Solution-focused sustainability assessments for the transition to the circular economy: The case of plastics in the automotive industry

Anne R. van Bruggen a,⁎, Michelle Zonneveld b, Michiel C. Zijp a, Leo Posthuma a,c

a Dutch National Institute for Public Health and the Environment, Centre for Sustainability, Environment and Health (DMG), Antonie van Leeuwenhoeklaan 9, 3721 MA, Bilthoven, the Netherlands
b Dutch National Institute for Public Health and the Environment, Centre for Environmental Safety and Security (VLH), Antonie van Leeuwenhoeklaan 9, 3721 MA, Bilthoven, the Netherlands
c Radboud University Nijmegen, Department of Environmental Science, Institute for Water and Wetland Research, Heyendaalseweg 135, 6525 AJ, Nijmegen, the Netherlands

ARTICLE INFO

Handling Editor: Cecilia Maria Villas Boas de Almeida

Keywords:
Automotive
Circular economy
Plastic
Barriers
Solutions
Sustainability assessment

ABSTRACT

To overcome barriers and make a societal transition towards a safe, healthy, and sustainable circular economy, realistic and ambitious solutions need to be identified. This study improves the Solution-focused Sustainability Assessment framework (SfSA) with a ‘chain approach’, which aims to involve stakeholders from across a product chain of interest to explore the ‘solution space’ from different perspectives. The approach allows to gain a broad insight into the scientific and practical aspects of a problem and its potential solutions. The approach is applied to a specific case: the circular economy of plastics in the automotive industry. Stakeholders across the value-chain together identified forty-one different barriers and various solutions. The stakeholders involved considered the solutions in the realms of policy and economics, such as pricing of environmental impact and norms for recyclate, as most feasible and impactful. Reflection on these results by experts underpinned and enriched these results. The emphasis on policy and economic barriers and solutions does not necessarily mean focus should solely be on solving policy and economic restraints and improving current policy measures. The results show that barriers are connected. When one barrier is overcome, another such as safety of substances may come to the forefront. The same holds for the solutions. The transition towards circular use of plastics in the automotive industry requires a network of solutions that together create systemic change, such as policy solutions as well as gathering data for assessments. This study shows the value of bringing together stakeholders from across the value-chain in a search for barriers and solutions: i) it provides new insights and data on barriers and solutions that cannot be extracted from literature; ii) it challenges stakeholders to see the system they are part of and think in terms of solutions; iii) stakeholders learn from each other and discover that there are more opportunities than they thought of beforehand. Work has to be done to make the solutions suitable for further quantification and to continue to involve stakeholders in the other SfSA steps to gather data, assess solutions, and implement those solutions together.

1. Introduction

Urgent and transformative action is needed to stay within planetary boundaries, realize the Sustainable Development Goals (SDGs), and make a societal transition towards a safe, healthy, and sustainable environment (Persson et al., 2022; Rockström et al., 2009). A circular economy (CE) contributes to realizing the SDGs, such as goals regarding clean water and sanitation, responsible consumption and production as well as the European Union (EU) goal of a toxic-free environment (Anastasiades et al., 2020; Dearing et al., 2014; European Commission, 2020a; Schroeder et al., 2018). The CE is generally an economic system aimed at narrowing, slowing, and closing the network of material and energy flows (Bocken et al., 2016). The increase of production diverse novel entities, defined as “new substances, new forms of existing
substances and modified life forms”, including chemicals, are a planetary boundary we are exceeding and pose challenges to realizing a CE (Beekman et al., 2020; Bernhardt et al., 2017; Steffen et al., 2015). Solutions are required to realize a safe CE and a reduction of risks from novel entities to stay within planetary boundaries. Following a broad evaluation of risk assessment practices, the U.S. National Academy of Sciences (NAS) concluded that exploring optional solutions in the earliest stages of risk assessment processes would provide the best information for decision making (Finkel, 2011; National Research Council, 2009). The present study improves the Solution-focused Sustainability Assessment (SfSA) framework inspired by this method and applies it to evaluating barriers and solutions to realizing a CE (Zijp et al., 2016).

The SfSA framework is improved with a ‘chain approach’, which aims to involve stakeholders from across a product chain of interest (from designers to recyclers) to explore the ‘solution space’ from different perspectives. This gives a broad insight into the scientific and practical aspects of the problem and the potential solutions. Involving stakeholders to explore risks as well as collaboratively select and implement risk reduction opportunities has been successfully applied to chemical pollution in the water cycle (Min VWS & Min IenM, 2019; Munthe et al., 2017). The approach to identifying barriers and solutions consists of a two-step participatory process that can be used in other cases. The steps include a portfolio of qualitative research approaches to listen carefully and systematically to stakeholders’ points of view. Here we improve the SfSA framework by implementing the chain approach for the exploration of barriers and solutions steps using a specific case: the CE of plastics in the automotive industry. The transformation of the global plastics economy requires “extraordinary effort” and “coordinated global action”, and plastics is a novel entity of “particular concern” to crossing planetary boundaries (Borrele et al., 2020; Lau et al., 2020; Persson et al., 2022). The automotive industry makes up around 10% of global plastic demand and its plastics commonly contain hazardous substances, which are a barrier to the CE (Buekens and Zhou, 2014; Miller et al., 2014).

The contribution of this paper is to develop the solution-focused chain approach and apply it to forward sustainable solutions in the implementation of the CE. Most research efforts have focused, so far, on barriers to a CE (Araujo Galvão et al., 2018; Hart et al., 2019; Kirchherr et al., 2018; Paletta et al., 2019; Ritzén and Sandström, 2017). Bening et al. (2021), focused on contested solutions with value chain actors, emphasizing the differences between actors. The present research expands on that by considering “mutually agreed solutions through discussion and learning” using the chain approach, so that different perspectives come together (Zijp et al., 2017). Cardamone et al. (2022) also focused on solutions, but specifically on vehicles at end of life. The present research focusses on the entire value chain. We integrate the method of searching for barriers and solutions in a broader SfSA framework, which can be employed to evaluate sustainability of alternative solution options through quantitative assessment of metrics in next steps. A transition to a CE and circular strategies may imply non-sustainable trade-offs between human and environmental health (Aurisano et al., 2021; European Commission, 2020a; Friege et al., 2019; Groh et al., 2019; Leslie et al., 2016; Zimmermann et al., 2020). However, human and environmental exposure to chemicals is not commonly taken into account when assessing solutions for material sustainability. This research has a unique focus to uncover to what extent the use of hazardous substances is seen as a barrier to a CE of plastics, to include this in assessments. The vision is that the solution-focused chain approach to identifying barriers and solutions, as well as lessons learned, can help industry, but also inform policy makers, researchers, citizens, and Non-Governmental Organizations (NGOs) to help improve the assessment of circular solutions and policy pathways.

1.1. Research questions

The solution-focused approach as proposed by U.S. NAS was developed in the context of risk assessments of chemicals and is now expanded towards exploring sustainable solutions for CE. The aim of this study is to improve the SfSA framework by implementing the stakeholder-chain approach, applying the approach to a case study of interest: the CE of plastics in the automotive industry, and evaluating the opportunities and limitations of the approach. The sub-questions formulated to investigate the case study are:

1) What are the most important types of barriers to realizing a CE of plastics in the automotive sector for Dutch stakeholders?
2) Is the use of hazardous substances seen as a problem in the realization of a circular use of plastic in the automotive industry, and if so, how does this problem relate to other barriers?
3) Which solutions are proposed by Dutch stakeholders in the automotive sector for the circular barriers they consider most important?

