Metal and Plastic Recycling Flows in a Circular Value Chain

Citation for the original published paper (version of record):
Shahbazi, S., van Loon, P., Kurdve, M. et al (2021). Metal and Plastic Recycling Flows in a Circular Value Chain. Towards a Sustainable Future - Life Cycle Management: 195-206.
http://dx.doi.org/10.1007/978-3-030-77127-0_18

Metal and Plastic Recycling Flows in a Circular Value Chain

Sasha Shahbazi, Patricia van Loon, Martin Kurdve, and Mats Johansson

Abstract Material efficiency in manufacturing is an enabler of circular economy and captures value in industry through decreasing the amount of material used to produce one unit of output, generating less waste per output and improving waste segregation and management. However, material types and fractions play an important role in successfulness of recycling initiatives. This study investigates two main fractions in automotive industry, namely, metal and plastic. For both material flows, information availability and standards and regulations are pivotal to increase segregation, optimize the collection and obtain the highest possible circulation rates with high quality of recyclables. This paper presents and compares the current information flows and standards and regulations of metals and plastics in the automotive value chain.

1 Introduction

In today's value chain, where production rate and correlated resource and energy consumption constantly increase, efficient and effective use of resources is imperative. In addition, recent concerns regarding non-renewable resources and environmental burden of extracting and producing products from virgin raw materials have been published in several reports and scientific publications such as [1–4]. Material efficiency is an approach within circular economy and resource efficiency to regain

S. Shahbazi (✉)
RISE IVF – Research Institutes of Sweden, Stockholm, Sweden
e-mail: sasha.shahbazi@ri.se

P. van Loon
Chalmers Industriteknik, Göteborg, Sweden

M. Kurdve
RISE IVF – Research Institutes of Sweden, Stockholm, Sweden

Department of Technology, Management and Economics, Chalmers University of Technology, Göteborg, Sweden

M. Johansson
Department of Technology, Management and Economics, Chalmers University of Technology, Göteborg, Sweden

Z. S. Klos et al. (eds.), *Towards a Sustainable Future - Life Cycle Management*,
https://doi.org/10.1007/978-3-030-77127-0_18

the original material value via reduction in industrial waste volumes and decrease of the total virgin raw material production per one unit of output, in addition to increasing the homogeneity of wasted material with better waste segregation [5]. The latter enables moving from landfill and waste incineration towards recycling, remanufacturing, reuse and repair (reverse material flow).

The importance of the production phase in the value chain is essential in sustainable development and circular economy as it currently accounts for 33% of total global energy consumption and 38% of direct and indirect carbon dioxide emission [6]. In addition, the production phase contributes to different environmental effects including increased (virgin) raw material and energy consumption, great industrial waste volumes and airborne emissions.

The automotive industry is of particular interest to study, due to the fact that it negatively contributes to the majority of environmental effects. According to the European Automobile Manufacturers Association [7], the production phase in automotive industry in 2017 contributed to 38.8 million MWh energy consumption, 9.47 million-ton CO_2 emission, 56.89 million cubic metre water consumption, 1.4 million-ton waste generation and 38.6 thousand-tons of volatile organic compounds emission. Considering material flows, automotive industry is of interest since metal is used as the primary product material, while several other material fractions such as plastics, chemicals, cardboard, wood and combustible are consumed as auxiliary materials. Furthermore, the generated waste from automotive industry are common residuals mainly including scraped aluminium and steel, chemicals and hazardous waste and packaging materials such as plastics, cardboard, wood and combustible waste. Figure 1 shows the common material flows in automotive industry using a framework presented by [8].

This paper presents and compares the current flows of metals and plastics in the automotive value chain by two criteria, namely, information flow and standards and regulations. An underlying reason is to learn from the relatively better working metal recycling when improving plastic recycling and highlight common needs in both loops. This contributes to the material circular flow knowledge by pinpointing

