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How circular is your tyre: Experiences with extended producer responsibility from a circular economy perspective

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A B S T R A C T

The circular economy (CE) emphasises closing material loops to retain material value. The current practice of tyre recycling in the Netherlands, through a system of extended producer responsibility (EPR), appears an overwhelming success, with claims of 100% recovery. Yet, there is limited critical understanding regarding the system's circularity, considering alternative value retention options and resource recovery outcomes. This study analyses this Dutch tyre EPR system and reflects on how it can be improved from a systemic CE perspective. It uses a qualitative case study approach, using interviews and a review of policy, legal and EPR reporting documents. This paper assesses the governance of this sector and reflects on the existing system, including its circularity and value retention outcomes. Our analysis reveals seven central issues concerning how the EPR system currently functions, resulting in limited circularity and sustainability outcomes, despite high material recovery levels. To address these issues we recommend the continuous improvement of recovery and sustainability targets beyond a single product life cycle, a more transparent and inclusive governance system, as well as a greater focus on sufficiency strategies, e.g. design for durability and a broader transformation of transport models. This paper adds a practical understanding of the capacity of EPR to contribute to CE.

1. Introduction

National, regional and local governments have recently begun to present the concept of circular economy (CE) as a new pathway to sustainability and economic prosperity. The championing of this inconsistent and contested concept (cf. Korhonen et al., 2018) comes amid increasing concerns over resource depletion, waste generation and overshoot of planetary limits induced by human activities on the biosphere (Henckens et al., 2014; Rockström et al., 2009). CE is broadly argued to meet these emerging challenges through slowing, closing and narrowing resource loops, i.e. maximising the functional utility of materials and energy (Geissdoerfer et al., 2017; Stahel, 2010). CE theoretically builds upon and goes beyond earlier measures of waste valorisation and cleaner production initiatives to an integrated systems perspective addressing both production and consumption practices (Ellen MacArthur Foundation, 2013; Vermeulen et al., 2018).

The European Commission (EC) frames CE in conjunction with economic opportunities stating that "[CE] will boost the [European Union] EU's competitiveness by protecting businesses against scarcity of resources and volatile prices, helping to create new business opportunities and innovative, more efficient ways of producing and consuming" (European Commission, 2015, p. 1). National governments have similarly outlined specific strategies, including the Netherlands, France and Italy; with the Netherlands setting an initial target of 50% less primary material use by 2030 (Ministry of Infrastructure and Environment and Ministry of Economic Affairs, 2016). Whilst the environmental and economic concerns underpinning CE might be perceived as new, the *means* through which they are being addressed are manifesting through more conventional or longer-standing organisational practices,

Abbreviations: CE, circular economy; EC, European Commission; EOL, end-of-life; EPR, extended producer responsibility; ETRMA, European Tyre and Rubber Manufacturers Association; EU, European Union; PRO, producer responsibility organisations; PRP, product responsibility providers.

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including increased recycling targets, waste legislation and extended producer responsibility (EPR) commitments (European Commission, 2015; Milios, 2018).

Scholars have devoted much time to analysing new business models and strategies related to CE (cf. Bocken et al., 2016; Lüdeke-Freund et al., 2018). Yet, there is also a need to reflect and examine these older CE initiatives and practices to understand their suitability and capacity to facilitate and address the emerging societal concerns evidenced within the existing CE debate.

One such system is EPR, which has been collectively and voluntarily adopted in many EU member states for different products, including passenger car tyres (European Commission, 2014). EU member states are free to choose how to organise the collections and treatment of tyres, which are reported to the European Tyre and Rubber Manufacturers Association (ETRMA); most member states have adopted EPR systems, which have successfully recovered high quantities of used tyres (recovery rates for end-of-life (EOL) tyres in Europe are above 90% since 2007) (ETRMA, 2017; ETRMA, 2018). However, despite such high levels of recovery, there is little direct substitution (closed-loop), i.e. new tyres have a low content of recycled rubber (ECHA, 2017). Indeed, up to 50% of collected tyres are burned – usually, for energy recovery (Scott, 2015) – a problem further compounded as natural rubber is a designated critical raw material (European Commission, 2017). Whilst the technological feasibility of such direct material substitution through devulcanization is being debated and explored (Myhre et al., 2012), there is a broader question about the organisation and performance outcomes of EPR as an older CE system to meet emerging societal challenges.