2. Mixed methods qualitative methodology

The methods section describes the methodological steps using the solution-focused ‘chain approach’ and the characteristics of the case study.

2.1. The case study: contents and motives

First, we select a complex case of importance to the CE: plastics in the automotive industry in the Netherlands. The focus on stakeholders from the Netherlands facilitated in-person stakeholder interactions. While the Netherlands has only few producers of cars, it has many Original Equipment Manufacturers (OEMs) and plastic producers as well as a dismantling and recycling infrastructure with Post Shredder Technology (PST). Plastics are a priority material in European and Dutch CE policy because of their high resource intensity (European Commission, 2018, 2019; Min IenM & Min EZK, 2016). The automotive industry makes up about ten percent of the total plastic demand, which is annually a million ton per year in Europe and 199 kilo tons in the Netherlands (Plastics Europe, 2020). Plastics are used in various parts of the car such as bumpers or dashboards. Over 35 types of polymers are used in cars, often in ways that prevent easy separation and thus recovery and reuse. Generally, the CE of plastics, including plastics in the automotive sector, is hindered by barriers such as lack of regulation that is fit for circular strategies, lack of economic incentives to make circular choices and attitudes that regard reused or recycled products as dirty (Araujo Galvão et al., 2018; Bening et al., 2021; Khodier et al., 2018; Kirchherr et al., 2018; Paletta et al., 2019). Furthermore, the different types of plastics may contain different hazardous substances, which is a barrier to the CE requiring specific systems for collection, reuse, and recycling (Buekens and Zhou, 2014; Miller et al., 2014; Wagner and Schlummer, 2020). If materials are reused or recycled at the end of life and will thus end up in second-hand parts or recycle, trade-offs between consumer health and safety have to be weighed with considerations of resource efficiency (Leslie et al., 2016). For example, there are technological solutions for recycling plastics, but economic barriers such as the lack of a market for recycle and lack of adequate recycling infrastructure hamper the implementation of these technologies (Miller et al., 2014).

2.2. Solution-focused chain approach

This research improves the first two steps of the SfSA approach by further developing the steps with a chain approach and applying them to a specific case (Zijp et al., 2016). The SfSA approach provides a systematic stepwise qualitative approach in the context of sustainability transitions (see Fig. 1). The first two steps are pre-assessment and developing solutions. The SfSA method does not prescribe precisely how to execute these steps to allow for a versatile approach. A mixed methods qualitative methodology was used to improve and implement the first two steps of the SfSA approach (Hesse-Biber, 2010) (see Fig. 1).
2.2.1. Step 1: Pre-assessment of the problem and its context

The first proposed step of the Solution-focused Chain Approach serves to explore the problem and the context and prepare for the second participatory step (Zijp et al., 2017). The pre-assessment harvests different views expressed by the stakeholders, without any limitation as to getting to know all practical, regulatory, or scientific arguments. We operationalized this step in three sub-steps (see Fig. 1).

2.2.1.1. Step 1A Exploratory literature review. An exploratory literature review identified barriers and solutions for plastics in the automotive industry. The review is explicitly not meant to be exhaustive. It aims to identify a broad set of barriers that serve as a starting point to stimulate the researchers familiar with the problems and their context. First, peer-reviewed manuscripts and grey literature for the CE of plastics in the automotive industry was reviewed (see Appendix A.1). Although not many articles for the automotive industry were found, the available information on barriers and solutions for plastics in the CE were collated (see Appendix A.2). The resulting insights also served to see if the barriers and solutions are specific for the automotive industry or for plastics in general. Barriers were described from the viewpoint of the actor encountering them and categorized according to the type (technical, economic, knowledge, skills, organizational/infrastructure, policy/legal, motivation/perception) as well as R-ladder or waste-hierarchy, a tiered model of reduce, reuse, and recycle (van Buren et al., 2016, see Table A3 in Appendix A.3).

2.2.1.2. Step 1B Stakeholder analysis. The stakeholder analysis gives an overview of the actors in the field of the CE of plastics and more particular the automotive industry (Bening et al., 2021; Zoeteman, 2012). Stakeholders were identified reviewing scientific and grey literature as well as news articles and by using search engines. In addition, ‘snowball sampling’ was used to identify relevant respondents for focus groups and expert reflection in step 2 (Sadler et al., 2010).

2.2.1.3. Step 1C Exploratory interviews. In step 1C, we selected three key parties in the Dutch automotive industry for an exploratory interview to get further insight into the context and test questions before convening the planned focus groups (step 2A). We interviewed the organization in charge of recycling and meeting the End-of-Life Vehicles (ELV) Directive standards, the branch organization for disassemblers and a platform that brings together stakeholders in the automotive value chain to work towards a CE.

2.2.2. Step 2: Developing solutions with the chain

In the second proposed step of the SfSA approach, we prioritize barriers and “derive mutually agreed solutions through discussion and learning” with stakeholders with diverse knowledge and experience (Zijp et al., 2017). We improved the SfSA approach, by detailing a ‘chain-approach’ in which all stakeholders along a (CE) product chain are brought together in an interactivist and transformative approach (Silverman, 1993; van Bruggen et al., 2019). The interactivist approach to stakeholder involvement, aims to shift current linear-oriented systems with a myopic view on their own practices and ‘nearest-neighbor’ relationships (producer-client) onto a pathway in which the chain actors are enabled to consider the whole chain and find innovative solutions (van Bruggen et al., 2019; Voinov et al., 2016). To improve the SfSA with the chain approach, we designed a process with again sub-steps using a dedicated mix of qualitative methods involving actors from across the chain outlined below. For this process we build on the existing guidance for this step of SfSA and use a mix of (brainstorming) techniques and iterative steps to identify a broad range of chain-specific barriers and solutions (Chamberlain-Salaun et al., 2013; Zijp et al., 2017) (see Fig. 1).

2.2.2.1. Step 2A Focus groups. In this step we organized four focus group sessions of one and a half hours each in one day in September 2020. The goal was to identify and prioritize barriers and formulate solutions together with industry, because, in the end, solutions for circular use of plastics in the automotive industry has to be implemented in the network of industries. In step 2C outlined below, we asked a group of experts to reflect on the outcomes. Focus groups are structured discussions with a small group of participants led by an experienced moderator, which can be organized to study the viewpoints of different social groups in a relatively short time. An important aspect of focus groups is that participants can respond directly to each other, thereby creating and developing chains of associations, describing personal experiences, and exploring norms and values (Merton and Kendall, 1946; Morgan, 1997). We selected a group of 65 stakeholders in the Dutch context, of which 40 were invited to focus groups, and eighteen organizations accepted the invitation. Each participant participated in two subgroups to allow “all stakeholders to ventilate their knowledge and perspective”
We invited industry stakeholders, some of which have a specific focus not only on making profit, but also on making the industry more ‘green’, or circular and sustainable (Ying & Li-jun, 2012).

