

Article

Analyzing How Governance of Material Efficiency Affects the Environmental Performance of Product Flows: A Comparison of Product Chain Organization of Swedish and Dutch Metal Packaging Flows

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Abstract: Environmental governance is commonly performed through recycling, but its effects are often difficult to predict. Studies have covered the environmental impacts and organizational structures of recycling and other circular economy governance, but only to a small degree related organization to environmental performance. We have therefore explored a methodological contribution for better understanding. We have applied and tested a hybrid, socio-material, approach, a product chain organization (PCO) study, in a comparison of governance of metal packaging product flows in Sweden and the Netherlands. A PCO study is a systematic and nuanced exploration of how nets of actions and actors shape environmental impacts. We identified that the policies in the two countries have focused on combined recycling rates, which has indicated superior Dutch governance. We, however, have discerned how various actions have been environmentally relevant, regarding inaccurate statistics, combining of waste streams, and consumption. We conclude that the test case on packaging shows how a PCO study can complement other approaches with a nuanced understanding of the environmental effects of governance toward a circular economy.

Keywords: recycling; socio-material, governance; life cycle assessment (LCA); methodology; inter-organizational; comparative studies; circular economy

1. Introduction

Recycling, reuse, and reduction are key principles in the literature on a circular economy (CE) [1,2]. Of these material efficiency approaches, recycling is currently performed to a considerable degree, but reuse and reduction are less practiced [2–5]. The prominence of recycling is suggested by an identification worldwide of 395 extended producer responsibility (EPR) policies on mainly take-back demands, disposal fees charged at the point of sale, and refund systems [3].

Despite the prominence of recycling governance—that is, recycling policies, related practices, and technical solutions—its environmental performance is difficult to predict. In a study on iron and steel scrap in the United Kingdom (UK), large losses of or lack of accounting for the scrap were identified [6]. Regarding packaging recycling rates in the European Union (EU), 2008 targets had not been reached in 2015 for 12 out of 27 countries, and in most of these cases, the 2015 rates were far from the goal [7]. In South Korea, an EPR program introduction coincided with a large decrease in their metal packaging recycling level [8]. In another study, it was concluded that proposed e-waste EPR programs in developing countries likely would be ineffective. The reason given was that EPR assigns responsibility to producers and that a large share of the products in question is supplied by actors that are difficult to identify [9]. Regarding the commonly used waste hierarchy, it was found not to apply

generally to plastics due to uncertain assumptions in existing studies [10]. In addition, it was shown that a majority of the scarce metals in Swedish vehicles were not functionally recycled and that this was obscured by a high overall recycling rate for the vehicles [11]. In conclusion, additional studies on recycling governance and its environmental performance seem warranted in order to gain a better understanding of governance solutions and their limitations.

We have identified various approaches to the study of recycling governance in the research literature: life cycle assessment (LCA) (e.g., [12]), socio-materially hybrid studies (e.g., [13]), and comparative studies (e.g., [14]). Each method addresses different aspects of recycling governance. Regarding LCA, it provides a systematic environmental approach for analyzing potential environmental impacts of the material flows, including waste flows, related to a product [3,12,15]. An LCA study, however, does not document or analyze the human actions that enable and condition these impacts, although considerable observation of them likely occurs during the study. In line with this observation, environmental studies of material flows [13,16,17], as well as management studies [18], have been suggested to consider *both* environmental and organizational aspects. Both fields thus seem to call for combined approaches. Finally, a comparison of relatively similar cases is in the social sciences seen as a requirement as well as an effective means of reaching understanding [14,19]. Because of the seeming relevance of each of these three approaches, combining them could be fruitful.

The three approaches have been used together to some extent in research on material efficiency governance. A comparison of textile waste management in the UK and Korea produced the conclusion that systematic governmental control and actor collaboration is important for reaching high recycling rates [20]. A comparison was performed on EPR on packaging and waste electrical and electronic equipment in 11 European countries [21]. The policies were found to be significantly more successful, regarding recycling and collection rates, where local authorities partake in developing systems, existing infrastructure is used, and producers and local authorities are given clear roles. E-waste management systems in Switzerland and India were compared regarding waste amounts, toxic emissions, and social aspects, and the conclusion was that no single solution exists [22]. The conclusion from a comparison of waste prevention in 11 countries was that the policies focus on supporting measures based on LCA, providing consumers clear LCA-based information, and encouraging collaboration along supply chains [23]. These studies, however, represent environmental impact through coarse parameters, such as recycling rate [21] and high or low toxicity level [22], and do not guide further studies by clearly presenting methods and delimitations. In addition, the studies to a considerable degree compared very different countries and did not focus on details of practices, and therefore mainly provided guidance at a general level without analysis of the practical feasibility of improving environmental performance. We thus see a potential for complementary approaches.

Our aim is to contribute methodologically toward a better understanding of how material efficiency and improved environmental performance are achieved. Specifically, our objective has been to apply and test the product chain organization (PCO) approach in a comparative study of Swedish and Dutch metal packaging flows. A PCO study relates a systematic environmental assessment to nets of human actions and allows the analysis of how governance affects environmental impacts.

2. Research Design: Methodology and Test Case Method

We introduce the general PCO methodology proposed for environmental governance studies before we describe the specific method used to test the PCO approach in the recycling governance study. The general methodology consists of procedures for socio-materially combined analysis. The approach links LCA-based studies to process-oriented organizational studies, through an explorative and nuanced use of different research techniques. The specific method is based on describing and analyzing how the steering approaches in the governance relate to environmentally relevant actions. In a subsequent step, the methodology was tested by relating these insights to the LCA approach and promising governance studies. The PCO approach has been applied to, for example, a comparison of

certified and non-certified cocoa supply chains [24], and a study of the supply of rare earth metals to electric vehicles [25]. This article presents its first application to a waste management focused case.

2.1. A Hybrid Methodology for Both Flows and Nets of Actions: Product Chain Organization (PCO) Study

A PCO study takes a socio-material approach to material flows. This means that material flows with their environmental impacts are studied in relation to the organization of actions and actors needed for the creation of the flows. The methodology combines an LCA-based environmental life cycle study of the material flows that pass through the production, use, and waste management of a product—the product life cycle [12]—with a study of the organizational processes that shape these flows through a net of actions—an action net [26,27]. The edge of an action nets study at the product life cycle is studied through the conceptualization socio-material interaction point at the product life cycle (SMIP) [28]. A SMIP is where there is a relation between action and material flow through hands-on activity, such as when a machine operator pulls a lever in a production facility or a consumer watches a product at a retailer. In a PCO study, SMIPs are constantly considered in order to approach for example the limited effect of policies and top management on the actions at the material flow realistically, although the SMIPs may not be covered in detail in a broad study. Figure 1 illustrates this structural basis of the methodology.