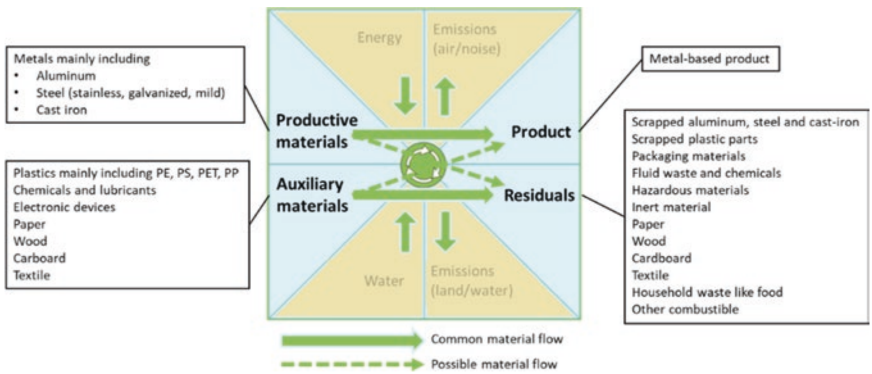

Fig. 1 Common material flows in automotive industry

the gaps, similarities and differences of two material flows as well as extending the collaboration in recycling loops. It is also a help for improving the overall material efficiency and industrial waste management practice.

2 Research Methodology

Research presented in this paper was carried out as a part of an ongoing Swedish research project called "Circular Models for Mixed and multi Material Recycling in manufacturing extended Loops" (CiMMRec), and with an extension pre-study on plastic loops in a research called "Sustainable plastic use by managing uncertainties for the market actors". The project aims to explore opportunities for extended collaboration in recycling loops, especially studying knowledge transfer, information flows, incentives, standards and regulations and business models for improved material recycling, and contributes to the area of circular economy [9] and sustainable supply chains [10]. With limited understanding and lack of empirical studies on characteristics of metal and plastic flows in an automotive value chain, a case study methodology was adopted to fulfil the research objective, consisting of real-time empirical data from different companies within the automotive value chain and a limited literature review. The studied companies are all value chain actors within the automotive industry but in the two separated metal and plastic loops. Studied companies range from primary production of raw materials, product manufacturers, foundry and waste management entrepreneurs to recycling companies.

Although the metal and plastic flows are generally different, the information flows and communication, incentives, business models and standards and regulations for these flows should not differ to a very large extent in order to have a successful recycling flow. Lack of recycling initiatives in any of these flows causes losing material values captured during the linear production processes of materials and products (linear production process as opposed to reverse processes of reusing, repairing, remanufacturing and recycling). As a result, multiple case design with embedded unit of analysis [11] was used, where one case represents metal value chain and the other represents plastic value chain (see Fig. 2). The product manufacturers in both cases are multinational manufacturing companies with global footprints in the automotive industry that use metals as primary production material (productive material) and plastics as auxiliary materials (see [5] for definitions). The selection of companies was mainly based on their close collaboration and project connections, which in turn was primarily based on their enthusiasm in improving their current systems for achieving sustainability and circularity in their materials flows. This close co-research connection facilitated accessing and data collection, arranging semi-structured interviews [12], direct observation by visiting operation sites [11], reviewing relevant documents and monitoring material and waste flows. In the first set of interviews, a total of eight people was interviewed, although some (waste management entrepreneurs) answered two sets of questions related to both metal and plastics. Each semi-structured interview lasted between 30 and 90