We divided stakeholders into one group with designers and (original equipment) manufacturers, including suppliers of automotive parts and raw materials, and another group with those involved in disassembly, sorting, and recycling of plastics in ELVs. The two parallel focus groups in the morning focused on identifying and prioritizing key barriers. For diverging, the brainstorming technique from the systematic family was used to analyze whether all possible options have been covered (Buijs and Van der Meer, 2013). Stakeholders responded to a presentation of barriers in literature (see Fig. 2). The ‘dотs technique’ was used to derive conclusions, whereby stakeholders voted on the derived the barriers to CE that were experienced as most important (Buijs and Van der Meer, 2013).

In the afternoon, materializing the solution-focused principle, the stakeholders were mixed to identify practice-based solutions for the identified most important barriers using a pre-made ‘solution canvas’ in collaboration with actors from other parts of the value chain (see Appendix B).

The stepwise chain approach resulted in a key finding, namely that a specific focus not only on making profit, but also on making the industry more ‘green’, or circular and sustainable (Ying & Li-jun, 2012).

The invited experts reflected in the validation steps on the combined list of 41 barriers. They generally recognized the barriers formulated, sometimes in a different formulation or with additions. They also rephrased, nuanced, or made additions to barriers, but did not.

The first research sub-question is: ‘what are the most important types of barriers to make the plastic use in the automotive sector circular?’

### 3.1. Barriers to a CE of plastics

#### 3.1.1. Identification of experienced barriers to CE

The first two steps of the SfSA chain approach yielded a combined list of 41 barriers for plastics in the automotive industry (see Appendix D.1). The first step of pre-assessment yielded 31 barriers for the automotive industry (see Appendix D.1) and 19 barriers for a CE of plastics in general (see Appendix D.2). Some of those 19 barriers are specific to plastic packaging, as most literature was on this topic. Half of the barriers found for the automotive industry are also found in the literature on general barriers for plastic in the CE, such as the barrier that recycled materials are more expensive and lack of clear information makes it difficult to make circular choices.

The stepwise chain approach resulted in a key finding, namely that a discussion on solution opportunities resulted in added barriers. That is, ten barriers were added by stakeholders in the second step (developing solutions) to get a total of 41 barriers. The barriers not mentioned by stakeholders that were found in step 1 (pre-assessment) include: the release of volatile organic compounds (#16B), the CO₂ impact of moving parts for disassembly (#19B); industry is more push-driven rather than pull-driven (#9B); and fear of being taken over by software companies (#11) (see Table D1 in Appendix D). One barrier from the literature was nuanced by the stakeholders: literature indicated it takes 15–20 years before changes in the design of a circular car are translated to the market, but, while the stakeholders during the focus groups indicated it would take around 10 years (#38) (World Economic Forum, 2020). Notably, the barriers concerning bioplastics (#3) and chemical recycling (#17, Appendix D.1), did not come back in the barriers research for the automotive industry, but as solutions.

Out of the 41 barriers, 10 concern policy and legal barriers, 10 concern motivation or perception, 9 are technical, 8 are economic, 7 are organizational or infrastructural, and 5 concern knowledge or skills (see Table D2 in appendix D). These results suggest that the ‘solution space’ is broad, and that effective solutions for a CE should address various barriers simultaneously, especially if it is considered that one barrier might halt implementing a CE step.

#### 3.1.2. Expert reflection on barriers

The invited experts reflected in the validation steps on the combined list of 41 barriers. They generally recognized the barriers formulated, sometimes in a different formulation or with additions. They also rephrased, nuanced, or made additions to barriers, but did not.
fundamentally dispute them (see Appendix D.3). For example, in relation to barrier #6 it was made explicit that current business models do not incentivize extending lifetime of vehicles, reuse or using recycled content, but rather production and sales of as many cars as possible. The validation experts also recognized the barriers that were identified by literature and not by stakeholders (#16B, #19B, #9B, #11) and recognized the barriers such as about chemical recycling and bioplastics were mentioned by stakeholders in the evaluation of optional solutions.

3.1.3. Prioritization of barriers with stakeholders

In Step 2A&B (developing solutions), ten barriers were marked as most important by the stakeholders (see Table 1).

Barriers of the type motivation and perception occurred most frequently, but were not necessarily prioritised highest by stakeholders (e.g., the perception that recyclate is of limited quality). According to the stakeholders these barriers can best be overcome by making legislation (rather than voluntary and market-based agreements) to motivate stakeholders to make their business cases circular. This is in line with the ELV directive evaluation and increasing calls for policy that not only bans or limit the use of plastics but stimulate the transition to a CE ensuring high level recovery and recycling of plastics (Borrelle et al., 2020; European Commission, 2021a; Hanemaaijer et al., 2021; Lau et al., 2020; Syberg et al., 2021). Concerns about the development of knowledge and skills, such as to install parts, were prioritized the least.

Stakeholders prioritized the barrier that there is insufficient data and methodologies for impact calculations that allow for making integral choices and identify trade-offs, particularly regarding Life Cycle Assessment (LCA) data. This corroborates the outcomes of the evaluation of the ELV Directive, which concluded that the available information on materials and components is not sufficient for disassemblers and recyclers to carry out their tasks (European Commission, 2021a).

Stakeholders also held barriers to be connected, as is also stated by Kirchherr et al. (2018); the way the vehicles are designed and manufactured affects the extent to which they can be disassembled or separated into streams that are easily recyclable. Similar versions of the same barrier are mentioned in different ways across the value chain. For example, the lack of a mature market for recyclate hinders the design phase where choices are made to apply recyclate, as well as the recycling phase where choices are made to invest in producing recyclate.

In step 2C (expert reflection), the experts generally agreed that the business case for both recycling as well as dismantling of automotive parts is not feasible in current policy and economic systems. The experts stressed the importance of economic barriers, which lack incentives for business models to become circular and particularly for recyclate to be competitive with virgin materials in terms of quality, cost, and security of supply with increasingly stringent requirements. As a result, only large manufacturers of parts can afford to spend time and effort to reuse and recycle plastics and there is a general preference for post-industrial over post-consumer recyclate. Additionally, the experts noted that there are currently no policy or economic incentives, such as design obligations to become circular. That is, the EPR schemes currently incentivize low R-strategies, including energy recovery from the latter. Several experts see economic barriers being at the heart of the issue and all other barriers as derivative of this barrier, and all mentioned the issue of insufficient data and methodologies to make impact calculations by stakeholders.