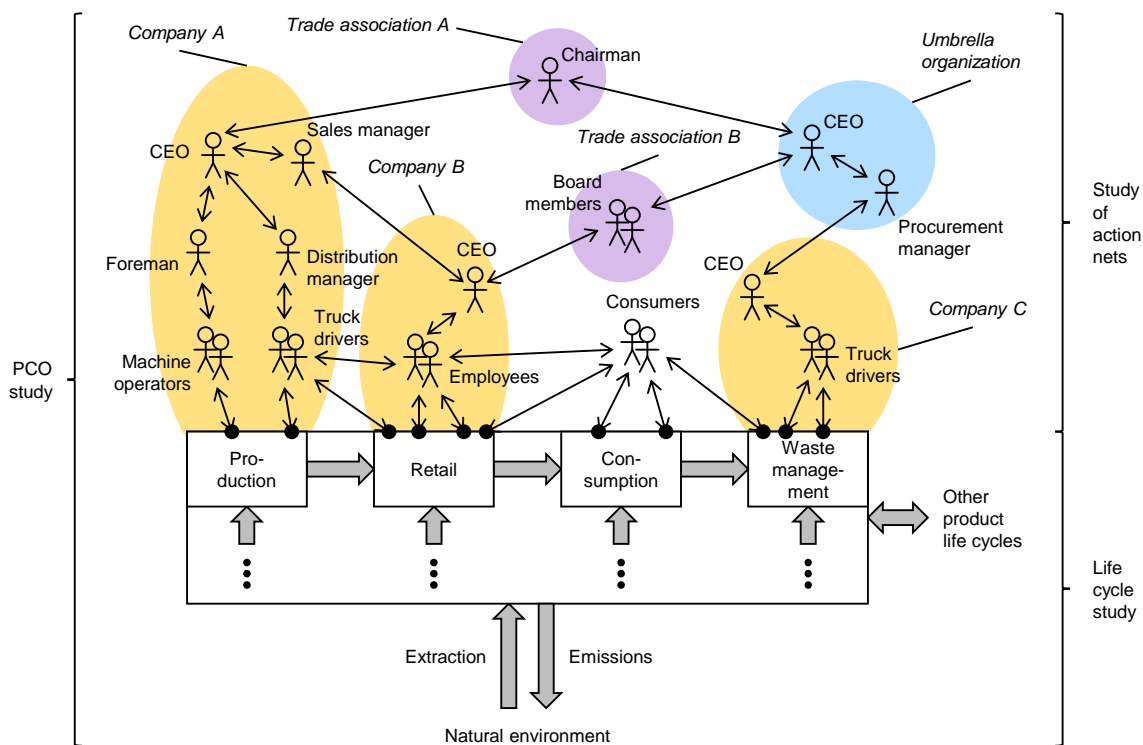


Figure 1. Structure of a hypothetical product chain organization (PCO) study and its results. An environmental life cycle study is related to a study of action nets via socio-material interaction points at the product life cycle (SMIPs) (larger black dots). Boxes represent technical processes, thick arrows represent material flows, vertically consecutive discs represent further material relations, and thin arrows represent human interactions. CEO = chief executive officer.

The methodology thus allows for the identification and analysis of environmentally relevant organizational processes. A conventional life cycle study maps only environmental impacts of technical processes, but a PCO study covers both these and the actions and actors affecting the material flow. A PCO study differs from conventional organizational studies [29] by following the organizing defined by the product material flow, rather than that of a company or other societal

actor. The action nets approach used is a type of organizational study that enables the covering of organization across organizations [30]. In addition, compared to social network analysis and other social science approaches more commonly used in relation to studies of material flows [13], the action nets approach is more descriptive and qualitative [26,27]. The action nets approach thus encourages a further study of how environmental impacts may occur and the implications of how they occur. Regarding the bridging between the social and the material, the PCO methodology aligns with the socio-material approaches that have become established in the social sciences and humanities [31–34].

A range of data collection techniques can be used in a PCO study, such as interviews, observation, and document studies [35]. When applying them, a stance similar to critical management studies [29] is useful, because it emphasizes how human actions shape information. We draw particularly on the approaches discourse analysis (DA) and conversation analysis (CA). In a DA, text and talk are considered to perform actions, and through a CA, conversations are seen as alterations between talking and listening and the effects of this are considered [35].

Regarding the procedure for applying the PCO methodology, earlier PCO study experience [24,25] has resulted in the following steps:

- (1) Describe product life cycles;
- (2) Identify socio-material interaction points at the product life cycle (SMIPs);
- (3) Trace and describe action nets between SMIPs at various places along the product life cycle;
- (4) Compose an overview—by merging descriptions from steps 1–3;
- (5) Analyze how material flows and environmental performance are affected by different actions in the action nets.

Detailed organizational studies [27,29] have inspired us to consider that practices build on specific and local interactions, and we, therefore, find it useful to design PCO studies as comparisons of relatively similar cases for obtaining a better understanding. In order to facilitate change, it is relevant to study interchangeable specific actions in addition to for example entirely different cultures that only seldom are changed drastically.

Finally, caution is advised concerning the results of a PCO study. The methodology is still under development and, although the approach is ambitious, a PCO study may not cover all the important details.

2.2. Test Case Method

We chose to test the PCO approach on metal packaging governance in Sweden and the Netherlands because of, among other, differences in recycling rates and similarities regarding overarching governance between the two countries. The rationale for choosing the test case is further described in the following and, subsequently, we outline the method for testing the PCO methodology in the case.

2.2.1. Selection of the Case

A starting point for studying the governance of metal packaging flows in Sweden and the Netherlands has been the considerable potential environmental impacts from the product life cycles of this packaging. The packaging has been consumed in considerable amounts in the two countries, according to reported figures: annually 1997–2014 around 6–8 kg/capita in Sweden and 10–15 kg/capita in the Netherlands (see also Figure 2a). The production of the packaging has been based on metals production [36,37] that according to calculations results in large environmental impacts [38,39].