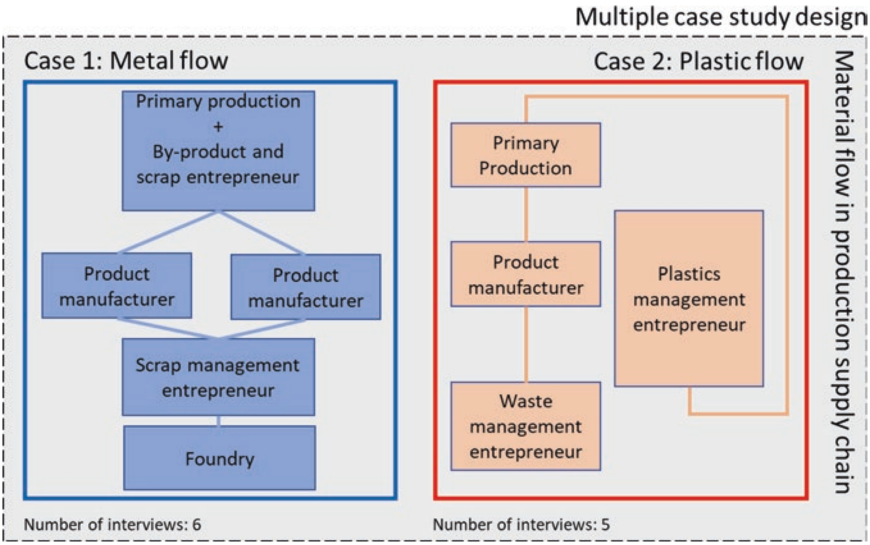

Fig. 2 Case study design

minutes and incorporated predefined questions regarding metal and plastic flows in value chain with several criteria such as information flow, regulation and business models. A second set of interviews included four interviews with six people from the same plastic flows as the first set of interviews. Considering these ongoing market changes, the supplier - user requirements were further elaborated. Data analysis and interpretation was performed within a very short time interval after data collection, as suggested by [11]. Consistency between interviews and for both material flows was maintained throughout the data collection and analysis, by continuously reviewing, comparing and discussing the results with project members including practitioners from the studied companies.

3 Empirical Findings and Discussions

The empirical findings and following discussions presented in this section are based on performed interviews of actors in the value chain shown in Fig. 2, reviewed documents and also direct observation in operation sites (where possible). This section is divided into the main material flows in automotive industry, i.e. metal and plastic. For each material flow, the two main criteria, i.e. information flow and regulations and standards, are discussed.

3.1 Metal Flow

Several different types of information and data are communicated between different actors within the value chain. However, our focus was on information that helps circulating the metal flow (mainly metal scrap in order to close the loop) for recycling and reuse. That being said, the main information flow within this value chain includes material type and fraction, sorting degree, physical shape and dimension, amount in terms of weight in kg, chemical composition and price. There has been a general consensus among the actors (interviewees) that currently sufficient amount and type of information is available (e.g. exact chemical composition of the waste), and there is no need to dig deeper to find the information. However, the problem is mainly information sharing, communication and transparency. It is also the matter of actors' ambitions to ask for more information and to put more effort and time in obtaining necessary information and analyse them for improvement. For instance, the communication between the scrap management entrepreneur and product manufacturers (and also right department, in particular purchasing who buys materials) could be improved; in a specific example, changing the material and/or supplier of components was not clearly communicated with scrap management entrepreneur. The main reason for this was that the product manufacturers were not aware that changing alloy or chemical content of materials and components would have serious consequential effects in end-of-life management and recycling. This issue does not require any regulation or legal intervention, but better information sharing and communication between the actors. Another issue related to information is variability. The majority of metal scraps and waste are generated due to deviations, errors and mistakes in production (see also [8, 13]); therefore, types, physical shapes and weights differ significantly from one to another. This variation negatively affects the number of transportations where sometimes half-full trucks are transporting the waste. There have been some unsuccessful attempts to solve this issue such as using sensors in the metal bin, but it did not work as good as for fluids. In another example, a camera was placed to monitor the content of the metal bin, but sharing this type of data between companies was problematic due to IT regulations. Nevertheless, it could be concluded that improvement actions should start from the product manufacturer, for instance, with better sorting or better communication of information with other actors.

Taking regulation and standards into consideration, there was an agreement among the actors that quality standards for secondary material (metal) would not only ease pricing based on value but also help improve waste segregation and recycling. However, there was also consensus that forced additional standards may disturb the market and distort the competition. The metal primary production actors believed that having more standardized fractions would lead to more complexity and therefore more cost would relate to type of scrap, handling systems and storage. According to metal primary production actors, European standards bring difficulties due to import and export regulations between different countries which take a lot of time and knowledge to fulfil those requirements. The interviewee from a foundry company also asserts “I don’t see any need for additional standards on iron and steel, but how well one manages to follow the standards is important … we don’t need any further pressure or temptation”. In Sweden, companies also follow the national iron standard (Järnbok), which does not always align with standards from other countries, e.g. when buying iron from Germany. Hence, in the long term, an international iron standard is needed to facilitate recycling. There was also difference of opinions on whether regulations and standards should be material or industry specific.

To summarize our empirical results on metal, information flow, actors’ role, technology development, market, regulation and standards, product design and behaviours work quite fine with the current infrastructure of metal flow, although several minor improvements (such as given in the examples above) can be made.

