Comparing this with the analysis in Section 4.2.1, of 22% for SBI 2415, the result of the CN is slightly outside of the bounds of the estimate.

For the import of scrap, TATA Steel does not have detailed data on the countries it imports from. This is mainly due to the international nature of their business transactions. Typically, they engage with the Dutch branches of companies, however the scrap can still originate from their German counterparts. TATA Steel in the Netherlands incorporates 15% to 20% scrap steel into all its steel production. This approach differs from global practices, where steel production may either use 100% scrap steel or none at all. The methodology of TATA aligns with Assumption 1, which states that all steel output maintains a consistent percentage of recycled content, thereby enhancing the research's accuracy and reliability.

5.1.2 Material flow monitor

The MFM developed by CBS integrates various national statistics on material flows and environmental impacts using the System of Environmental-Economic Accounting principles. A Discussion paper on the MFM is published by Delahaye, Tunn, and Tukker (2023). The MFM tracks national resource extraction, product imports and exports, inter-sectoral product flows, and emissions and waste streams from economic activities. This system is developed to provide a base for a more coherent framework for CE monitoring. The MFM details the physical material flows measured in millions of kilograms within, into, and out of the Dutch economy, covering approximately 500 product groups such as raw materials, energy carriers, waste, and CO_2. Despite its comprehensive scope, the MFM faces challenges regarding data reliability and completeness, as highlighted in Delahaye et al. (2023). According to the authors, "one limitation of the MFM is that the reliability of the most detailed data available cannot be easily verified. Data are collected from sources of varying quality, and often no alternative data sources are available."

Usage per SBI	2415	2445	2510	2529
Iron waste	1251			
Non iron waste		6		
Non metal waste	262			
Recy. iron	629			
Recy. non iron		96		
Recy. metal waste	268	51		

Table 5.1: The usage of the SBIs of the DMI in 10^6 kilogram, extracted from the MFM.

The data presented in Table 5.1 delineates two distinct categories: waste and recycled material. *Waste* encompasses materials or products that are discarded, which may be designated for recycling, incineration, landfills, or export. In contrast, *recycled material* refers to products that have been processed within the 'Preparation for Recycling' sector and are now suitable for reuse as raw materials. This categorization poses a risk of double counting, as materials classified as waste, once sent to the 'Preparation for Recycling' sector, are subsequently reclassified as recycled material upon being prepared for reuse. Hence, it is crucial to consider both categories independently and avoid aggregating their quantities directly. Out of the MFM in Table 5.1, it can be concluded that only SBI 2415 and 2445 have an inflow of metal scrap within the DMI. While in the data from the CN, clearly inflows of recycled material metal can be seen for SBI 2510 and 2529, as shown in Figure 5.1.

Comparing the values between Table 5.1 and Figure 5.1 is difficult since the figure shows monetary transactions and the table shows kilograms of metal waste. This is due to uncertainty in the prices of the different types of metal wastes.

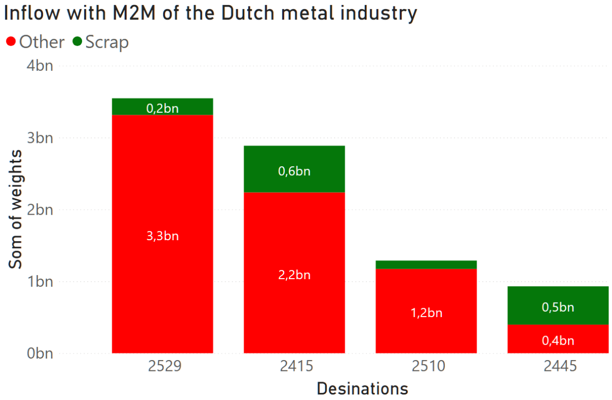

Figure 5.1: Inflow of scrap versus other material for the DMI, by taking into account the metal-to-metal industry transactions as well.

5.2 Validation Design

To validate the framework presented in Section 4.3, a validation workshop was held with the data science community of the CBS. The data science community consists of eight people with different study backgrounds, from data science to econometrics, and will be future users of the framework. To simulate their use of the framework three cases of industries within the Netherlands were selected. The community was divided into three groups to try and identify indicators, set up a boundary and scope, develop methods to measure circularity under certain assumptions, and set up validation steps. Afterwards, they filled in an assessment form and we discussed their feedback and identification of weaknesses within the framework.