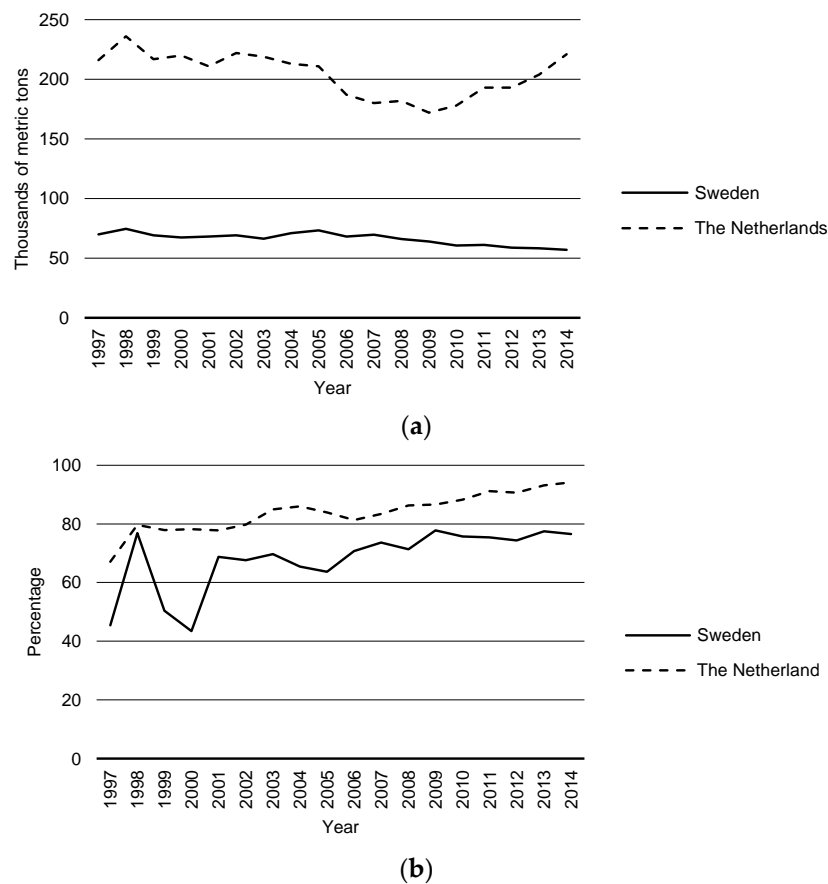


Figure 2. Reported annual metal packaging amounts in Sweden and the Netherlands [40]. (a) Generated waste amounts, adapted from [41] with permission from the copyright holder; (b) recycled amounts.

Flow differences and governance approach similarities between the countries further motivate the study. Regarding differences, metal packaging consumption per person has been higher in the Netherlands than in Sweden, but the recycling rate has been higher in the Netherlands, as Figure 2b shows. Regarding comparability between the two countries, both have applied EPR to metal packaging since the early 1990s and their main approach has been recycling through re-melting [42–44].

Taken together, practices related to metal packaging in the two countries have both been similar to and different from each other regarding core aspects. We thus conclude that exploring the actions that have mattered for the environmental impacts of these product life cycles can provide insights for governance.

2.2.2. Test Case Method

The testing of the PCO approach for guidance on material efficiency governance consisted of performing the case study on metal packaging flows, and evaluating it in relation to other research approaches. The case study followed the above-presented PCO procedure. Regarding the scope of the case, the following delimitations were made:

- Materials: Steel and aluminum, which are the metals covered by the packaging EPR in each of the two countries [36,37];
- Geographical extent: Based on product life cycles of the metal packaging waste generated in the two countries;
- Time window: From the take-off of this governance in the early 1990s until 2017, in order to seek insights on changes in governance.

Data was collected through both document studies and field studies. We used reports, web pages, and research literature (mainly for the life cycle studies and the studies of SMIPs). Interviews and field visits provided additional data (mainly on the organization between SMIPs). We used public sources to identify actors in industry and government as the main actors that are related to the EPR governance. Subsequently, we performed interviews with and field visits through representatives from these actors. An overview of the data sources and amounts used is presented in Table 1.

Table 1. Data collection: sources and amounts.

Source	Number of Sources		
	Sweden	The Netherlands	Both Countries
Report	18	8	15
Web page, e.g., on trade organization information	15	6	
Research literature		1	1
Interview	3, with industry and public agency representatives	2, with industry and public agency representatives	
Field visit and interview combined	4, at 3 public collection stations and 1 local intermediary storage facility		

Based on the collected data, we composed overviews with the main technical processes and material flows between them, SMIPs, and action nets between SMIPs.

Using the overviews as a starting point, we analyzed the environmental significance of how action nets were connecting different parts of the material flow. The first part of the analysis looked at the main environmental impacts through a screening life cycle study. In the second part of the analysis, we searched for differences in action nets that could explain the difference in environmental performance between the two countries.

Finally, the test of the PCO approach was performed by comparing the analytical insights to the outcome from other research approaches.

3. Results: Central Product Flows of Metal Packaging and their Organization

In this chapter, we present a guide to and basis for analyzing the environmental relevance of the studied metal packaging governance. We provide an introduction through outlines of the technical basis, SMIPs, and organization between the SMIPs for Sweden and the Netherlands. This is followed by further detailed overviews for each of the two countries.

3.1. Identification of Product Life Cycles

Based on the material covered by the EPR for metal packaging, previous LCA and life cycle studies [39,45], we identified the following technical processes in the two countries' product life cycles:

- Upstream production: Extraction of iron ore for steel and bauxite for aluminum and metal production, including recycling through re-melting;
- Downstream production: Packaging production, filling, import, and sale;
- Use;
- Waste collection;
- Preparation for recycling, including separation of different materials in the collected waste from one another.

The main flows in the product life cycles within society consist of the material flows within and between these processes.

3.2. Identification of Socio-Material Interaction Points at the Product Life Cycles (SMIPs)

A large number of SMIPs were identified where changes could have occurred to the material flows in the studied product life cycles. These SMIPs concern mainly the general activities that determine amounts and types of material transferred and identified, such as sourcing and monitoring; and modification of the physical properties of the material, such as re-melting and packaging manufacturing. We identified the following SMIPs:

- At each technical process: Interactions that determine amounts and types of material transferred between technical processes and monitored;
- At upstream production: Refining and shaping of the ores and bulk metals;
- At packaging production: Packaging production, which has determined, among other qualities, size and thickness;
- At waste collection: Choice between disposal for separate collection or in residual waste (which affects the properties of the different waste streams);
- At preparation for recycling: In Sweden, compression, and separation of steel, aluminum, and residuals from one another; in the Netherlands, incineration of the metals in residual waste, and separation of metals from incineration ashes and these metals from one another.

3.3. Identification of Action Nets between the SMIPs

We traced a considerable number of actions and actors linking the different SMIPs. The following groups of processes have been involved in these nets:

- The organization at each of the technical processes;
- Regulations;
- Governance by producers and users, such as using umbrella organizations to set up waste collection services;
- Statistics management;
- Public reporting;
- User contact, such as waste management organizations informing users.

3.4. Product Chain Organization for Metal Packaging EPR in Sweden—An Overview

In order to facilitate analysis of the environmental relevance of action nets and navigate the PCOs of the two countries, we produced overviews on central material flows and their organization. We present an overview of the Swedish case here and of the Dutch case in the next section. Figure 3 shows the identified Swedish structure.