Previous research on EPR and tyre recycling in the EU have examined the various treatment options (Torretta et al., 2015) and progress across member states, including the steady departure from landfilling (Sienkiewicz et al., 2012). Alternatively, Winternitz et al. (2019) examined the EPR systems of three European countries, reflecting on their varying policy approaches, successes and potential limitations. Their findings demonstrated that an EPR system does not necessarily guarantee that waste tyres are disposed of in the most environmentally beneficial manner. Similarly, Lonca et al. (2018) examined the trade-offs of increased material circularity of tyres, contracted against other sustainability indicators, e.g. human and ecosystem health. Their research found that increased material circularity is beneficial from a resource perspective, but not necessarily from other environmental perspectives (Lonca et al., 2018). Such research adds to the complexity of organising disposal systems in a dynamic way that accounts for potentially conflicting issues within EOL processes.

Building on these examples, this article aims to critically examine the organisation and performance of an existing EPR system, to reflect on its strengths and suitability to deal with the broader needs within the contemporary CE debate. Based on this, we examine the question "how effectively do current ERP systems function from the current ambitions of CE?" We use EPR for tyres in the Netherlands as a case study to explore this question. This article, therefore, adds a practical understanding of the contribution of EPR to CE and provides insights for new and existing EPRs globally.

This article is structured as follows. First, a literature review of CE, EPR and tyre treatment practices is presented to further contextualize the analysis (Section 2). Next, the research methods are presented (Section 3). This is followed by a description of the structure and outcomes of the EPR system for tyres in the Netherlands (Section 4). Our analysis (Section 5) builds on these results, showing the limitations and challenges for EPR systems to lead to a sustainable CE transition before concluding (Section 6).

2. Literature review

2.1. Circular economy: origins, history and implementation

While the CE concept itself dates back to 1989 (Pearce and Turner, 1989), the idea builds on a long history of literature on resource limits and ecological transformations such as the "Limits to Growth" (Meadows et al., 1972), the "Tragedy of the Commons" (Hardin, 1968), the "Economics of the Coming Spaceship Earth" (Boulding, 1966), "Small is Beautiful" (Schumacher and Ernst, 1973) and "The Closing Circle" (Commoner, 1971).

More recently the CE has drawn its theoretical underpinnings from Industrial Ecology (IE) (Aryes, 1989; Saavedra et al., 2018), cradle-to-cradle (McDonough and Braungart, 2002) and performance economy (Stahel, 2010). The concept of CE is muddled and convoluted but is broadly based on the premise of retaining the functional use of products and materials within the economic sphere as long as possible. It is being advocated, in particular, by private sector consultancies, e.g. the Ellen MacArthur Foundation (UK) and Circle Economy (NL). Estimates suggest the cumulative outcome of earlier CE-policies has resulted in the (re)cycling of as little as 6% of global materials, 12% within the EU27, leading to an increased focus on increasing the value retention of material throughput (Haas et al., 2015).

The CE is also discussed as an evolutionary concept (cf. Blomsma and Brennan, 2017; Reike et al., 2018). Of particular importance for our analysis are the three phases of the CE concept proposed by Reike et al. (2018). First, CE 1.0 (1970–1990), is characterised by early waste management practices focused on waste output as an environmental pollution problem to be dealt with through EOL policies. This is when waste treatment and incineration plants started to be developed and operated, especially in the Global North.

The second phase CE 2.0 (1990–2010), saw the development of many "win-win" strategies, which make use of waste outputs as valuable resource inputs such as IE (Frosch and Gallopoulos, 1989), Cleaner Production (Fresner, 1998), Industrial Symbiosis (Chertow, 2000), Product-Service System (PSS) (Goedkoop et al., 1999), and EPR (Davis and Wilt, 1994). This is when the concept of CE was first coined by Pearce and Turner (1989) and when associated ideas appeared, such as "biomimicry" (Benyus, 1998), "cradle to cradle" (McDonough and Braungart, 2002), and "performance economy" (Stahel, 2010). This period also saw the widespread implementation of integrated waste management and recycling systems in the Global North, including EPR systems, which mandated new responsibilities for private sector actors (Reike et al., 2018).

The third phase of CE 3.0 (from 2010), when discussions of the concept of CE became more widespread and began to be framed against encroaching societal threats, including planetary limits (Rockström et al., 2009), resource depletion, biodiversity loss, excessive waste generation etc. (Reike et al., 2018). This has led to a more integrated and holistic understanding of material use, which aims to slow, reduce, narrow and close resource cycles in a systemic manner through changes of consumption and production structures and patterns (Reike et al., 2018). However, this is also a period where varying visions of CE are conceived, which are either transformative or reformist depending on their position regarding the capacity for capitalism to overcome resource limits and decouple ecological degradation from economic growth (see Reike et al., 2018; Calisto Friant et al., 2020).