Based on the assessment form and its SWOT analysis the following weaknesses and threats were identified and shown in Figure 5.2. The weaknesses identified are no time indication of steps and dependence on external parties and comparable studies. These weaknesses highlight a lack of internal control and potential delays in the process, as well as possible inconsistencies due to varying external influences. For the threats, it is noticed that there is a validation step without data. Consequently, the validation of methods is heavily influenced by subjective judgments.

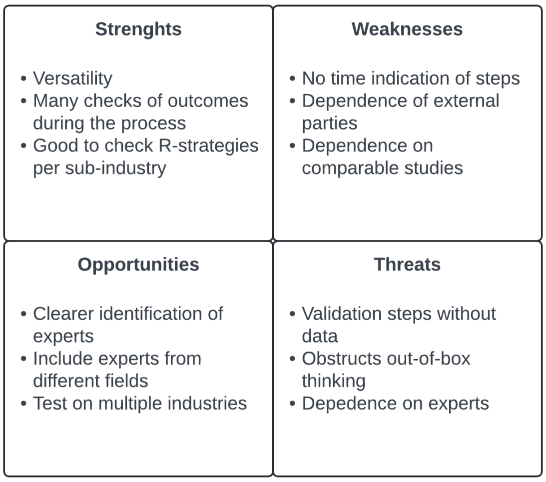

Figure 5.2: SWOT analysis of the framework, extracted from the validation workshop.

In the discussion followed we talked as well about possible solutions to solve these threats and weaknesses. To solve the lack of time identifications an additional step was identified where a Gantt chart should be made to track progress and ensure all steps are time-bound. For the dependency on external parties and experts in the field, it was suggested to have a more diverse group of experts to avert volatile external influences. During the discussion, an additional issue emerged: the interpretation of the indicators. Utilizing dashboards, we can deliver a comprehensive final product that presents the circularity indicators of an industry. However, to give context to the graphs within the dashboards, they must be compared with data from different years. This longitudinal analysis will enhance the reliability and interpretability of the findings, providing a clearer picture of trends and improvements over time. In conclusion, the framework presented in Section 4.3, was slightly revised. The new framework is presented in Figure A.7.

6 Discussion

As discussed in Chapter 1, the transition to a CE is crucial for sustainable economic growth and environmental preservation. In this study, we designed a framework to identify circularity within Dutch industries, using company-to-company transactions of the CN. This discussion will evaluate our research findings, address the challenges encountered, and highlight the implications for policy formulation, particularly for the DMI, as the subject of the empirical test study.

By answering the research questions stated in Section 2.3, circular activities within the CN for the DMI are identified and analyzed. By addressing RQ 1, it becomes evident that the R-3, reuse, cannot be identified. This is due to the lack of data on reuse activities within companies in the CN dataset. However, capturing R-3 is crucial as it influences resource efficiency, thereby affecting all three points of the definition of the circular economy. Within the MFM, R-3 is captured for some specific wastes, but not all reuse within the Dutch economy is documented. Therefore, the CBS should actively capture data on reuse to get a sharper image of the circularity within the Dutch economy.

In RQ 2, the circular material inflow, material ending up at landfills, and upcycling and downcycling are researched within the CN. We assessed the circular material inflow rate, which measures the financial input of recycled material for the DMI. The analysis shows that 16.79% of the total inflow for the DMI comes from recycled material. However, this does not account for intra-DMI recycled material flows. Assuming equal percentages of recycled metal in all outflows, Assumption 1, this figure increases to 17.68%. In the validation, the inflow of SBI 2415 was compared with data from TATA steel. Although, they were estimates, and TATA steel is not the only company within SBI 2415, a small difference is observed between the outcome of the CN and the data of TATA. Capturing circular material inflow is crucial as it enhances resource efficiency, providing a clearer picture of circularity within the Dutch economy. However, the research faces significant shortcomings: it relies on assumptions and lacks data on detailed material breakdowns into circular material and noncircular material within transactions, as stated in Section 4.2.2. Additionally, the current analysis may contain inadequate data on account imports, as it cannot be stated with absolute certainty that only GDV 3811580 contains scrap metal for SBI 2414, as stated in Section 5.1.1. Therefore, future research must focus on improving data collection and reporting on both domestic and imported recycled materials, ensuring comprehensive tracking of intra-industry flows and more precise categorization of recycled inputs. Moreover, having more comparable data is essential to validate the outcomes of the CN with TATA, highlighting the need for improved data accuracy and consistency.

When comparing the research with the MFM in Section 5.1.2, some differences emerged. The research indicated that SBIs 2510 and 2529 have an inflow of scrap metal, while the MFM assumed these SBIs do not use scrap metal. Therefore, it is recommended that the CBS update their methods to include SBIs 2510 and 2529 within their scope when analyzing waste streams in the MFM. To improve the compatibility of the MFM and CN, a method for bridging their results should be established, allowing for the integration of both sets of data.