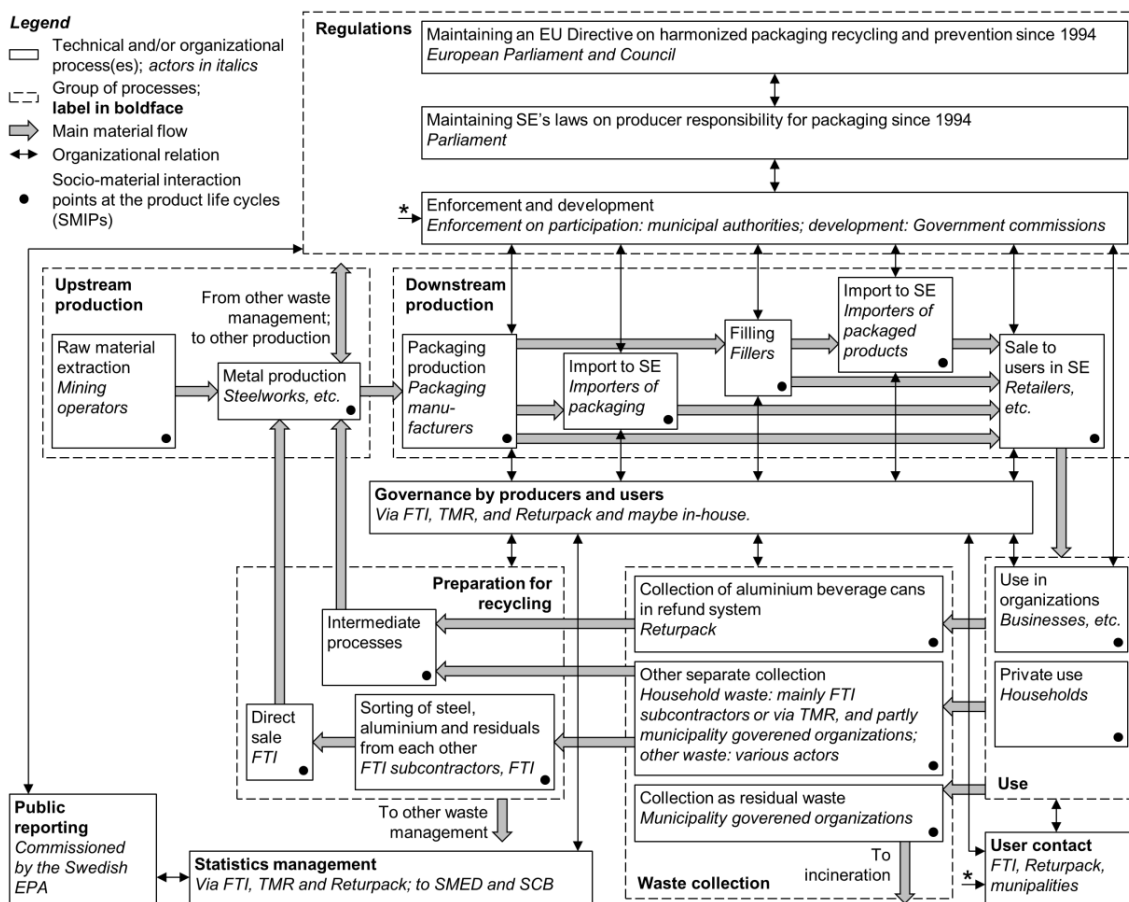


Figure 3. Central flows and organization in the Swedish metal packaging PCO, mainly for 2013–2017. * denotes the two ends of one organizational relation. EU = European Union, FTI = Förpacknings- och Tidningsinsamlingen, SCB = Statistics Sweden, SE = Sweden, SMED = Svenska MiljöEmissionsData, Swedish EPA = Swedish Environmental Protection Agency.

3.4.1. Regulations

Swedish laws on EPR for metal packaging have focused on recycling rates and assigning responsibility for these to downstream producers and certain users [42,46,47]. The laws also include requirements on minimizing packaging material consumption and on information. Such laws have been in force since 1994 for all types of metal packaging, and have followed an EU Directive [47–52]. The recycling goal has been 90% for metal beverage packaging since 1998. For other types of metal packaging, it has been 70% 2001–2020 and planned to be 85% from 2020. The municipalities have been responsible for ensuring that the producers and users partake [53]. The laws are developed following a series of government-commissioned investigations [42,54–57]. The general laws for metal packaging have been complemented by laws on return systems for metal beverage packaging since 1982 [46,58].

The EU Directive [15], from 1994, has focused on harmonizing regulation between member states. The Directive mainly targets recycling rates but also included requirements on packaging material minimization. Since 2001, the goal is to reach at least 50% recycling of metal packaging at the latest in 2008.

A summarizing illustration is provided in the “Regulations” part in Figure 3.

3.4.2. Upstream Production

Metals production has entailed many processes [39,59], but they have little relevance for the studied governance [52]. We, therefore, noticed the presence of a few technical processes and actors,

such as in mining and at steelworks [39,59]. A summarizing illustration is provided in the “Upstream production” part of Figure 3.

3.4.3. Downstream Production, Use, and Governance by Producers and Users

We identified that downstream producers and certain users of metal packaging have organized governance in a few different ways over the years [60–67]. A summarizing illustration is provided in the “Downstream production,” “Use,” and “Governance by producers and users” parts of Figure 3. As per rule, a producer or user of metal packaging other than beverage packaging has paid a fee to a service provider arranging for collection and recycling. The fees are proportional to the amount of packaging waste filled or sold. However, the organization has changed over the years. Between 1994 and 2005, the requirements could be fulfilled by joining MetallKretsen, which managed the waste. Since 2005, corresponding services have been provided via FTI and TMR. FTI has been owned via among other MetallKretsen. In turn, its owners have not remained the same and have recently been two wholesale and retail trade organizations. TMR is a private company.

Regarding types of producers and users that have been encouraged to join, FTI has differentiated between them contrary to TMR’s practices [64,68]. FTI’s main rule has been that importers or fillers of packaging/packaged products can join. For packaging that is designed to use not until the final sale, such as aluminum containers for takeaway meals, the importers or Swedish manufacturers have been suggested to join. Finally, when appropriate, such as when selling directly to Swedish consumers, foreign companies have been allowed to join.

Metal beverage packaging waste has been handled by Returpack [65,69–72]. They have run an aluminum can refund system since 1984. Its ownership has been shared between three trade organizations that represent brewers and retailers.

As of 2001, 50–60 companies, including Volvo and Lindex, reported that they were running their own packaging waste management [42]. However, we have not been able to deduce whether they have handled metal packaging or not.