3.2. The importance of safety of substance related barriers

To answer the second research sub-question, stakeholders were asked to what extent safety concerns related to the use of hazardous substances are seen as a barrier and if so, how the problem relates to

| # | Barrier description | Type of barrier |
|---|---------------------|-----------------|
| 1 | In the design of new products and materials, the business case is calculated in relation to business as usual instead of a scenario in which we no longer have the material at a low cost. Therefore, it is difficult to make a circular business case in the present-day system. | Economic, perception |
| 2 | OEMs are primarily driven by profit motives and have no economic incentives to research new technologies or materials to become circular. | Economic, motivation |
| 3 | Environmental standards (CO₂ reduction) require from manufacturers to make vehicles more light weight to make them more energy efficient. The focus in the design stage is to make the vehicle energy efficient for example through using lightweight materials such as plastic in the use phase, shifting burdens to the end of life stage where they have to be recycled. | Policy |
| 4 | Opportunities for suppliers to collaborate with manufacturers, tier one suppliers and OEMs in the Netherlands on Research and Development (R&D) to make cars more circular remains unused, because R&D often takes place at an European or international level. | Organizational/infrastructure |
| 5 | The application of recyclate in a constant composition (non-virgin plastic sometimes has different grades of contamination or quality depending on the type of recycling). The quality has to live up to the demands of OEMs, which is easier for post-industrial than for post-consumer waste. | Economic, technical, perception (dependent on the actor and car part) |
| 6 | Reuse of parts is difficult and expensive, because each car brand uses its own type of parts. Manufacturers even make new components for new types of cars from the same brand that cannot be used in their own old cars, making dismantling even more difficult. | Organizational, economic, motivation |
| 7 | Disassembly and reuse of car parts is difficult due to frequent use of glue, welded joints, and composites. | Technical |
| 8 | As cars become more complex and contain digital components, reuse requires not only knowledge of separate car parts, but also on how they work together. Many components have to be digitally installed and programmed. This specialist knowledge/skills are insufficiently available, and mistakes are costly, especially for independent garage owners. | Knowledge/skills |
| 9 | The quantitative standard of 95% recycling from the ELV Directive stimulates downcycling and thus stands in the way of high-quality recycling. The Directive establishes a minimum reuse and recycling rate of 85% of vehicle total weight and a minimum reuse and recovery rate of 95% of the same total weight (2000/53/EC). It is, in other words, impossible to reach the norm when disassembling a car, and as a result, more car parts are recycled that could have been reused as a whole without the norm. | Legal |
| 10 | Insufficient data and methodologies about plastic recycling in the automotive industry makes impact calculation to make choices for recycling for different types of impact such as climate, circularity and safety more difficult. When the impact of options is unclear, it is difficult to make circular choices. | Knowledge, organizational, technical |
other barriers. In total eight safety-of-substance related barriers were either recognized from literature or articulated by the stakeholders. See Table 2 for an overview of these barriers.

Regarding the research question on barriers related to hazardous chemicals, it appeared that (out of the eight safety related barriers) five barriers relate to legislation and policy on Substances of Very High Concern (SVHCs) and specifically the complexity of the constantly changing regulation (ECHA, 2019a; UNEP, 2018). As an example, industry argues the new European ‘Substances of Concern In articles as such or in complex objects Products’ (SCIP) database is an administrative burden which will not incentivize manufacturers and OEMs to change materials to avoid hazardous materials (ECHA, 2019b; Friege et al., 2021; Ministerie van Infrastructuur en Waterstaat, 2020). Three barriers concern knowledge. The barrier concerning lack of information and techniques to identify circular solutions and weigh different kinds of impacts was mentioned most often, and also was the only safety-related barrier that was prioritized in the top 10 most important barriers (see Table 1).

In the validation step, experts recognize the importance of safety-barriers, but miss the discussion about chemical recycling which can produce high-quality recycle of plastics with(out) (legacy) substances. Stakeholders mentioned chemical recycling only as a solution, but several experts mentioned the barrier that chemical recycling technologies are expensive, not yet widely developed and available. One expert explained the economic barriers stem from a conflict of interest that is created through the involvement of primary plastic producers in both the production of (toxic) additives for polymers as well as in designing regulations that restrict their use. In waste flows the toxic and non-toxic waste streams are combined and limit recyclability. The ELV Directive incentivizes manufacturers specifically “to make new vehicles without hazardous substances, so their parts can later be reused” (European Commission, 2020b). Experts agree that safety-related barriers are not as problematic as other barriers to realize a CE. Some argued that safety barriers will be overcome through technological advancement. Another said that in the future, as economic and policy barriers are overcome, the safety related barriers will come more to the foreground, as it already has come in other plastic streams, such as packaging.

### 3.3. Developing solutions with the chain

In this section we address the third research sub-question: ‘Which solutions are proposed by Dutch stakeholders in the automotive sector for the barriers they consider most important?’ Figs. 3–8 show the results of solutions found in literature and proposed by stakeholders for the top six barriers experienced by stakeholders. The green box with the lamp icon below shows the solution from the literature to the barrier and the blue box with the survey icon contains additional or alternative solutions formulated by stakeholders. The solutions are presented by order of the impact of the solution as rated by the stakeholders for the most important barriers: Lastly, the box with the graph includes scores on impact on a scale of 1–10 and feasibility on a percentage scale of 0–100%. While the scores give a general idea, it is not clear if the stakeholders rated only the impact and feasibility of the solution presented in the literature or also considered additional solutions or conditions which were different for each stakeholder. It is assumed that they primarily scored the solution presented from the literature. For the barrier where there were no solutions found in the literature (see Fig. 4), stakeholders seem to have provided a score on impact and feasibility for the solution they offered themselves.

### Table 2
Overview of safety related barriers categorized by phase in the value chain and type of barrier.

| # | Barrier description | Type of barrier |
|---|---------------------|-----------------|
| 1 | Strict safety requirements from policy limit the engineer in the use of recycle or modular construction. Materials must meet increasingly strict requirements for the presence of substances of very high concern; proving that these are not present in recycled materials is difficult and expensive. | Legal, economic |
| 2 | Circularity is considered less important by manufacturers than safety for the users of the car, the appearance of the car and climate (less greenhouse gas emissions), which hinders the implementation and innovation of circular solutions. | Policy/legal, motivation |
| 3 | Long qualification paths to comply with regulation for new products for OEMs make it more difficult to implement more sustainable or safer alternatives. | Policy, perception |
| **Recycling** | **SVHC (Substances of Very High Concern) that are added as additives to the plastics of cars hinder the recycling of car (parts).** | Technical, knowledge |
| 4 | The list of SVHCs and the number of substances under the Regulation for the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) legislation and the persistent organic pollutant regulation (POP) is growing and changing, making it difficult to keep up with requirements for recycling of plastics even more difficult (ECHA, 2019a, 2019b; UNEP, 2018). | Policy/legal, technical |
| 5 | Many cars now offered for recycling contain legacy substances, which are substances that are no longer added to new materials, but are still in old designs that met standards 15–20 years ago (Wagner and Schlummer, 2020). | Technical, knowledge |
| 6 | There are many complex laws and regulations regarding recycling and the use of SVHC, for example the REACH, the ELV and Waste from Electrical and Electronic Equipment (WEEE) directives. These are complex, constantly evolving, sometimes overlap or are inconsistent. This makes recycling more difficult. | Policy/legal |
| 7 | Insufficient data and methodologies about plastic recycling in the automotive industry makes impact calculation to make choices for recycling for different types of impact such as climate, circularity and safety more difficult. When the impact of options is unclear, it is difficult to make circular choices. | Knowledge, organizational, technical |

### 3.3.1. Policy and economic incentives

In line with the barriers that were prioritized (policy and economic barriers), the solutions that were formulated to allow more circular choices frequently involve incentives from policy and economic changes. Most stakeholders emphasized the importance of legislation, which can be the game changer in situations where circular choices have a negative impact on profit (Bening et al., 2021). The analysis of the solutions and how they are prioritized shows that stakeholders score solutions differently, but it is possible to make general observations.