The research revealed that the CN could benefit from incorporating internal recycling. TATA stated that for them it accounts for approximately 45% of the total recycled material, as mentioned in Section 5.1.1. This could contribute to capturing R-3, reuse. Additionally, the lack of data in the CN for identifying flows to landfills, as stated in Section 4.1.3, and for R-9, recover energy, were highlighted as another critical area. Addressing this data gap could be a potential area for cooperation between the MFM and CN. The analysis of the leasing and repair, in Section 4.2.3 and Section 4.2.4 respectively, underscore the importance of the interpretation of the indicators. It is evident that while certain SBIs like 2529 show substantial transaction volumes with both the leasing and repair industry, this alone does not conclusively indicate higher circularity. The difficulty lies in correlating transaction values directly with circular economic principles, especially considering activities like vehicle leasing that may not contribute significantly to overall circularity metrics.

Formulating effective CE policies requires comprehensive data collection systems that can provide detailed insights into material flows, waste streams, and circular activities. The designed framework helps to analyze the data from the CN and come up with indicators and methods to measure these indicators. However, as can be seen in the empirical test study on the DMI, the Dutch industry is very dependent on neighboring countries, Section 4.2.2 Figure 4.4. This dependence complicates the implementation of national-level policies. The dependence on neighboring countries was discussed and validated as well with Sekhar Lahiri, director of Vereniging Nederlandse Metallurgische Industrie, the advocacy organization of the DMI. He stated as well that effective circularity policies must consider cross-border material flows and harmonize with the regulatory frameworks of neighboring countries. Collaborative international efforts are necessary to develop cohesive and effective CE policies that can drive meaningful progress.

7 Conclusion

In conclusion, this study underscores the critical importance of transitioning towards a CE to achieve sustainable economic growth and environmental conservation. By designing a framework to assess circularity within Dutch industries using the CBS company-to-company transaction data, we aimed to identify and analyze circular activities specific to the DMI.

Our findings highlight significant challenges and insights for policy formulation. Notably, the study revealed gaps in data availability, particularly in capturing reuse activities and detailed material flows essential for accurate circularity metrics. Assumptions made in the analysis underscore the need for more precise data collection methods, especially concerning intra-industry and cross-border material flows. Comparison with the MFM revealed some discrepancies, suggesting the necessity to update analytical methods to ensure comprehensive coverage of industries and waste streams. Additionally, integrating internal recycling data could significantly enhance the accuracy of circularity assessments. Moreover, the study emphasized the interconnected nature of global supply chains, indicating the importance of international collaboration in developing effective CE policies. Addressing cross-border material flows and harmonizing regulatory frameworks with neighboring countries are essential for successful implementation.

Moving forward, enhancing data granularity and refining analytical methodologies will be crucial in advancing CE initiatives within the Netherlands. By leveraging comprehensive data insights, policymakers can better tailor strategies to promote resource efficiency, reduce waste, and foster a CE that supports long-term sustainability goals.