Finally, when the packaging has been filled as well as discarded by one organization, as in the case of barrels [47], this actor is both a producer and user.

3.4.4. Waste Collection

We identified several different channels for collecting metal packaging waste within the organizations developed by producers and users [36,42,57]. A summarizing illustration is provided in the “Waste collection” part in Figure 3. Channels for separate collection have started at collection facilities for beverage containers, public collection stations, residences, municipal recycling centers, facilities where organizations can deliver waste, the pick-up of waste at organizations by different market actors, and possibly at the mentioned in-house waste management. Disposal via residual waste to incineration has also taken place.

The channels originating at collection stations, residences, and municipal recycling centers have been designed for households’ packaging waste but have also been used for some waste from organizations [36,57]. The collection station system was set up with 6000–7000 stations in 1995–1996 [36]. As of 2012, collection stations channeled the majority of the households’ packaging waste [57]. The stations have been run by either FTI or TMR. Regarding FTI, they have owned the containers at the stations, rented the land at the stations from municipalities, and used subcontractors for collecting the material [36]. No corresponding information was deduced for TMR.

Regarding collection at residences, FTI has refunded any authorized actor for collection [73], and TMR has provided the service through cooperation with municipal waste management companies, property owners, and environmental and recycling companies [74].

For collection at organizations, FTI has refunded the operator of choice, while TMR has provided a wide range of solutions [74,75].

3.4.5. Preparation for Recycling

We identified several related processes for the further handling of the collected metal packaging waste [36]. The waste collected at stations and residences supervised by FTI has been brought to local intermediary storage facilities. Typically, these facilities have also received the waste directly provided from organizations and by the market actors collecting at organizations. Preliminary sorting out of misplaced content and subsequent compression is performed here. Further transport has brought the material to a few sorting facilities and one shredder. From the sorting facilities, steel and aluminum have been sold directly to steel and aluminum production plants due to large quantities. Regarding involved actors, different approaches have been used. The running of the storage facilities has been procured. The further transport has been procured as well, under contracts separate from those concerning the storage. Finally, FTI has owned the subsequent sorting facilities but not the shredder. Corresponding information was not deduced for the running of these operations by TMR. Regarding residual waste, we identified no extraction of metal packaging waste for further recycling. A summarizing illustration is provided in the “Preparation for recycling” part in Figure 3.

3.4.6. Statistics Management and Public Reporting

Statistics management for and public reporting on metal packaging have involved many actors and have been based on a merging of data streams [43,53]. Statistics on the amount of generated packaging waste have been produced via the producers and users paying for the shared waste management and possibly from those with in-house waste management. Data for calculating the recycling amount have been collected via questionnaires from the collection and recycling actors. Recycling rates have been calculated as the metal from packaging re-melted relative to the metal used in packaging. Different organizations have been involved in these tasks. Svenska MiljöEmissionsData has organized the recycling questionnaires. Statistics Sweden has performed statistics quality control. The Swedish Environmental Protection Agency (Swedish EPA) has published reports on the packaging EPR. The preparation of these reports has been commissioned. A summarizing illustration is provided in the “Statistics management” and “Public reporting” parts in Figure 3.

3.4.7. User Contact

Information on packaging waste collection to households has been required by law to be provided by municipalities [52,76]. In addition, FTI and Returpack have issued information substantially and voluntarily [75,77,78]. Regarding municipalities, they have been required to inform about among other the obligation to use the services for separate waste collection. FTI has cooperated with municipalities on effective communication. Returpack has since 2004 used a specific brand, Pantamera, for its information campaigns. A summarizing illustration is provided in the “User contact” part in Figure 3.

3.5. Product Chain Organization for Metal Packaging EPR in the Netherlands—An Overview

The Dutch PCO has differed considerably from the Swedish one regarding details, although their overarching approaches, such as focusing on recycling and producer responsibility, have been similar. We present a further overview of material flows and their organization in the Dutch metal packaging PCO in this chapter. Figure 4 shows the identified structure.