Stakeholders expect most of solutions that focus on policy and economic incentives such as norms, design criteria, and subsidies for recycling. The solutions that focus on platforms and increasing collaboration across the value chain, score notably lower on impact and feasibility. In general, the involved stakeholders are in favor of measures that reward rather than punish. They also see more value in solutions that reward circular choices in structural ways, such as through exemption of taxes for reducing raw material use, rather than open-ended commitments, acts, or nudges. They say governments should offer structural support to stimulate parties across the value chain to make circular choices, for example to share information across the value chain to encourage recycling. Stakeholders said the burdens that come with implementation of solutions which cost more than options in the business-as-usual scenario should be shared equally across the value chain and a level playing field should be created.
Stakeholders also indicated that just as barriers are connected, a mix or synergy of different types of solutions and a systemic view is needed (Siltaloppi and Jähi, 2021). Most barriers require a mix of economic, legal, and organizational incentives for solutions to be effective. For example, to implement a norm for high quality recycling or reuse of components, it is also necessary to improve information sharing systems on parts and components across the value chain. Implementing one solution such as a norm for recyclate, can also trigger other solutions like increased collaboration across the chain.

Experts agree with the analysis that financial drivers will provide the most important incentives for circularity and that policy should provide a framework to make sustainable measures profitable. However, experts also say the scenarios in their current form are too detailed, embedded in the current situation or not radical enough. Experts give other examples of how policy can provide a framework for circularity, for example through taxing negative side effects (e.g., a carbon tax through extension of the EU Emissions Trading System (ETS) regulation and nitrogen tax), subsidizing activities with positive side-effects (e.g., stimulate recycling inside the EU, obligation for recycled content) and stimulating research that makes activities with positive side-effects more profitable. The balance needs to be found between whether costs are covered by society or by producer responsibility. Also, it must be insured that regulations do not have too high maintenance costs to check and regulating too many details with may unintentionally reduce the solution space for industry or incentivize going around them.

Experts also agree a mix of solutions is required. For example, the norm for recycled content of parts, should be combined with for example using post-consumer waste to stimulate advances in (chemical) recycling technologies, with a shared database to calculate sustainability of recycling. Modularity (solution VI, Fig. 6) has a low feasibility across OEMs but could be implemented by a single producer in combination with new business models such as car sharing. Experts point out that the use of glue is not the only solution, but also requires different design and ease-of-dismantling. Finally, experts added that a change of the ELV directive and mandatory recycled content targets are important, and the feasibility score should be higher. The mandatory percentage for the application of recyclate of car parts (Solution III, Fig. 5), experts were surprised by the low impact and feasibility scores, as it is feasible according to other research and therefore expected to be introduced as novel practice.

Fig. 3. Solution I – Norm that stimulates upcycling.
Legend: 1. Gate icon: barrier to which a solution is presented 2. Lamp icon: solution from the literature 3. Survey icon: additional or alternative solutions formulated by stakeholders 4. Graph icon: scores on impact on a scale of 1–10 and feasibility on a percentage scale of 0–100%.

Fig. 4. Solution II - Design for recycling (for this barrier, we did not identify any solutions from literature).
3.3.2. Safe and sustainable by design

Many solutions found in this study require an involvement from the actors at the design stage to tackle the barrier at its origin: the way the product and the system in which it is produced and disposed of are designed. This is in line with the current strategies emphasized in policy on safe and sustainable design, which hold that circularity and multiple life cycle loops should be taken into account when designing a product or service (European Commission, 2020a, 2021b). Other types of solutions support better design as well, such as the solution that focuses on increased collaboration between OEMs and recyclers (Fig. 5). To implement design for recycling and disassembly methods, it is necessary to stimulate collaboration across the value chain. Several stakeholders mentioned the example of a previous collaboration across the chain, initiated by a network organization that made innovation possible that was previously thought to be impossible. This example demonstrates that when stakeholders come together from across the chain to find solutions, the basic idea of our approach, more is possible than previously thought.

For policy solutions, stakeholders include a condition that solutions must not be worked on solely on a national level, but on an EU level and require collaboration across the value chain. The design of solutions must consider the global nature of the automotive industry. Furthermore, many regulations for the stakeholders in the Netherlands are determined on a European level and operationalizing solutions on a European level enables more integral steering or direction to the transition from a systems perspective.

Experts agree that there is room for innovation in the design space where circularity must be made a key priority, which can be aided by other transitions such as the ‘sharing economy’ and ‘mobility as a service’. Regarding collaboration, an expert suggested perceived complexity of solutions can be reduced not only through collaboration, but also by giving access to information for example to a database with
recyclability rates for materials. The experts also agree solutions must be operationalized on an EU level as the EU can ensure competitiveness for the industry with non-EU regions through harmonization of rules.

4. Discussion

The stepwise approach followed, led to insights regarding the use of the Solution-focused chain Assessment Framework as well as the specific case. In this section the conclusions, the method, and avenues for future research are discussed.

4.1. Insights on the case-study: barriers, solutions and the role of safety

The involved stakeholders agreed that circular strategies that are technically or organizationally feasible are not yet sufficiently supported by economic and policy stimulants. Such support is needed to realize this technical potential and change behavior in line with circular thinking. For example, recyclate of sufficient quality is often more expensive to apply compared to virgin plastics and more incentives are needed to adopt them. Stakeholders emphasized the importance of focusing on the design phase, where solutions help to overcome barriers across the life cycle. Stakeholders indicate that interactions of all actors across the chain are still limited in the current linear structures. Experts recognized the priority of policy and especially economic barriers and solutions. Economic measures should be taken to primarily take away cost barriers to circularity and this should be operationalized on an EU level, not the Dutch level. The need to overcome policy and economic barriers aligns with observations in the Netherlands and EU that the transition towards the CE is in its first and exploratory phase and stronger policy and economic incentives are needed to realize a CE (Araujo Galvaão et al., 2018; Hanemaaijer et al., 2021; Ritzén and Sandström, 2017). In addition to policy and economic constraints, both stakeholders and experts prioritize the need for data and methodologies to make impact calculations to assess solutions.

Although the emphasis on policy and economic barriers and solutions seems to suggest focus should be on solving policy and economic restraints and improving current policy measures, this is not necessarily the entire truth for three reasons.

The first is that, as observed by the stakeholders as well as experts, the barriers are connected, and several barriers need to be addressed simultaneously, especially if the problem cannot be fully solved from the design phase. Stakeholders and experts indicate that for solutions to be successful, they need to be implemented as solutions networks: a combination of solutions or a solution with several conditions in place in which different actors collaborate (cf. Jaakkola and Hakanen, 2013). For example, a European norm for recyclate combined with economic incentives would make application of recyclate more likely. Hence, when looking for solutions for the barriers that are perceived as most important, a system perspective with insights in the other barriers is necessary to overcome the barrier successfully. The chain approach thus brought to light a diverse set of issues. Since challenges in the reuse and recycling phase can be addressed effectively in the design phase, policy and legislation that support safe and sustainable by design is an essential step in the transition towards a CE (Wolfram et al., 2020). Policy addressing...
several solutions and barriers issues is in the making, such as the Eu-
ropean Chemical Strategy for Sustainability, a norm for the applica-
tion of recycle, and a review of the ELV directive (European Commissi-
on, 2020a, 2020b).