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A Appendix figures

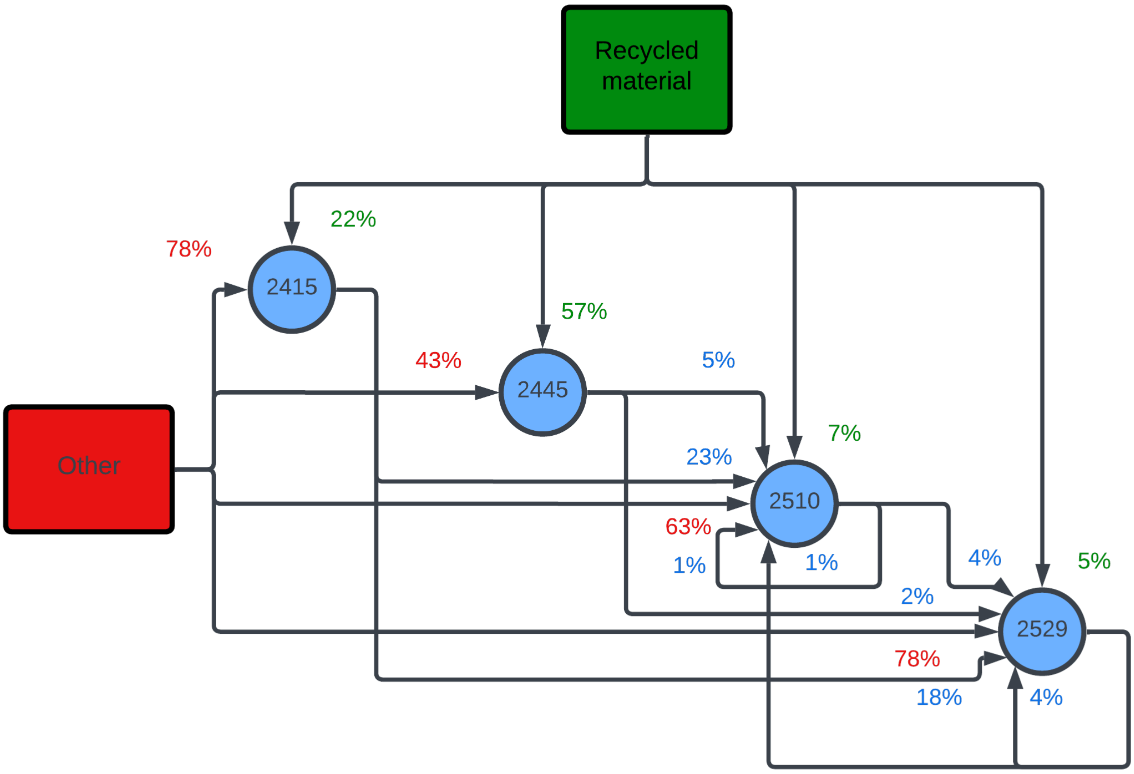

Figure A.1: Inflow of the DMI, with a difference made between inflow between metal industries in blue, recycled inflows in green and other in red.

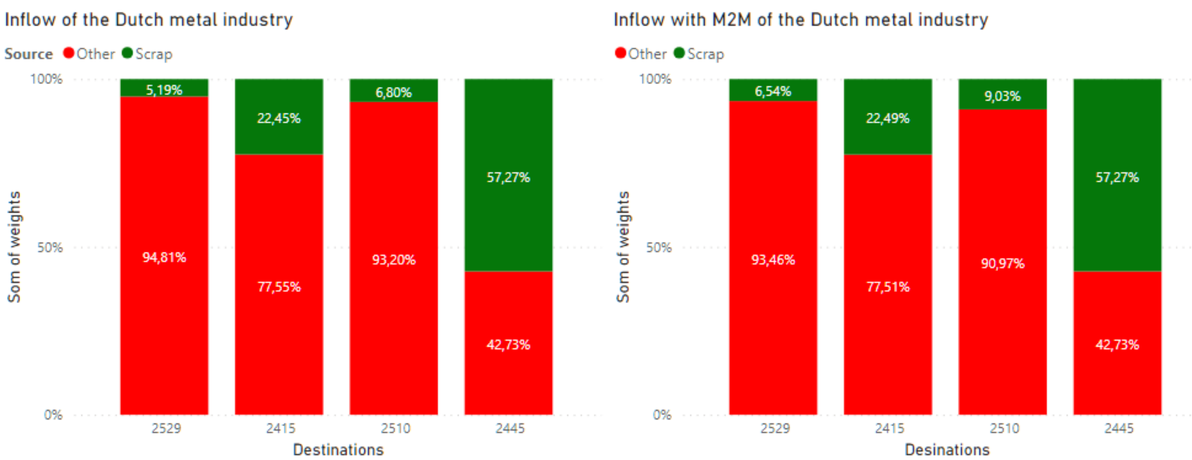

Figure A.2: The inflow of scrap versus other material for the DMI. The chart on the right takes as well into account the metal to metal industry transactions and their recycled material output.