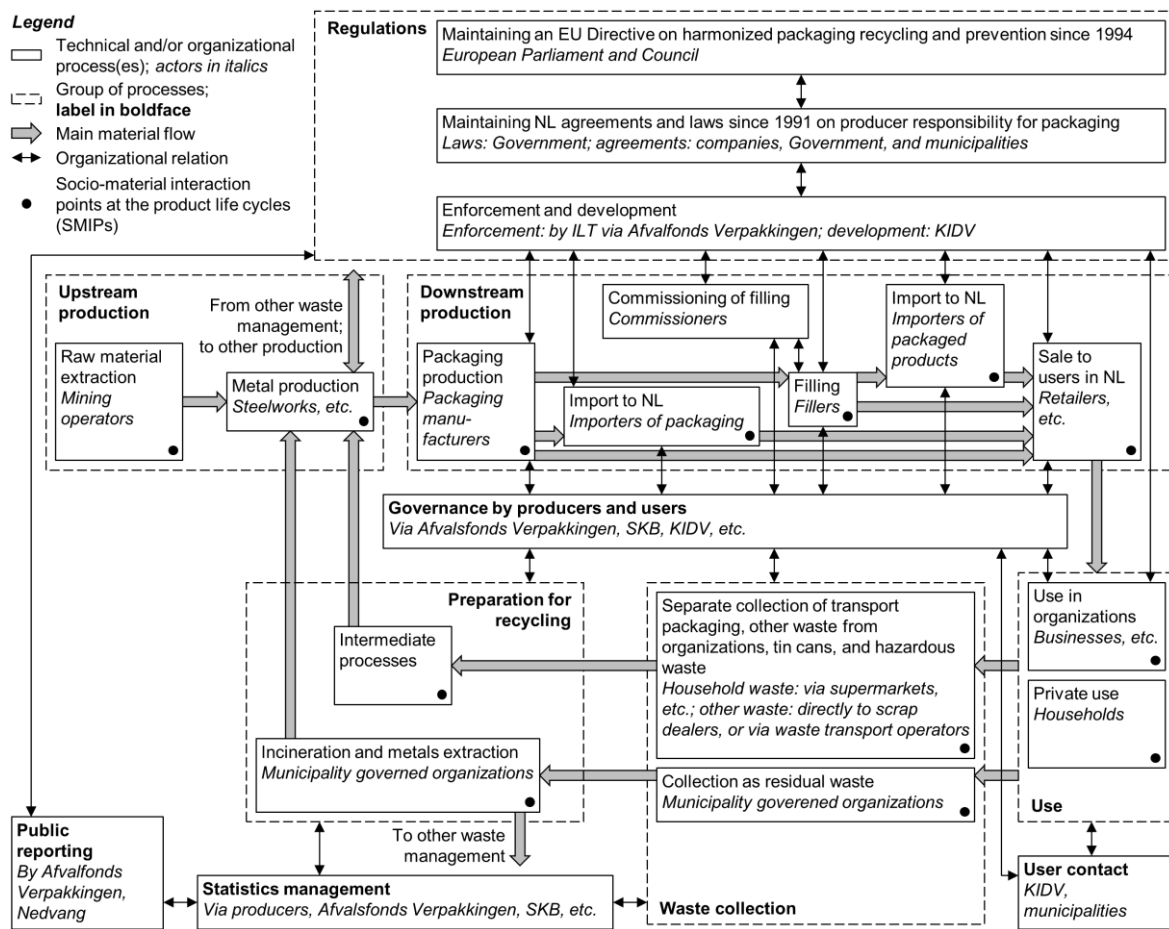


Figure 4. Central flows and organization in the Dutch metal packaging PCO, mainly for 2013–2017. ILT = Inspectie Leefomgeving en Transport, KIDV = Netherlands Institute for Sustainable Packaging, NL = the Netherlands, SKB = Stichting Kringloop Blik.

3.5.1. Regulations, Downstream Production, and Use

EPR policies on metal packaging in the Netherlands have focused on recycling rates and the assignment of responsibility for these to certain producers and users [44,79–82]. The policies also include requirements on packaging material minimization. Packaging EPR in the Netherlands took off through a 1991 covenant that protected producers and certain users from further regulation if they fulfilled stated goals. Higher recycling targets were introduced through subsequent covenants. In addition, laws were taken into force, to follow the EU Directive on packaging (described in Section 3.4.1) and to guarantee targets fulfilment. This has led to a recycling target for metal packaging of 85% since 2003. A packaging fee and a framework agreement were introduced in 2008 due to concerns about waste collection and recycling. The fee is proportional to the weight of packaging material produced. However, producers of transport packaging and those producing less than 50 metric tons per year have been exempted from the fee. The agreement was settled between municipalities, the government, and producers. It binds producers to fund and organize the packaging waste management through a fund—Afvalfonds Verpakkingen. Since 2013, a Waste Management Contribution Agreement between sector organizations for packaging has also been in place, in part for regulating liabilities.

The producers and users that the policies hold responsible are primarily anyone who brings a filled packaging onto the market [80]. If a filled product has been imported, however, the importer has been responsible. In cases where a subcontractor has performed the filling of a packaged product using

the brand name or similar of the commissioner, the commissioner has been responsible. For packaging intended for use by consumers, the seller has been responsible. The filler is also the user for packaging discarded before the sale to private consumers.

Regarding enforcement, the agency Inspectie Leefomgeving en Transport has inspected the packaging system monitoring [83]. They have reported to Afvalfonds Verpakkingen. Further enforcement has been performed if necessary. In turn, Afvalfonds Verpakkingen has outsourced the monitoring to Nedvang.

Since 2013, development activities, such as research, towards a circular economy for packaging materials have been performed by the Netherlands Institute for Sustainable Packaging (KIDV) [84,85]. Afvalfonds Verpakkingen has funded the institute.

A summarizing illustration is provided in the “Regulations,” “Downstream production,” and “Use” parts of Figure 4.

3.5.2. Upstream Production

Upstream production in the Netherlands, like in Sweden, has been of little relevance for the studied governance [86]. A description that represents the Netherlands as well is presented in Section 3.4.2, and a summarizing illustration is provided in the “Upstream production” part of Figure 4.

3.5.3. Governance by Producers and Users

We identified that Dutch metal packaging producers and users have taken part in the organization of EPR activities through chains of actors [82,87]. The producers have been active in the overarching organization Afvalfonds Verpakkingen through a materials committee where five organizations represent the different material sectors. Stichting Kringloop Blik (SKB) has been representing the metals sector. SKB has been managed by ten trade organizations in manufacturing, sales, and recycling of packaging and packaged products.

The research and development agency KIDV has been governed by a board of governors with seven seats and an advisory board with nine seats [82,85]. The metal packaging actors have been able to be part of the advisory board via one seat held by the materials committee of Afvalfonds Verpakkingen.

A summarizing illustration is provided in the “Governance by producers and users” part in Figure 4.

3.5.4. Waste Collection

The Dutch metal packaging waste management has been performed via either separate collection or via residual waste [37,88]. The distribution in 2011 was by weight 57% and 43%, respectively. The household part of this waste has been mainly collected via residual waste, but also separately at for example supermarkets and canteens. Metal packaging waste from organizations has been mainly separately collected due to its material value and has been either directly transported to scrap dealers or handled by waste transport operators. A summarizing illustration is provided in the “Waste collection” part in Figure 4.

3.5.5. Preparation for Recycling

We identified additional procedures for the metal packaging waste collected through residual waste. This waste has been incinerated at designated plants, and remains from the metal packaging have been extracted from the ashes [89]. The metals have been required by law to be removed before the ashes can be used as, for example, road filling [82]. Steel and iron have first been sorted out; the remains have been sold to other companies that have sorted out aluminum and other metals. A summarizing illustration is provided in the “Preparation for recycling” part in Figure 4.

3.5.6. Statistics Management and Public Reporting

We identified several involved actors and procedures in the statistics management and public reporting [79,90]. The monitoring by Nedvang has built on a combination of methods. Consumption statistics have been based on reports from producers and users registered with Afvalfonds Verpakkingen, estimates for smaller producers and users, and SKB questionnaires on transport packaging. Recycling amounts have been calculated from SKB reports on collection and recycling, extraction from incineration ashes reported by Vereniging Afvalbedrijven, and estimates of the composition of household waste from Rijkswaterstaat. Recycling rates have been calculated as recycling per consumption. Public reporting has been produced jointly by Afvalfonds Verpakkingen and Nedvang. A summarizing illustration is provided in the “Statistics management” and “Public reporting” parts of Figure 4.

3.5.7. User Contact

The research and development agency KIDV has been the main platform for contact with users on packaging [84,91]. Among other, guides have been provided for the communication between municipalities and consumers. A summarizing illustration is provided in the “User contact” part of Figure 4.

4. Analysis of Environmentally Relevant Actions Not Covered in the Policies

Based on the overviews presented in the previous chapter, we have analyzed environmentally relevant actions not covered in the two countries’ steering approaches to metal packaging governance. The analysis also built on an additional environmental assessment and complementary results on the material flows and action nets.

4.1. Environmental Impacts

We performed a systematic environmental analysis, based on the central product flows identified in the previous chapter. The screening life cycle study covered four main environmental impacts identified [15,44,45]: energy use (a proxy for many environmental impacts, such as land use for energy supply), climate change, resource scarcity, and landfill space scarcity. This led to recognizing that the overall environmental performance of the studied PCOs has depended on the relationship between consumption and recycling levels. Therefore, we evaluated both existing impacts and impact reductions from a hypothetical increase of the recycling rates. Estimated impacts, data sources, and analysis criteria are described in Table 2.