3.2 Plastic Flow

The main information flow within the reverse plastic value chain (mainly recycling and reusing) includes plastic type, fraction and prime material, sorting degree and cleanness, shape and dimension, volume in terms of weight in kg, chemical composition and price. Unlike the metal flow, the general consensus among the actors was that more and better information and communication are needed, particularly on exact sorting degree and exact type of plastic and fraction, including details on risk of contamination with unwanted substances. The information flow from the plastic supplier to product manufacturer seems to be working better than the information flow to the waste management and also further back to the plastic management entrepreneur (see Fig. 2). In spite of this, also the information required and given from the supplier has gaps. For instance, it is now the product manufacturer that almost solely decides on the selection of supplier and also type and material of the plastic packaging of purchased components. This decision is mainly based on requirements on the products’ protection during transport, due to legal issues (the one who determines the packaging is responsible for parts broken during transport), and until just recently, the footprint of the packaging material has not been in requirements. However, such decisions could involve waste management entrepreneur to explore and discuss opportunities to exclude plastic packaging to a certain possible level and use less additive to ease recycling.

According to the interviews with actors in the plastic value chain, there are several issues with the plastic recycling, including the following:

(1) Recycled plastic does not always have the exact same quality/properties as specified in current parts.
(2) Price of recycled plastic has often been more expensive compared with the relative low prices of plastics made of virgin material, although recently virgin prices have been perceived as more volatile according to the second sets of interviews.

(3) The reverse value chain is not as smooth and steady as the forward value chain and has lots of interruptions, delays and bottlenecks due to unevenness of availability of recycled plastics and variable lead time in collection of plastic waste and recycling. Within the automotive industry, manufacturing companies have the obligation to produce the exact same product for several years, e.g. 10 years, and hence, they need a guarantee that the recycled plastic with the same properties and quality is available for the next 10 years and can be delivered steadily in order to be able to produce the same product with the same properties and quality.
(4) There has not been a customer requirement on the share of recycled plastic in the products. Increasing the share of recycled plastic without the customers' requirement and with current higher prices of recycled plastic compared to virgin plastic would make the product more expensive and hence less competitive.
(5) The interviewees also highlighted issues with the plastic recycling process itself, including lack of plastic sorting. Increase in the number of bins to better segregate plastics into more fractions is a great challenge because usually there is not enough space inside and outside the factories. In addition, managing five to eight different plastic fractions would be time-consuming and expensive for the product manufacturer considering the relatively low market prices. There are also more combustible bins on the shop floor with less walking distance than a specific plastics bin. Consequently, with intrinsic indolence of human being and weariness and exhaustion from work, plastics are usually discarded in combustible bins. One potential solution would be to somehow achieve higher market price for the sorted recycled plastics.
(6) Unlike the household plastic waste that is separated after collection by the waste management entrepreneur in exchange of a small fee, in the industrial system, the product manufacturer is not willing to pay the waste management entrepreneur for segregation, which substantially limits the segregation. At the same time, factory workers do not understand the need for sorting plastics in multiple fractions as just one bin for plastics is used for households. Therefore, a behavioural change or education/training in industry is needed for further waste segregation of plastics.
(7) Low volume fractions are not economically viable for separation and recycling. According to the interviewees and our previously published study [14], polyethylene (PE) account for 40–74% of total plastic waste from automotive manufacturing, which can and must be separately segregated for recycling. However, the remaining fractions (such as polypropylene – PP) have relatively low volumes, and hence, efforts for separation are perceived not to be economically viable.
(8) There is a transportation efficiency issue with correlated high costs that trucks need to be full for economic and environmental reasons. A sufficient volume for each transport can be 3–4 tons for PA (polyamide) and 5 tons for PP, a relatively high amount compared to the general low volumes of sorted plastic waste in many automotive plants.

(9) Separation should be based on polymer which is difficult for operators to distinguish the type of plastic; hence, environmental education as well as plastic labelling is important as unmarked plastics cannot be segregated.
(10) Segregated plastics should not be contaminated with dirt, sand, metal chips, etc.
(11) There is a lack of information, e.g. precise volume, sorting degree and type of material for transportation. Not all companies provide the necessary information to the waste management or plastic management entrepreneur. Sometimes, the information provided is also wrong. Therefore, extra time and cost have to be put in testing the fractions randomly by the waste management or plastic management entrepreneur.
(12) Current technologies for plastic segregation and recycling (e.g. segregation machine based on plastics colour shade) are inefficient and expensive, and also the process is time-consuming, which neither the customer nor the product manufacturer willing to pay for that.
(13) Demand for recycled plastics has been low and separation is being done manually; hence, there is a high associated cost.
(14) It is simply too expensive to recycle plastics, compared to incinerating it. However, this issue is related to Sweden where it is relatively cheap to incinerate to produce household heat; hence, little incentive exists for industry to recycle more. Government intervention or tax is needed to solve this problem and gives motivation to make changes, for example, by looking into other countries such as France where it is rather expensive to incinerate or the Netherlands where it is forbidden to incinerate certain materials.