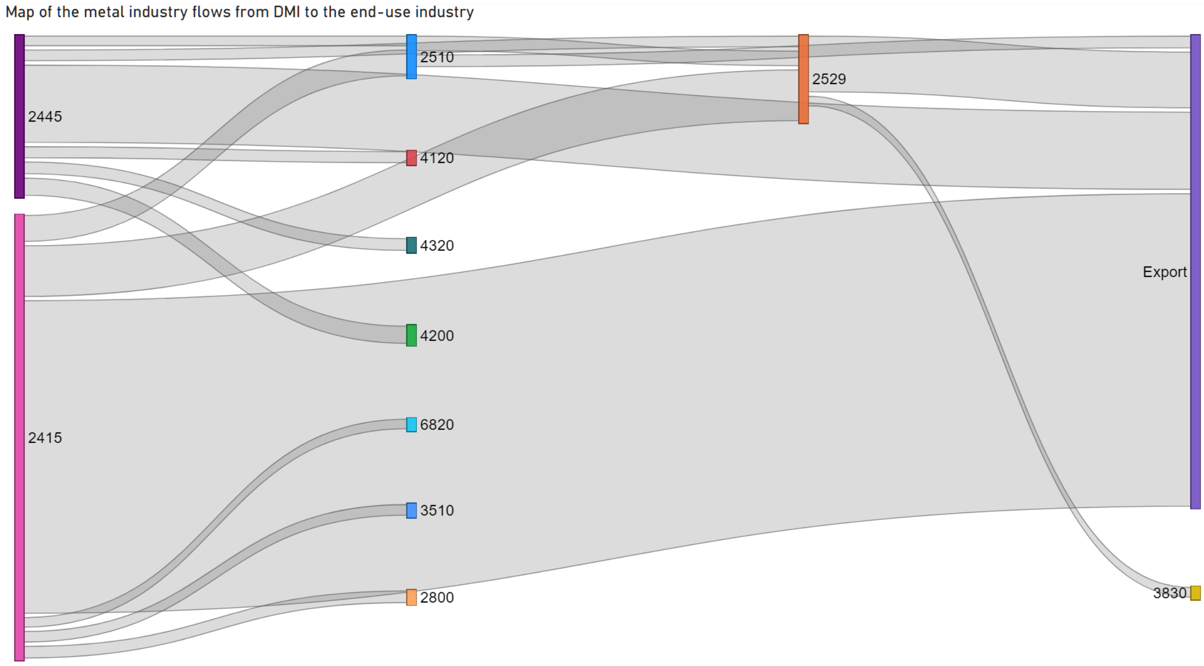

Figure A.3: Sankey diagram of the inflow of the end-use industries from the DMI. Within this diagram only connections between DMI and end-use industries with a value higher than 4×10^7 are shown, to present a sharper image.

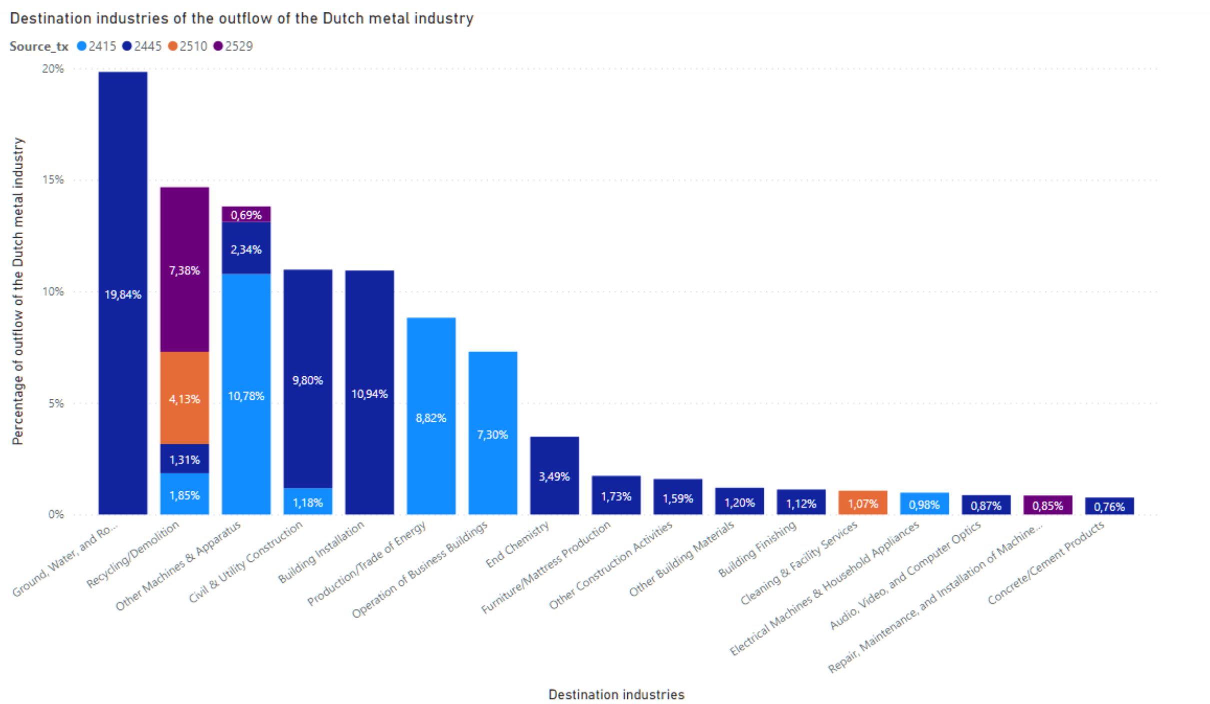

Figure A.4: The destinations of the outflow within the CN of the DMI, divided into the SBIs of the DMI.