Second, when policy and economic barriers are overcome, it may be
expected that other barriers and specifically those concerning safety
of substances may come to the forefront. This observation was confirmed
by expert elicitation. When policy stimulates circular choices, the safety-
related barriers such as the lack of data and tools on sustainability and
safety to make integral assessment to weigh circular choices may come to
the forefront. This already occurred in other plastic value chains, such
as packaging.

Third, stakeholders aware of barriers and possible solutions can also
proactively take action to go beyond legislation and pioneer solutions,
such as designing materials and products that can be used, reused and
recycled safely, gather and share information across the chain, and take
collective responsibility for use of substances of concern for which there
are currently no alternatives (Beekman et al., 2020). Such action can be
taken in anticipation of new legislation to incentivize circular design
being developed, such as an update of the ELV directive and the SCP
data base. Stakeholders now indicated they already comply with current
policy and – even though technically more is feasible for safe and sus-
tainable design – the incentives for this are lacking.

4.2. Reflection on the method

The step 1 and 2 of the SISA approach was improved in the context of
the CE-transition by employing mixed methods that are well-known and
described in different contexts, with specific emphasis on involving all
actors along the (currently mostly linear) product chain, for the specific
case of plastics in the automotive industry. The methods served to have
different rounds of iterations to come to conclusions on how the industry
stakeholders see barriers and solutions and increase the reliability of the
data with different perspectives included. About one fourth of the bar-
rriers found in this research were not yielded from the literature review,
but by stakeholder participation. This shows the importance of stake-
holder participation from across the chain in research projects that focus
on knowledge and solutions that support the transition towards a safe
and sustainable CE. The reflection by experts added further details. The
integral approach and opportunity to consult in focus groups on barriers
and solutions, has helped actors see new possibilities and gain inspira-
tion that more is possible than previously thought.

The design and review of solutions by stakeholders was exploratory,
in contrast to the barriers where the iterative steps served to generate an
exhaustive list. Stakeholders worked in mixed groups with different
actors from across the value chain to develop solutions. This was useful
to discover novelties. For example, stakeholders in the design group
discovered from the interaction with stakeholders from the recycling
group that it is easier to overcome barriers to the CE such as recycle-
tate than previously thought. The solution canvas provided a helpful struc-
ture for designing solutions and especially the direction in which solu-
tions should be found. However, in this constitution it appeared to be
challenging to derive solutions that are specific and go beyond solutions
formulated as the opposite of the problem. Experts also reflected that
solutions found are too detailed and not radical enough. The next step,
towards more detailed solution descriptions, will require more time and
creative facilitation of the solution development. Involving other stake-
holders in step 2A and B of developing solutions, such as NGO’s,
consumers and policy makers, would probably result in a broader set of
solutions and different prioritization. However this also comes with the
need for more focus groups in order for the stakeholders from the dif-
f erent realms to understand each other. E.g., policy makers might
think there is technical innovation required, while the industry has the
innovations available but waits for a policy or economic window of
opportunity. Furthermore, policy makers and experts approached before
the focus group, preferred to reflect on the results rather than participate
directly. In this case, a good understanding of the perspectives was
reached by involving industry and having experts reflect. However, who
to involve also depends on the case study. For example, consumers
generally have limited influence and domain knowledge on the design or
end of life stage of the car and were left out in this case while they may
have more influence in other case studies, such as textiles. Useful in-
sights could be gained from specific focus groups on consumer choices
and preferences, as this provides viewpoints that may influence the
supply chain actors and add to the current method.

The research in the current form aimed to understand and identify
the knowledge, experiences and viewpoints of the stakeholders on their
own terms, with the aim to formulate barriers and solutions as the sector
sees it to stay close to the field where the solutions should be imple-
mented. The expert reflection gave insight into whether vested interest
from industry stakeholders would have skewed results and gave room
for analyses from different perspectives (Benig et al., 2021; de Jesus
et al., 2019). Experts generally agreed with the focus on policy and
economic barriers and solutions, but added important nuances or di-

densions to current barriers. For example, how lack of financial in-
centives creates further barriers due to the conflict of interest from
primary plastic producers. Experts did remark the barriers could all be
grouped as variants of economic barriers. Furthermore, experts were
surprised by the low impact and feasibility scores of some solutions such
as a mandatory percentage of applying recylcate, as it is feasible ac-

cording to other research and expected to be introduced. This shows the
importance of expert reflection on results to avoid bias and the iterative
approach taken to coming to conclusions on barriers and solutions.

4.3. Future research

In the next step of the SISA approach, in which it needs to be decided
which solutions are implemented along a particular product chain (see
Fig. 1), the solution focused ‘chain’ approach needs to be extended with
a procedure comparable to Multi Criteria Analysis to guarantee trans-
parency (Zijp et al., 2016). In this part industry stakeholders, experts,
and policy makers can be included and the discussion could take place
on the EU level. Efforts to gather required data to calculate which
measures are the most sustainable may further aid industry together
with economic incentives to widen the solution space and take measures
to go beyond current societal needs, policy ambitions, and associated
legislation. When selecting methods, solutions can be further assessed
through a dynamic system model to analyze the interaction between the
stakeholders and the impact of policy measures and solutions for
example an Agent-based Model (van Dam et al., 2012). The potential
effects of stimulating the R-strategies with these solutions on resource
flows, safety, and environmental and social impacts can be analyzed
using tools such LCA. This would require efforts to actively gather
and make available additional data that is now not gathered or accessible.

To further expand the chain approach to other steps of the SISA
framework, the solutions that were formulated, require further specifi-
cation. A solution needs to be expanded also in terms of who does what,
which piece of information needs to be mandatory to share, as well as
the infrastructure and policies required to make it work. Furthermore,
such solutions should be focused on what stakeholders themselves can
do, so they can share relevant data and lessons and thus iteratively learn
about the effectiveness of the solution in collaboration with policy
makers and knowledge institutes.

The steps taken to extend the SISA approach, could be applied to a
different case such as the CE of plastics in textiles, possibly with ad-
justments suggested here, to further explore the value of the SISA-chain
approach in identifying barriers to CE and solution-packages that pro-
mote CE for the pertinent product category. It is recommended to
continue to work in iterative steps of learning and decide at each stage
whether other methods are needed to come to conclusions on devel-
oping solutions (Zijp et al. 2016). Another question for further research
is the extent to which the barriers and solutions are generalizable
5. Concluding remarks

Bringing together stakeholders from a value chain to formulate solutions is necessary and valuable to gain insight into existing and perceived barriers and how they can be overcome. The chain approach brings together the existing knowledge of the system, in the wider context of the product chain, from which original solution packages can be generated and should be realized. This interaction is required to make a next step towards a CE and makes possibilities visible. Expert reflection on the outcomes serves to further improve the barriers and solutions formulated. The next step is to extend the chain approach to the next steps of the SISA framework: gathering data, assessing, and implementing the solutions. The ‘chain approach’ could be repeated for other priority material streams for the CE such as textiles, steel, biomass, and food or the manufacturing industry, and based on that experiences be improved.

Funding sources

The research is part of the Qonnect project (S/030001) which is commissioned by the Director General Hans Brug and funded through the RIVM Strategic Research Budget.