Taking regulation and standards into consideration, in general it was believed that more regulation would be helpful to close the plastic loops; however, the so-called carrot approach was more favourable than the stick approach. During the interviews, several regulation suggestions were proposed including the following:

- Better suited industrial waste fractions standards (not necessarily regulated), adapted for how to sort to reach marketable fractions and material properties.
- Regulations and standards that take away tax on recycled material to lower costs for using recycled plastics. Maybe also subsidies to start demand for recycled plastics will help. Likewise, shifting tax from labour to tax on virgin materials might help sort and recycle plastics better.
- Regulations and standards on having the same type of plastic for all packaging to reduce diversity and ease sorting. Purchasers can make demands on suppliers to use only a certain type of plastic.
- Regulations and standards on number of polymers allowed in a single product. Many products include several types of plastics which are difficult to separate. Shredding or incinerating those products is the only current possibility. Perhaps some legislation on not mixing several types of plastics might be helpful.
- Regulations and standards on labelling the plastics. Unmarked plastics cannot be segregated into plastic fraction and hence are thrown in combustible bins without any recycling. Companies could demand suppliers to mark their plastics.

Although label is mainly for end-customers, it might lead to OEM wanting a higher share of recycled materials in their parts.

- Regulations and standards to force product manufacturing companies to take responsibilities for their plastic waste and segregate it (e.g. PE as mentioned earlier).
- Tax on waste incineration; alternatively, prohibiting incineration of recyclable materials.
- Regulations and standards to put requirements on sorting and recycling waste; alternatively, tax on unsorted waste.
- Regulations and standards to put requirements for manufacturers to use a certain level of recycled material.

Nevertheless, some concerns regarding regulations were also expressed including limiting regulation from European Union that hinder the plastic recycler and recycled plastic seller to purchase and import from non-EU countries, which exacerbate the abovementioned issue of insufficient volume. It was of concern that having strict legal requirements only in Sweden might lead to a shift to other countries outside Sweden to stay competitive in the market; therefore, regulations and standards must aim at EU and/or global level. Furthermore, waste management entrepreneurs were concerned about standardization that would also mean increased logistics and increased requirements of more bins and space. Plastics have a large volume compared to weight. Therefore, for efficiency transportation, a shredder is needed to make plastic more compact to increase the volume for each transportation.

There was difference of opinions on whether regulations and standards should be material or industry specific. One example of industry-specific regulations and standards was to have a simple guideline for automotive industry to pinpoint few possible improvement steps for better plastic segregation and recycling. An example of material-specific regulations and standards was to put tax on certain virgin materials. However, this proposition was argued to be counterproductive in a way that it might decrease the use of virgin plastic but not necessarily increase the recycled plastics. Tax cut could improve the situation, but the price of recycled plastic is much higher than the tax on it and therefore would only have a very limited effect.

There is some sort of circular business model in the studied product manufacturing company to reuse some plastic components where slightly lower properties are required and also some variations are possible. Nevertheless, proper reuse and remanufacturing of plastic parts is not possible. There is not much commodity between parts and it is much easier to melt down plastic and recycle it. However, it would be still very costly to have an additional flow of used plastic parts in production. This requires a big design change in the automotive industry, e.g. less durability requirement in vehicles for carpooling.

4 Conclusion

There has been a consensus among interviewees that competition for recycled material will increase and more manufacturing companies will ask for recycled material. Hence, waste management need to be integrated in daily operations, to effectively meet the increased demand. According to our empirical study and performed interviews, metal waste is segregated to a high degree and with low level of errors, while mostly the exact chemical composition of the metal scrap is known. For instance, to get the best recycling option, steel is not mixed with non-ferrous metals like aluminium or copper. The demand for recycled metals is also relatively good and current standards are fine. However, there are still some improvement potentials in metal flow management such as better communication and information sharing among actors which could positively affect the number of transportations and incoming material selection for better recycling options at the end-of-life. These issues are apparent also in the small plastic recycling flows. On the other hand, the major problem for plastic recycling is that plastic waste has low level of segregation with high level of errors in the segregation process. The full chemical composition is usually not known either. As a result, the plastic waste needs to be regularly checked, which implies additional waste handling and administration. With such low level of separation (due to several reasons discussed earlier) and correlated low volumes, inefficient transportation, quality errors and contaminations, technological issues and top of all insufficient demand for recycled plastics and low price of virgin plastics, recycling were commonly not regarded as economically interesting for companies in the value chain. There is a rather great requirement for more standardized fractions, and legal requirement as well as an economic or regulatory motivation.