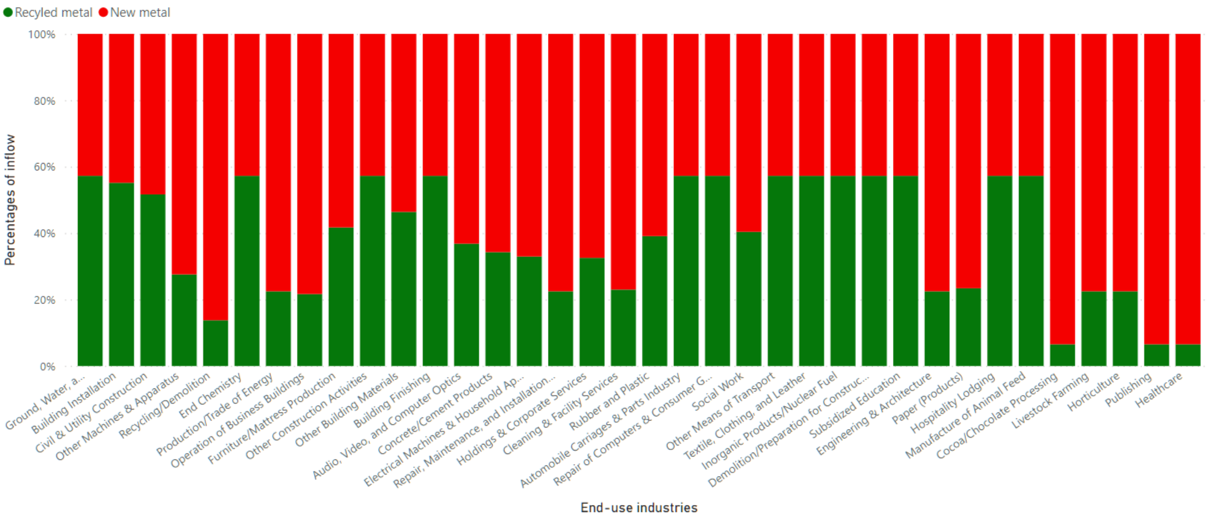

Figure A.5: The inflow of the end-use industries from the DMI, divided into New metal and Recycled metal