CRediT authorship contribution statement

Anne R. van Bruggen: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing. Michelle Zonneveld: Conceptualization, Methodology, Investigation, Writing – review & editing. Michiel C. Zijd: Conceptualization, Methodology, Writing – review & editing, Funding acquisition. Leo Posthuma: Conceptualization, Methodology, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We thank our colleagues Lise de Boer, Michiel van Kuppevelt, Erik Dekker, and Susanne Waaijers-van der Loop for reviewing the article. We also thank Fabrice Mathieu from the JRC for engaging discussions and encouragement to publish the article. We thank the stakeholders as well as experts for their participation and input.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2022.131606.

References

Anastasiades, K., Blom, J., Boye, M., Audebert, A., 2020. Translating the circular economy to bridge construction: lessons learnt from a critical literature review. Renew. Sustain. Energy Rev. 117 https://doi.org/10.1016/j.rser.2020.109552.

Araujo Galvão, G.D., de Nada, Z., Clemente, D.H., Chinen, G., de Carvalho, M.M., 2018. Circular economy: overview of barriers. Procedia CIRP 73, 79–85. https://doi.org/10.1016/j.procir.2018.03.049.

Aurisano, N., Weber, R., Fantke, P., 2021. Enabling a circular economy for chemicals in plastics. Curr. Opin. Green Sustain. Chem. 31 https://doi.org/10.1016/j.coteco.2020.100513.

Benavente, M., Bakker, J., Bodar, C., van Leeuwen, L., Waijier-van der Loop, S., Zijd, M., Verhoeven, J., 2020. Coping with substances of concern in a circular economy. https://doi.org/10.21945/IV/2020-0049.

Bening, C.R., Pruess, J.T., Blum, N.U., 2021. Towards a circular plastics economy: intersecting barriers and connecting solutions for flexible packaging recycling. J. Clean. Prod. 302 https://doi.org/10.1016/j.jclepro.2021.126966.

Bernhardt, E.S., Rosi, E.J., Gesnner, M.O., 2017. Synthetic chemicals as agents of global change. Front. Ecol. Environ. 15 (2), 84–90. https://doi.org/10.1002/fee.1490.

Bocken, N.M.P., de Pauw, L., Bakker, C., van der Grinten, B., 2016. Product design and business model strategies for a circular economy. J. Ind. Prod. Eng. 33 (5), 308–320. https://doi.org/10.1002/jpe.1612124.

Borrell, S.B., Ringma, J., Law, K.L., Monnahan, C.C., Lebretón, L., McGavern, A., Murphy, E., Jamecek, J., Leonard, G.H., Hilleary, M.A., Erikson, M., Possingham, H.P., de Frend, H., Gerber, L.R., Polidoro, B., Tahir, A., Bernard, M., Mallos, N., Barnes, M., Rochman, C.M., 2020. Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. Science 369 (6510), 1515–1518. https://doi.org/10.1126/science.aba3656.

Buekens, A., Zhou, X., 2014. Recycling plastics from automotive shredder residues: a review. J. Mater. Cycles Waste Manag. 16 (3), 398–414. https://doi.org/10.1007/s10163-014-0244-z.

Buijs, J., Van der Meer, H., 2013. Integrated Creative Problem Solving. Eleven International Publishing.

Cardamone, G.P., Ardolino, F., Arena, U., 2022. Can plastics from end-of-life vehicles be managed in a sustainable way? Sustain. Prod. Consum. 29, 115–127. https://doi.org/10.1016/j.spc.2021.09.025.

Chamberlain-Salaun, J., Millis, J., Usher, K., 2013. Linking symbolic interactionism and grounded theory methods in a research design. Sage Open 3 (3). https://doi.org/10.1177/2158244013505797.

de Jesus, A., Antunes, P., Santos, R., Mendonça, S., 2019. Eco-innovation pathways to a circular economy: envisioning priorities through a Delphi approach. J. Clean. Prod. 228, 1494–1513. https://doi.org/10.1016/j.jclepro.2019.04.049.

Dearing, J.A., Wang, R., Zhang, K., Dyke, J.G., Haberl, H., Hossain, M.S., Langdon, P.G., Lenton, T.M., Raworth, K., Brown, S., Castenssen, J., Cole, M.J., Cornell, S.E., Dawson, T.P., Doncaster, C.P., Eigenbrod, F., Florke, M., Jeffers, E., Mackay, A.W., Poppy, G.M., 2014. Safe and just operating spaces for regional social-ecological systems. Global Environ. Change 28, 227–238. https://doi.org/10.1016/j.gloenvcha.2014.06.012.

ECHA, 2019a. REACH: regulation for the registration, evaluation, authorisation and restriction of chemicals. Retrieved november 2019 from. https://echa.europa.eu/reach/understanding-reach.

ECHA, 2019b. SCP database. Retrieved november 2019 from. https://echa.europa.eu/scp-database.

European Commission, 2018. In: A European Strategy for Plastics in a Circular Economy, p. 18. Brussels.

European Commission, 2019. The European green deal. (COM(2019) 640 final). Brussels Retrieved from. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1588580744049&uri=CELEX:52019DC0640.

European Commission, 2020a. Chemicals strategy for sustainability towards a toxic-free environment. https://ec.europa.eu/environment/pdf/chemicals/2020/10/Strategy.pdf.

European Commission, 2020b. End-of-life Vehicles - Evaluating the EU Rules. European Commission. Retrieved 8 june from. https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/1912-End-of-life-vehicles-evaluating-the-EU-rules_en.

European Commission, 2021a. COMMISSION STAFF WORKING DOCUMENT EVALUATION of Directive (EC) 2000/53 of 18 September 2000 on end-of-life vehicles. (SWD(2021) 60 final). Brussels Retrieved from. https://ec.europa.eu/in fo/law/better-regulation/have-your-say/initiatives/1912-End-of-life-vehicles-evaluating-the-EU-rules_en.

European Commission, 2021b. Sustainable product initiative. Brussels Retrieved from. https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12567-Sustainable-products-initiative_en.

Finkel, A.M., 2011. Solution-focused risk assessment*: a proposal for the fusion of environmental analysis and action. Hum. Ecol. Risk Assess. 17 (4), 754–787. https://doi.org/10.1080/10807039.2011.588142.

Friege, H., Kummer, B., Steinhauser, K.G., Wuttike, J., Zeschmar-Lahl, B., 2019. How should we deal with the interfaces between chemicals, product and waste legislation? Environ. Sci. Eur. 31 (1) https://doi.org/10.1186/s12302-019-0236-7.

Friege, H., Zeschmar-Lahl, B., Kummer, B., Wagner, J., 2021. The new European database for chemicals of concern: how useful is SCP for waste management? Sustain. Chem. Pharm. 21 https://doi.org/10.1016/j.scp.2021.100430.

Greb, K.J., Backhaus, T., Carney-Almroth, B., Gusek, B., Inostroza, P.A., Lenquint, A., Leslie, H.A., Maffini, M., Shenge, D., Trasande, L., Warhurst, A.M., Muncke, J., 2019. Overview of known plastic packaging-associated chemicals and their hazards. Sci. Total Environ. 651 (Pt 2), 3253–3268. https://doi.org/10.1016/j.scitotenv.2018.10.015.
Hanemaaijer, A., Kishma, M., Brink, H., Koch, J., Prins, A.G., Rood, T., 2021. Netherlands circular economy report 2021, English summary. https://www.pb.nl/sites/default/files/downloads/2021-pbl-icer-2021-english-summary-4226-0.pdf.