Table 2. Environmental findings on the relation between consumption and recycling of the metal packaging in Sweden (SE) and the Netherlands (NL). Estimates for 2011 and for the potential case of full recycling. ¹

Aspect	Estimated Impact ²	Reduction Potential for Each Country’s Metal Packaging Impacts from Increased Recycling ³	Remarks
Energy use ⁴ [37,39,40,92–97]	1/400–1/300 per capita compared to the total global average. SE: 250 MJ/capita. NL: 220 MJ/capita.	Steel: 4–6%, 17 MJ/kg. Al: 30–60%, 150 MJ/kg.	
Climate change ⁴ [37–40,94,95,98]	1/600–1/500 per capita compared to the total global average. SE: 14 kg CO ₂ eq./capita. NL: 12 kg CO ₂ eq./capita.	Steel: 7%, 1.5 kg CO ₂ eq./kg. Al: 30–60%, 8.2 kg CO ₂ eq./kg.	

Table 2. Cont.

Aspect	Estimated Impact ²	Reduction Potential for Each Country's Metal Packaging Impacts from Increased Recycling ³	Remarks
Scarcity of iron ore [37,40,92–95,99–101]	1/300 per capita compared to the total global average. SE: 0.6 kg/capita. NL: 0.5 kg/capita.	All	
Scarcity of bauxite [37,39,40,94,95,99,101]	1/12–1/6 per capita compared to the total global average. SE: 1.0 kg/capita. NL: 0.5 kg/capita.	All	Economically not viable sources were essentially inexhaustible
Landfill space scarcity [37,40,94,95,102]	1/40–1/30 per capita compared to the total global average. SE: 1.6 kg/capita. NL: 1.0 kg/capita.	SE: steel: 0.6 kg/capita; Al: 1.0 kg/capita. NL: 0.5 kg/capita for each metal.	

¹ Al = aluminum, eq. = equivalents. ² The shares refer to per capita impact from metal packaging in SE and NL, respectively, compared to impacts from all activities globally (not only metal packaging) per capita globally; Amount per country refer to impacts from the product life cycles related to the country's metal packaging waste generation. ³ The reductions are relative to estimated impacts from the country's metal packaging before reductions, and reductions per kg refer to reductions per additional kg packaging recycled. ⁴ Energy use and climate change potential are for steel packaging based on global figures that follow a gate-to-gate product life cycle that excludes mining, use, and waste management prior to re-melting; and for aluminum based on European figures that cover a product's life cycle from mining to aluminum sheet production.

From the environmental analysis, we have identified that

- The metal packaging flows have resulted in notable contributions to overall environmental impact in both countries and would have done so at 100% recycling;
- The estimated environmental impacts per capita have been greater in Sweden than in the Netherlands in spite of a lower amount of generated waste in Sweden and assisted by higher recycling levels in the Netherlands;
- Increased recycling of aluminum packaging would compared to a corresponding increase in steel packaging recycling have led generally to greater environmental gains.

4.2. Influence on Environmental Performance from Action Nets

According to the environmental assessment, the environmental impacts of the metal packaging can be reduced via decreased consumption and via increased recycling. Thus, a good understanding of actions that affect consumption and recycling levels in the environmentally preferable directions are key to achieving environmentally effective governance. This, in turn, requires that the action nets enable accurate transfer of information and environmentally effective action at SMIPs.

We have identified several ways that the action nets have influenced the environmental impacts of the metal packaging via inaccurate statistics, mixing of waste streams, and consumption. The findings are described in the following and summarized in Table 3.

Table 3. Starting points for understanding how actions have influenced the environmental performance of metal packaging flows in Sweden (SE) and the Netherlands (NL).

Theme	Actions
Inaccurate statistics	SE: The statistics have been based on the recycling but not the production of packaging from 'free riders', thereby leading to errors when calculating the recycling rate as recycling per production. NL: The statistics have been based on estimates of extraction from ashes that are difficult to get accurate. SE: There has been little evaluation of the accuracy of the statistics.
Mixing of waste streams physically and in policies	Both countries: Aluminum and steel flows have been treated as one flow in the policies. NL: Non-functional incineration of metal packaging waste in residual waste. NL: Extraction of other valuable metals has driven extraction from incineration ashes. SE: Investigations on mixing streams led to keeping the separation between the materially incompatible streams of metal packaging and other household metal waste. SE: Misunderstandings has contributed to not complementing source separation with extraction from ashes.
Consumption	Both countries: Use of qualitative goals but not incentives for absolute reduction of packaging material.

4.2.1. Influence via Inaccurate Statistics

Reported recycling rates have been used as the key indicators for metal packaging governance in the two countries. Inaccuracies in recycling rates complicate their use as proxies for environmental impact, with unclear effects on decisions on changing or keeping certain practices. The rates in the Netherlands have been produced from investigations of the actual efficiency of each waste management process [37] while the rates in Sweden have been calculated from comparing separate waste management and production data. This complicates the comparison of national statistics.

Inaccuracies have been introduced in different ways in the two countries. In Sweden, the recycling but not the production of metal packaging from 'free riders' has been included. This is an issue since free riders produced an estimated 9.6% of the metal packaging in 2005 [103]. Municipalities have been responsible for the practically difficult task of enforcing Swedish producers to register [53].

In the Netherlands, however, the data has been based largely on extraction from incineration ashes, which has been difficult to determine accurately [37,83]. These statistics are based on samples to be feasible, and the input has varied in composition and contained other steel and aluminum waste as well.

Computational methods have as well differed between the two countries. In the Netherlands, the methods are transparent and target actual recycling [83]. On the other hand, in Sweden, unclear questionnaire replies have been used [53]. They do not include specification of calculation methods. In addition, they are only crosschecked to a small degree and against the previous year's results. For the Swedish statistics, public-private conflicts may have had an effect. Waste management generally has been seen as a conflict area. The reason is that the introduction of EPR for packaging resulted in private actors handling a considerable share of waste that municipalities previously managed [36]. Due to the uncertainties about future ownership and responsibility for the packaging governance, improvements of packaging monitoring have been stalled [53].