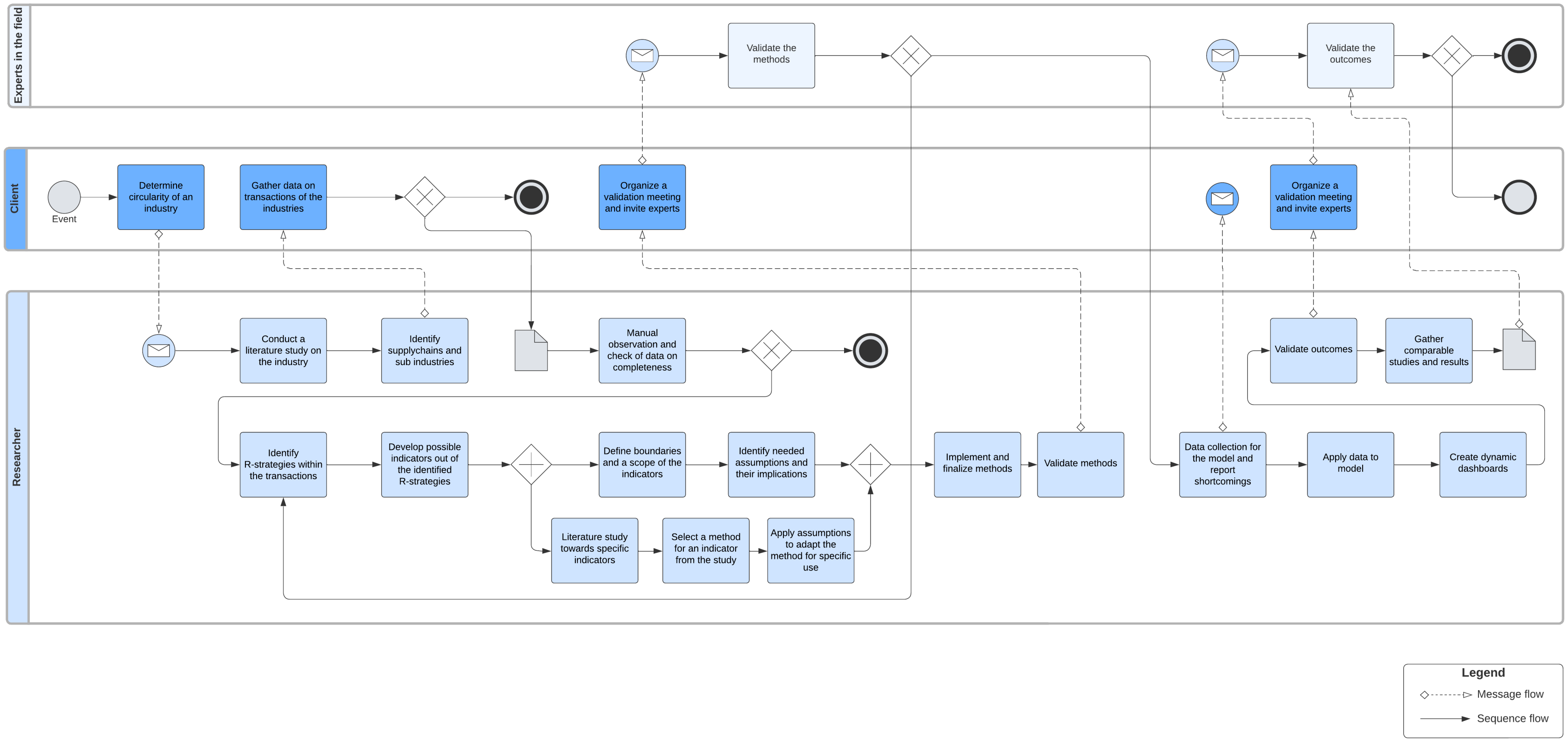

Figure A.6: BPMN for determining circularity within industries in the Netherlands.