Hart, J., Adams, K., Giesekam, J., Tingley, D.D., Pomponi, F., 2019. Barriers and drivers in a circular economy: the case of the built environment. Procedia CIRP 80, 619–624. https://doi.org/10.1016/j.procir.2018.12.015.

Hesse-Biber, S., 2010. Qualitative approaches to mixed methods practice. Qual. Inv. 16 (6), 455–468. https://doi.org/10.1080/10770100416641111.

Jakkola, E., Hakanan, T., 2013. Value co-creation in solution networks. Ind. Market. Manag. 42 (1), 47–58. https://doi.org/10.1016/j.indmarman.2012.11.005.

Khedier, A., Williams, K., Dallison, N., 2018. Challenges around automotive shredder residue production and disposal. Waste Manag. 73, 566–573. https://doi.org/10.1016/j.wasman.2017.05.008.

Kirchherr, J., Piscicelli, L., Bour, R., Kostene-Smit, E., Muller, J., Huibrechtse–Hanemaaijer, A., Kishna, M., Brink, H., Koch, J., Prins, A.G., Rood, T., 2021. Netherlands plastics valorisation in the context of a circular economy: case studies to explore and decide on sustainable solutions for wicked problems. Environ. Int. 91, 230–234. https://doi.org/10.1016/j.envint.2016.05.012.

Merton, R.K., Kendall, P.L., 1946. The focused interview. Am. J. Sociol. 51 (6), 541–557. https://doi.org/10.1086/219886.

Milios, L., Holm Christensen, L., McKinnon, D., Christensen, C., Rasch, M.K., Hallstrom, Khodier, A., Williams, K., Dallison, N., 2018. Challenges to plastics valorisation in the context of a circular economy: case studies to explore and decide on sustainable solutions for wicked problems. Environ. Int. 91, 230–234. https://doi.org/10.1016/j.envint.2016.05.012.

Morten, S., Sandstrom, G.O., 2017. Barriers to the circular economy – integration of perspectives and domains. Procedia CIRP 64, 7–12. https://doi.org/10.1016/j.procir.2017.03.005.

Rockstrom, J., Steffen, W., Noone, K., Persson, A., Chapin III, F.S., Lambin, E., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P.K., Costanza, R., Svedin, U., Foley, J., 2009. Planetary boundaries: exploring the safe operating space for humanity. Ecol. Soc. 14 (2) https://doi.org/10.5751/es-03810.140222.

Sadler, G.R., Lee, H.C., Lim, R.S., Fullerton, J., 2010. Recruitment of hard-to-reach population subgroups via adaptations of the snowball sampling strategy. Nurs. Health Sci. 12 (3), 369–374. https://doi.org/10.1111/j.1442-2018.2010.00541.x.

Schroeder, F., Anggraeni, K., Weber, U., 2018. The relevance of circular economy practices to the sustainable development goals. J. Ind. Ecol. 23 (1), 77–95. https://doi.org/10.1111/jiec.12732.

Siltanen, J., Håkkinen, T., 2021. Toward a sustainable plastics value chain: core conundrums and emerging solution mechanisms for a systemic transition. J. Clean. Prod. 315 https://doi.org/10.1016/j.jclepro.2021.128115.

Silverman, D., 1993. Interpreting Qualitative Data. Methods for Analysing Talk, Text and Interaction. SAGE.

Steffen, W., Richardson, K., Rockstrom, J., Cornell, S.E., Farley, J., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reynolds, B., Sørlin, S., 2015. Sustainability: Planetary boundaries: guiding human development on a changing planet. Science 347 (6223), 1259855. https://doi.org/10.1126/science.1259855.

Syberg, K., Nielsen, M.B., Westergaard Clausen, L.P., van Calster, G., van Wesel, A., Rockman, C., Koelmans, A.A., Cronin, R., Pahl, S., Hansen, S.F., 2021. Regulation of plastic from a circular economy perspective. Curr. Opin. Green Sustain. Chem. 29 https://doi.org/10.1016/j.jcogsc.2021.100462.

UNEP. 2018. Chemicals proposed for listing under the Convention. Retrieved 10-05-2018 from http://www.pops.int/TheConvention/ThePOPs/ChemicalsProposedforListi ng/tabid/2510/Default.aspx.

van Bruggen, A., Nicolai, L., Kwakkel, J., 2019. Modeling with stakeholders for transformative change. Sustainability 11 (3), 825. https://www.mdpi.com/2071-071X/11/3/825.

van Buren, N., Demmers, M., van der Heijden, R., Witlox, F., 2016. Towards a circular economy: the role of Dutch logistics industries and governments. Sustainability 8 (7). https://doi.org/10.3390/su8070647.

van Dam, K., Nicolai, L., Lukuzo, Z., 2012. Agent-Based Modelling of Socio-Technical Systems. Springer Science & Business Media.

Voinov, A., Rolandan, N., McCall, M.K., 2016. Preface to this virtual thematic issue: modelling with stakeholders II. Environ. Model. Software 79, 153–155. https://doi.org/10.1016/j.envsoft.2016.01.006.

Wagner, S., Schlummer, M., 2020. Legacy additives in a circular economy of plastics: current dilemma, policy analysis, and emerging countermeasures. Resour. Conserv. Recycl. 158 https://doi.org/10.1016/j.resconrec.2020.104800.

Wolfram, P., Tu, Q., Heeren, N., Pauliuk, S., Hertwich, E.G., 2020. Material efficiency and climate change mitigation of passenger vehicles. J. Ind. Ecol. 25 (2), 494–510. https://doi.org/10.1111/jiec.13067.

World Economic Forum, 2020. Forging Ahead A Materials Roadmap for the Zero-Carbon Car (Circular Cars Initiative, Issue. W. E. Forum).

Ying, J., Li-Jun, Z., 2012. Study on green supply chain management based on circular economy. Phys. Procedia 25, 1662–1688. https://doi.org/10.1016/j.phpro.2012.03.095.

Zijp, M.C., Posthuma, L., Wintersen, A., Devilee, J., Swartjes, F.A., 2016. Definition and composition. Environ. Int. 145, 106066 https://doi.org/10.1016/j.envint.2016.01.006.

Zijp, M.C., Posthuma, L., van Buren, N., Demmers, M., van der Heijden, R., Witlox, F., 2016. Towards a circular economy: the role of Dutch logistics industries and governments. Sustainability 8 (7). https://doi.org/10.3390/su8070647.

van Dam, K., Nicolai, L., Lukuzo, Z., 2012. Agent-Based Modelling of Socio-Technical Systems. Springer Science & Business Media.

Zippin, L., 1975. The nature and meaning of sampling errors. In: Statistical decision theory and quadratic forms. Academic Press, New York.

Zukin, S., 1982. Place and space in urban social analysis. In: Handbook of urban sociology. Sage, Beverly Hills, CA.

Zukin, S., Regan, J., 1985. The nature and meaning of sampling errors. In: Statistical decision theory and quadratic forms. Academic Press, New York.

Zukin, S., Regan, J., 1985. The nature and meaning of sampling errors. In: Statistical decision theory and quadratic forms. Academic Press, New York.