4.2.2. Influence via Mixing of Waste Streams Physically and in Policies

We identified that the mixing of waste streams physically and in policies in the two countries has influenced environmental performance not only via generation of inaccurate statistics. The environmental impacts have been influenced via combined policy goals on steel and aluminum, and through incinerating metals in mixed streams. In addition, separation has been performed between

steel and aluminum for some but not all streams. Regarding causes of separation, it is sometimes a side effect and in other cases planned. Finally, there are cases where additional separation was intended but not implemented. Regarding physical and policy separation between steel and aluminum, this is important because of different effects of the recycling of the two metals. Reaching full aluminum compared to steel packaging recycling could have resulted in a larger or partly similar decrease of the four studied environmental impacts except for resource scarcity if recently not economically viable sources were used (see Table 2).

Regarding environmental problems of physical and policy mixing of streams, the two countries' recent laws and reporting have not differentiated between steel and aluminum packaging [43,47,79,80].

In addition, environmental impacts have occurred due to the Dutch focus on extraction after incinerating residual waste that includes metal packaging. This practice results in lower energy recovery from the incineration and subsequent environmental impacts from other energy supply than the Swedish approach of focusing on the separate collection of metal packaging waste.

On partial separation, in Sweden, aluminum beverage packaging has been treated separately and recycled to a high degree [43]. However, due to consumption levels and low levels of recycling other types of aluminum packaging [36], the overall result is considerable environmental impacts.

Regarding causes for separation, the presence of other profitable metals in the waste has had an influence in the Netherlands [82]. Their presence in the ashes resulting from incineration of residual waste is a driver for increased extraction and thus recycling of both these metals and the metal packaging waste present in the ashes.

On the other hand, recent separation practices in Sweden have been the result of planning. The Swedish authorities searched for a waste separation that was more logical to consumers (due to recycling via residual waste this is not applicable to the Netherlands). Three large investigations evaluated a mixing of metal packaging waste and other metal waste [54–56]. Eventually, however, these attempts to merge streams were abandoned due to risks of lowered material quality [57]. Copper from other metal waste and tin in the packaging were considered problematic [36]. Thus, the result of the planning is that the separation between the two waste streams was kept.

Finally, regarding additional separation, the collection of metal at the waste source and extraction after incinerating residual waste could have been further combined in Sweden. The latter method has recently not been used. A misunderstanding, however, contributes to this situation. Thord Göring, at FTI in Sweden, had earlier suggested such complementary extraction. At that time, the Swedish EPA did not approve of it due to a strict policy against incinerating non-combustible materials [36]. The representative for the EPA as of 2013, Catarina Östlund, however, had not heard of the issue and showed an open mind toward such extraction [62].

4.2.3. Influence via Consumption

Not only recycling but consumption levels as well, influence overall environmental impacts of the metal packaging flow. These levels can be changed via users, through for example choice or level of purchasing products. Producers can also influence the amounts by using less packaging per service delivered. The policies have included qualitative goals on reducing the amounts of materials used in this packaging production [47,80]. However, no quantitative goals or incentives have been included. In practice, the user contact has been dedicated to encouraging an increased waste collection, thus mainly affecting the recycling levels [75,77,78]. In addition, and in spite of the policies, it is difficult to determine if an actual lowering of the levels has occurred [36,83]. The decrease reported for Sweden (see Figure 2a) might be a result of switching to other materials for tin cans and paint buckets, among other.

5. Discussion—the Contribution of a Socio-Material Approach

Based on the results and analysis of the flows and organization of metal packaging, we have explored the relevance of the PCO methodology compared to other approaches. We have compared the

PCO methodology and the case study to the LCA approach and comparative studies of environmental and organizational aspects of material efficiency governance.

An LCA can provide a comprehensive comparison between the environmental impacts generated via different product life cycles and detailed insights into the most environmentally impacting technical processes in a product flow [12]. A PCO study combines a screening approach to LCA with a study of the action nets that shape the product life cycle and its environmental performance. The test case on metal packaging covered four highlighted environmental impacts for generic and partly truncated product life cycles. An LCA could provide a more case-specific assessment for a larger number of environmental impacts and a weighted score of them. Regarding different options, an LCA would typically identify the different environmental profiles of the two metals in the packaging and source separation and extraction after incineration as the main options. It, however, would not cover the majority of the aspects identified through the PCO case study: how a multiplicity of actions have influenced environmental impacts via determining the reliability of official statistics, mixing and sometimes separating waste streams, and affecting consumption levels.

The earlier comparative governance studies have generated insights on that one solution for all cannot be found [22]; that among other actor collaboration [20] and use of existing infrastructure [21] are important for success; and that policies focus on for example providing consumers clear LCA-based information [23]. These studies have been focused on providing lists of key aspects for governance. The PCO approach, on the other hand, is aimed to be a methodological contribution to studying environmentally relevant actions. Its contribution is that it brings into light the importance of the action nets and the SMIPs that determine the actual handling of the material flow of the product for the resulting environmental impacts. This approach offers a new way to explore and describe how governance of material efficiency influences environmental performance. In the test case, specific actions and material properties have been central to findings on, among other, the misunderstanding on incineration of metals influencing waste management options and that extraction from ashes has been difficult to measure, respectively. Thus, the PCO approach is designed to complement the search for overarching properties in the other comparative studies.

In addition, the PCO methodology is aimed at complementing the approaches to environmental analysis in the earlier comparative studies. These are based on reported recycling rates [20] and qualitative proxies such as high or low toxicity level [22] for environmental performance. The quantifying of four environmental impact categories in the PCO test case was performed in order to minimize the risk of environmentally misleading analysis and contributed to the analysis findings on aluminum recycling, the use of extraction from residual waste incineration, and little focus on consumption levels.

Despite being limited, our comparative PCO study provides a complementary perspective to previously reported findings on governance of recycling and other circular economy approaches. The study illustrates the possibilities of using the methodology in comparison to using LCA or previous approaches to studying the governance of material efficiency.

6. Conclusions

We have presented how governance of material efficiency approaches can be studied by considering the nets of actions and actors that shape environmental impacts via product life cycles. We have described a test of the PCO approach through a comparison of governance of metal packaging product life cycles in Sweden and the Netherlands. Governance of these packaging flows has focused on recycling rates and statistics, and implied superior Dutch governance. By constructing overviews of the packaging material flows and their organization, we have obtained 'maps' of how human actions are related to environmental impacts. The overviews and subsequent analysis showed that comparison of reported recycling rates is not straightforward owing to differences in the action nets influencing the consumption and recycling levels and their statistical representation. Environmental improvements would require attention to these nets.

The PCO approach could complement other approaches. A PCO study extends the LCA methodology to the actions conditioning environmental impacts. In addition, the PCO methodology can further previous governance studies by providing a comprehensive socio-material framework in which various analyses can be made. In general, PCOs can provide overviews that are useful before deciding on detailed studies on governance of material efficiency, or can be frameworks that bring together detailed studies.

PCO studies are still limited, but we conclude that the findings presented here encourage further research on how recycling and a circular economy more broadly can be governed and understood.

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