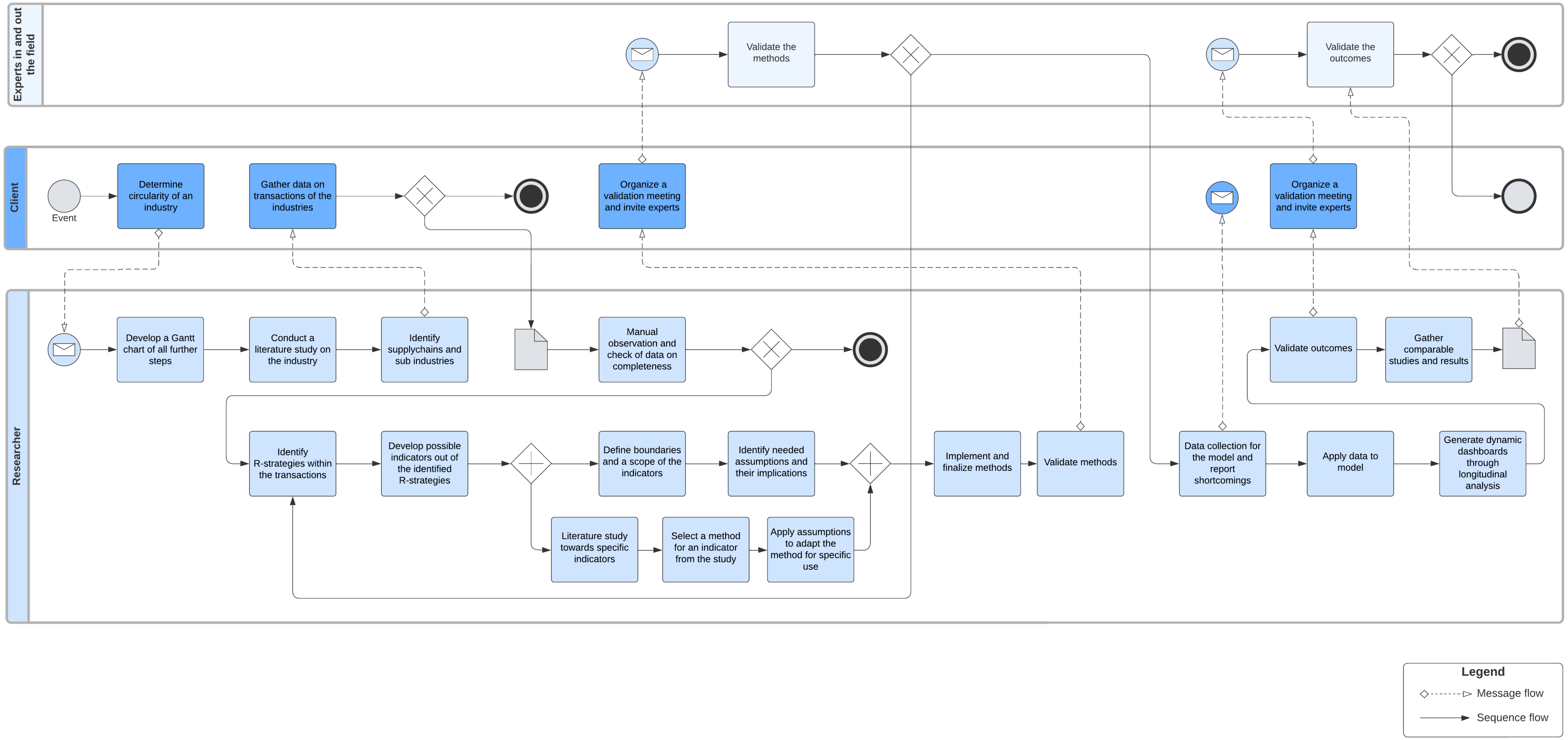

Figure A.7: Revised and validated BPMN for determining circularity within industries in the Netherlands.

B Appendix tables

		SBI user	2415	2445	2510	2529
SBI supplier	**GDC**	**Name**	iron, steel, ferro, and alloy	non-ferrous metals	metal building construction	other metal production
2415	2412300	Ferrous metals & plate/tube	1%	0%	42%	39%
2445	2440000	Non-ferrous metal & semi-finished products	0%	1%	9%	5%
2510	2412300	Ferrous metals & plate/tube	0%	0%	2%	8%
2529	2412300	Ferrous metals & plate/tube	1%	0%	2%	9%
	3811580	Waste metal and slag	1%	0%	0%	0%
3789	3811580	Waste metal and slag	7%	0%	0%	0%
3830	2412300	Ferrous metals & plate/tube	47%	0%	12%	10%
	2440000	Non-ferrous metal & semi-finished products	7%	28%	0%	1%
4677	3811580	Waste metal and slag	12%	40%	0%	0%
8400	3811580	Waste metal and slag	2%	4%	0%	0%
other	3811580	Waste metal and slag	0%	2%	0%	0%
other	3811912	Other waste	0%	0%	0%	0%
-	-	Other	22%	25%	33%	28%

Table B.1: Inflow of the Dutch metal industry per SBI and GDC.

	SBI	2415	2445	2510	2529
GDC	**Name**	iron, steel, ferro, and alloy	non-ferrous metals	metal building construction	other metal production
500000	Coal/lignite	31%	0%	0%	0%
700000	Metal ores	23%	0%	0%	0%
2412300	Ferrous metals & plate/tube	36%	4%	67%	78%
2440000	Non-ferrous metal & semi-finished products	3%	57%	13%	10%
3811580	Waste metal and slag	0%	23%	0%	0%
-	Other	7%	16%	20%	12%

Table B.2: Import of the Dutch metal industry per GDC.

		SBI user	2415	2445	2510	2529
SBI supplier	GDC	Name	iron, steel, ferro, and alloy	non-ferrous metals	metal building construction	other metal production
7710	7711000	Rental & lease car	4.34×10^6	1.00×10^3	1.00×10^3	9.05×10^5
	7791200	Rental of other movable property	0	0	6.49×10^6	2.68×10^6
7723	7711000	Rental & lease car	3.15×10^6	2.59×10^6	1.10×10^7	1.10×10^7
other	7711000	Rental & lease car	9.92×10^5	0	0	1.84×10^6
	7791200	Rental of other movable property	3.10×10^6	0	1.87×10^6	2.15×10^7

Table B.3: Leasing transactions with the Dutch metal industry per SBI and GDC.

		SBI user	2415	2445	2510	2529
SBI supplier	GDC	Name	iron, steel, ferro, and alloy	non-ferrous metals	metal building construction	other metal production
3300	7010000	Intra-corporate services	0	0	0	1.20×10^7
	7791200	Rental of other movable property	0	0	0	1.87×10^7
4512	7711000	Rental & lease car	9.92×10^5	0	0	0
	7791200	Rental of other movable property	1.99×10^6	0	1.87×10^6	2.83×10^6
9500	9500000	Repair computers & consumer items	0	1.83×10^6	0	1.58×10^6
other	9500000	Repair computers & consumer items	3.98×10^6	7.84×10^5	0	1.81×10^6

Table B.4: Repair transactions with the Dutch metal industry per SBI and GDC.