As it can be perceived from literature and our empirical study among actors in the value chain, the metal flow is more matured than the plastic flow. This can be argued with the long history of metal industry development since the 1850s, and even far back earlier in the prehistory where human used metal to build tools and weapons. On the other hand, plastic industry development is relatively new, started in almost the 1950s. While the plastic manufacturing and use in a variety of applications expanded exponentially, little thought and research has been given to the impact of such quick growth and to develop proper waste management system for plastics. In addition, this can be reasoned with the fact that the metallurgical properties of metals allow them to be recycled repeatedly with no or neglectable degradation in performance and quality, and from one product to another. Deteriorating, plastic recycling is challenging, thanks to the variety of additives and blends used in manufacturing, low demand of recycled plastics and cheap price of virgin plastic.

With such underdeveloped plastic waste management and the sudden decision of China in 2016 to terminate importing plastic waste for recycling, we need to create the motivation in developed countries to develop an effective domestic recycling infrastructure, expand domestic market for recycled plastics, change the product design for better recycling and reuse and make the business model economically more interesting for actors in the value chain. A developed market and competition can be enablers for self-imposing regulation in increasing the share of recycled material in the products, increasing tax on virgin materials and reducing tax on recycled materials, subsidies, etc., which will happen gradually and naturally over time.

Our studies were carried out in automotive industry where metal is the dominant material, and circulation (recycling in this case) of the dominant materials is of most importance due to volume and value. However, this should not justify the low circulation/recycling rate of other materials, particularly plastics.

References

1. Litos, L., & Evans, S. (2015). Maturity grid development for energy and resource efficiency management in factories and early findings from its application. *Journal of Industrial and Production Engineering, 32*(1), 37–54.
2. Mistra Closing the Loop, Closing the Loop for industrial by-products, residuals and waste: From waste to resource. 2015, The Swedish Foundation For Strategic Environmental Research, Sweden.
3. Worrell, E., Allwood, J., & Gutowski, T. (2016). The role of material efficiency in environmental stewardship. *Annual Review of Environment and Resources, 41*(1), 575–598.
4. Ellen MacArthur Foundation, Circularity indicators: an approach to measuring circularity-Methodology. 2015, Ellen MacArthur Foundation, UK.
5. Shahbazi, S. (2018). Sustainable manufacturing through material efficiency management. In *Innovation, design and engineering*. Mälardalen University: Sweden.
6. Garetti, M., & Taisch, M. (2011). Sustainable manufacturing: Trends and research challenges. *Production Planning & Control, 23*(2–3), 83–104.
7. The European Automobile Manufacturers' Association, A., The automobile industry pocket guide 2018/2019. 2018.
8. Shahbazi, S., et al. (2018). Material efficiency measurements in manufacturing: Swedish case studies. *Journal of Cleaner Production, 181*, 17–32.
9. Ellen MacArthur Foundation, Towards the circular economy. Economic and business rationale for an accelerated transition – Executive Summary, 2012. Ellen MacArthur Foundation.
10. Brandenburg, M., et al. (2014). Quantitative models for sustainable supply chain management: Developments and directions. *European Journal of Operational Research, 233*(2), 299–312.
11. Yin, R. K. (2014). *Case study research: Design and methods* (5th ed.). Sage.
12. Kvale, S., & Brinkmann, S. (2009). *InterViews: Learning the craft of qualitative research interviewing*. Sage.
13. Kurdve, M., van Loon, P., & Johansson, M.. (2018). *Cost and value drivers in circular material flow logistics*. In 5th International EurOMA sustainable operations and supply chains forum.
14. Shahbazi, S., et al. (2016). Material efficiency in manufacturing: Swedish evidence on potential, barriers and strategies. *Journal of Cleaner Production, 127*, 438–450.