The implementation of CE-related activities and policies occur in a variety of geographic contexts and scales. CE practices thus range from national programmes, e.g. China's 2009 CE 'Promotion Law' or international policies, e.g. the European Commission, 2014 CE 'Action Plan' (Ghisellini et al., 2016), to business models and individual company strategies (see Lüdeke-Freund et al., 2018). Scholars have sought to define CE activities through the potential value retention options that can be initiated throughout a product or material lifecycle, commonly described as the R-hierarchy. These range from 3Rs (Reduce, Reuse and Recycle) to iterations from four to ten. A recent review of 69 such R-imperatives outlined a synthesis of 10 comprehensive value retention options, which we adopt as our conceptual framing (Reike et al., 2018)(Appendix A). Whilst the narrative and framing around CE articulates its "newness", much of the EU policy approach follows or seeks to build upon older CE practices (European Commission, 2015; cf. Gregson et al., 2015; WFD 2018/851, 2018).

2.2. Extended producer responsibility

One such older CE practice is EPR, which is defined as "an environmental protection strategy to reach an environmental objective of a decreased total environmental impact from a product, by making the manufacturer of the product responsible for the entire life-cycle of the product and especially for the take-back, recycling and final disposal of the product" (Lindhqvist, 2000, p. 37). Crucially, the concept implies integrating responsibility in the whole product life cycle, where the physical and monetary waste managerial responsibilities (usually assigned to authorities and consumers) are transferred to the product producers.

EPR emerged in the 1990s, building on the experiences of waste managers, recyclers and a policy approach concerned with promoting cleaner production initiatives (Lindhqvist, 2000). Such developments illustrated the more proactive role private sector actors played in these earlier CE systems, giving them greater responsibility for the stewardship of their products. Such 'public-private' configurations represented new steering programmes practised by governments, as opposed to the conventional waste management policy of earlier years (CE 1.0) (Reike et al., 2018; Vermeulen and Weterings, 1997).

EPR builds on the "polluter pays principle", incentivising producers to prevent waste generation, whilst (supposedly) encouraging eco-design and supporting the appropriate EOL processes, e.g. promoting recycling and reusing activities (Deutz, 2009; Ferrão et al., 2008). However, previous studies show EPR activities are overtly focused on EOL activities, negating an integrated lifecycle perspective that pursues continuous improvement and higher environmental performances through, for example, material choices and design for disassembly options (Vermeulen and Weterings, 1997). The EU has mandated responsibility of EOL disposal of vehicles, batteries and accumulators, waste electrical and electronic goods to producers, whilst most member states have additionally implemented a producer responsibility organisation to process used tyres (Deutz, 2009; European Commission, 2014; ETRMA, 2015; Winternitz et al., 2019). Member states must ensure their EPR schemes have an appropriate collection and accessible schemes.

Alternatively, EPR has also been adopted in various countries in the Global South as a product management tool for EOL tyres (Banguera et al., 2018; Zarei et al., 2018). However, recent studies have illustrated the challenges of adopting EPR in these countries. Such challenges include the limited knowledge of effective practices in Botswana (Mmereki et al., 2019), incentivising and integrating necessary actors in operations in Colombia (Park et al., 2018), and directly transposing a European policy tool to Brazil (Milanez and Bührs, 2009). Conversely, Cecchin et al. (2019) study in Ecuador highlighted the potential of integrating social economy goals with conventional EOL practices associated with EPR.

EOL processing in EPR systems can be organised in various ways. Spicer and Johnson (2004) outline three approaches to implementation: (1) 'Original Equipment Manufacturer' takeback, where the original producer takes direct responsibility for collecting and processing; (2) 'Pooled Takeback', where responsibly is shared between a consortium of producers, known as the producer responsibly organisation (PRO), usually organised by a product category code, e.g. tyres; and (3) 'Product Responsibility Providers' (PRP), where a private third-party is contracted by the PRO and assumes EOL responsibly for the product on their behalf. This (theoretically) results in dual benefits for manufacturers and the general public, including, eliminating the financial risk associated with complex EOL processing activities (recycling, incineration, disassembly, remanufacturing, refurbishing etc.). Governments are responsible for rewarding and motivating good behaviour. Key regulatory aspects of an effective EPR system includes formulating long-term objectives, fostering continuous improvements and updating targets, e.g. future scenarios, whilst encouraging front-runners and compelling laggards (Vermeulen and Weterings, 1997). Public benefits include distributed local demanufacturing facilities and immediate economic feedback to product design, driving improvements (Spicer and Johnson, 2004). Challenges for local demanufacturers include knowledge of the original product blueprints, which producers can be unwilling to transfer, and finding suitable markets for recyclable materials. Earlier studies argued that this collective responsibility will weaken the eco-design drive of individual companies (Castell et al., 2008). Next, we document the characteristics and treatment options for tyres.

2.3. Composition and treatment options for tyres

Rubbers are thermosetting materials, which makes material recovery challenging because of the vulcanization process during manufacturing (see Adhikari et al., 2000; Medina et al., 2018). Pneumatic tyres are a combination of synthetic and natural rubber, carbon black, elastomer compounds, steel chords, textiles fibres in addition to several other inorganic and organic compounds (Torretta et al., 2015). Natural and synthetic compounds act as sealants while fibre and steel chords give structure and carry tension (Feraldi et al., 2013).

There are several principal treatment practices for EOL tyres (see Table 1). First, product reuse (R2), which involves the direct sale of a tyre whose tread is still deep enough for safe use (the minimum tread depth is 1.6 mm in the EU). Second, retreading (R5), which involves replacing the outer tread of a tyre, when its general condition is insufficient. Repurposing (R6) is the reuse of a tyre for alternative uses, for which it was not originally designed, such as protection of racing tracks, materials for artwork, swings etc. Grinding (R7), involves the crushing and granulation of tyre to extract rubber and other components, such as steel and textile fibres (Aiello et al., 2009; Landi et al., 2018a, 2018b). Grinding produces rubber that is of relatively low quality, meaning only a small percentage (1–5%) can be used in new tyres. Devulcanization (R7) is a technological process where the rubber is chemically recycled to obtain higher quality rubber that can be used in higher percentage in new tyres (up to 30%) (Myhre et al., 2012). However, this technology is not yet commercially viable and has not been deployed on a large scale (Saiwari et al., 2019). Finally, pyrolysis (R8) is the uses high temperatures (without oxygen) and chemical additives, for the recovery of energy, carbon black, activated carbon, oil and steel from EOL tyres; if well managed the process can have relatively low emissions (Myhre et al., 2012; Myhre and MacKillop, 2002; Sienkiewicz et al., 2012). Moreover, incineration (R8) involves the burning of tyres with oxygen for the recovery of energy (often for cement kilns and other industrial furnaces); this process is less complex than pyrolysis but creates a significant amount of greenhouse gases and other air pollutants (Myhre and MacKillop, 2002).

Table 1
R-hierarchy for tyre treatment.

R	Treatment Options
R0	**Refuse** via reducing vehicle ownership and using alternative modes of transport;
R1	**Reduce** via life extension
R2	**Resell/Reuse** discarded tyres which are safe and functional
R5	**Remanufacture** by retreading functionally sound discarded tyres
R6	**Repurpose** without or using less physical or chemical treatment
R7	**Recycling** via processes including devulcanization and grinding.
R8	**Recovery** of energy via pyrolysis or incineration

Whilst the notion of the 'R-hierarchy' might presuppose a prescriptive and preferable set of recovery operations, these only relate to the product or material attributes and do not account for contextual and broader systems factors, e.g. energy recovery; this might mean a lower R-strategy, could be preferable under some contexts and conditions. Deciding on the most effective treatment option can usually be ascertained through conducting a life cycle assessment (LCA). Various studies have explored this exact question in different national contexts (cf. Corti and Lombardi, 2004; Clauzade et al., 2010; Li et al., 2010; Fiksel et al., 2011; Feraldi et al., 2013; Ortíz-Rodríguez et al., 2017). There is a broad consensus that energy recovery as fuel can only capture up to 40% of the embedded energy within tyres (Amari et al., 1999). However, these assessments differ in terms of the geography and scope, are non-standardised, hard to compare and, overall, they show conflicting and inconsistent outcomes. This points to the need for more standardised impartial regional (Social)LCAs, attributional and consequential, with local data, that can inform specific EPR systems as to the most preferable recovery and treatment option.

New CE business models of the 'performance economy' such as Product-Service Systems (PSS), that promote the leasing of products, services or performance instead of direct consumer ownership could facilitate high-value retention options (Camilleri, 2018; Kjaer et al., 2019; Stahel, 2010). Indeed, firms that maintain the ownership of their tyres are incentivised to design long-lasting (R1), reusable (R2), recyclable (R7) and retreadable (R6) tyres. However, this is not always the case, and strong regulation and careful management of possible rebound effects are needed to ensure that PSS′ lead to positive environmental outcomes (Demyttenaere et al., 2016; Hobson and Lynch, 2016; Junnila et al., 2018).

3. Materials and methods

To evaluate the organisation and performance of an EPR scheme, this research adopted a case study research design, following procedural insights as outlined by Yin (2003). Case studies are defined as an in-depth description of a bounded system and are useful to examine phenomena in their contextual settings; they are particularly adept to understanding contemporary events (Yin, 2003, p. 5). Case studies are suited for qualitative methods, including those used in the study: interviews, literature review, policy and document analysis (Bryman, 2012).

This research uses the case study of EPR of tyres in the Netherlands, a system which has been in operation (to some degree) since 1995. This case selection was justified through two core reasons: (1) the Netherlands has, since 2005, had a high collection rate (≥100%) (ETRMA, 2015; Winternitz et al., 2019); and (2) the Netherlands has a substantially higher level of material reuse (e.g. direct reuse and recycling) than the European average, which is roughly 50% recycling and 50% energy recovery (Scott, 2015). This second point corresponds to the intentions of moving up the waste hierarchy, the underlying principle for all EU recycling activity (European Commission, 2008). On this basis, the Netherlands represents a highly successful European EPR example and therefore the case for this research (cf. European Commission, 2014).

A limitation of a case study approach of a single EPR system is that it cannot lead to generalizable recommendations, even though the analysis provides useful practical insights for other cases. Nonetheless, the analysis of a single case can be used to generate preliminary observations and questions that can form the basis to evaluate future case-studies or comparative research. Indeed, considering the specific history, geopolitical situation, socio-economic conditions and governance mechanisms in the Netherlands, lessons from this research cannot be generalized to other contexts, especially in the Global South, where conditions differ greatly. Moreover, all waste streams are unique due to their complex composition, legalities, processing techniques, hazardous nature etc. Therefore, the results and recommendations from this research are most relevant to our specific case study. Nevertheless, some of the lessons might apply to other socio-economic contexts and material streams, when supplemented by additional research on those other sectors and conditions.

Data collection was undertaken in two phases. First, we reviewed the available literature on CE, EPR and tyres (Section 2). This set our theoretical framing and perspectives for critically evaluating the EPR system (Section 4). The core data is comprised of policy and legal documents on EPR in the Netherlands since its inception in 1995–2017. This was supplemented with the EPR performance data, which (from 2005) has been reported annually to the government. Fieldwork was conducted between January to May 2019 which included nine in-depth unstructured interviews, lasting between 30 and 90 min, with government officials, industry and EPR representatives for tyres in the Netherlands. Interviewees either worked for the PRO, were members (producers, importers, distributors or EOL processors of tyres) or government officials involved in the monitoring the performance of the EPR system. Fieldwork also included two site visits to tyre manufacturing and recycling facilities based in the Netherlands. Interviews were used to explain and elaborate on insights gained from the literature and documents analysis. A complete list of the interviewees, data and their sources are in Appendices B and C.

Next, we analysed the data. First, we reviewed the policy documents and performance data and, in conjunction with interviews, constructed an overview of the EPR system in the Netherlands (Section 4); this included history, an overview of the policy structure, actors, targets and key roles. Furthermore, we coded the performance of the EPR data using the 10R framework of Reike et al. (2018) to categorise the treatment outcomes. Second, we undertook a critical evaluation and reflection, using insights from the interviews and the literature to reflect on the strengths, weaknesses and issues about organisation and performance; including aspects of continuous improvement, policy scope and value retention outcomes (see Section 5).

4. Case study description

4.1. Regulatory and legal overview

The introduction of EPR in the Netherlands originates to the 1988 Note on Prevention and Recycling of Waste, in which context the government introduced the concept of EPR in 1990 to enable a series of participatory policy projects designing the recycling strategies for 29 waste streams (Vermeulen and Weterings, 1997; Vermeulen et al., 1997).

Consequently, for the tyres waste stream the Dutch government introduced the Besluit Beheer Personenwagenbanden (Management of Passenger Car Tyre Decree) in 1995. Broad responsibilities were attributed to producers and importers to organise the collection and treatment of EOL tyres. In this EPR system, garages and tyre service companies collected old car tyres (mostly after replacing them for new ones) and charged the customer a fee for this collection and purchase of new ones. Garages and tyre service companies then passed the used car tyres to collection and processing companies along with the collection fee, to sort and adequately process used car tyres. A provisional collection target in the Decree was set at 60% product reuse (direct reuse is defined here as any recovery activity from R2 to R8, see Table 1), which included a minimum 20% material reuse (R2 to R7) and maximum 20% energy recovery (R8).

However, this system was open to exploitation, primarily through collectors taking the consumer fee and not passing the tyres onto processors. The consequential stockpiling resulted in municipalities and provinces financing the collection and treatment of illegally dumped EOL tyres (RecyBEM B.V., 2017, Supplementary material).

Following several meetings between sectoral representatives and Ministry of Housing, Spatial Planning and the Environment in 2000, resulted in the 2003 Besluit Beheer Autobanden (Car Tyre Management Decree). Producers were responsible for organising EOL collection and treatment, either individually or collectively. Key provisions of this act included (i) a focus on car tyres, caravans and trailers; (ii) a broad definition of ‘producer’, to include all producers, distributors and importers, who are responsible for organising the collection and treatment; and (iii) an old-for-new or 1-for-1 regulation, where the final user of the tyre, must be allowed to return the old tyres at no cost when purchasing a new one. All producers are required to pay a disposal fee, for every product brought onto the Dutch market. The treatment targets were not adjusted from the 1995 Decree, setting material reuse (R2 to R8) at 20% of the total weight of collected materials.[3] Moreover, producers and importers were required to report their performance to the government each year. This report must include (a) the number of car tyres that were made available to a party for the first time in that calendar year; (b) the number of used tyres collected in that calendar year; and (c) the percentage of used tyres processed.

Besides the 2003 Decree, the treatment for tyres has been regulated by EC Directive 1999/31/EC, which prohibits rubber tyres going to landfill, and the Dutch Landelijk Afvalbeheerplans (LAPs) (National Waste Management plans) of 2003 (LAP 1), 2009 (LAP 2) and 2017 (LAP 3).

The first National Waste Plan of 2003 establishes the goal for 50% of the total weight of used rubber tyres to be reused as material (R2 to R8). However, the 20% goal of the Car Tyre Management Decree of 2003, has precedence over any objective of the LAPs. LAP 2 continued with the same objectives as the previous one but in its 2014 modification, it adds a “minimum standard” of at least “material recycling” (R7) for all tyres that can be recycled for less than €175 per tonne. For tyres that are not suitable for recycling or that cannot be recycled for less than €175 per tonne, energy recovery is considered the “minimum standard”, and is thus allowed. In 2017, LAP 3 further increases the “minimum standard” for energy recovery to tyres that cannot be recycled for less than €205 per tonne.

The “minimum standard” is based on the ‘Ladder van Lansink’ (a motion accepted in the Dutch Parliament in the 1980s), which recommends reuse, recycling, energy recovery and landfilling as the appropriate sequence of treatment options (Lansink and Veld, 2010). A 2014 modification to LAP2 further expanded the collection responsibilities from passenger cars and light commercial vehicles to also include motor tyres, trucks, buses, agricultural vehicle tyres etc. Tyres from bicycles and scooters are excluded.

In 2018, the EU outlined a CE package, which amended the framework directive on waste (Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste). The renewed waste directive creates new requirements for EPR systems, including having effective data collection processes, transparent operations (including on the selection procedure for waste management operators), and dialogue and collaboration with civil society organisations including social economy actors. The Directive also encourages (not mandatory) member states to establish ecodesign requirements that ensure products are easily recyclable, reusable, repairable and technically durable, contain recycled materials, and have reduced environmental impacts throughout their entire lifecycle.

These requirements were set to ensure that EPR contributes to a CE transition and operate according to the EU waste hierarchy, as established in article 4 of Directive (2008)/98/EC. However, these new requirements have not been transposed into Dutch law yet as the Member States have until the 5th of July 2020 to do so, whilst EPR systems have until the 5th of January 2023 to update their structure and operations. Whether this results in substantial changes in the Dutch EPR scheme remains to be seen. However, it provides an opportunity to revisit the governance and circularity of the EPR system for tyres.

4.2. Extender producer responsibility: structure and implementation

In response to the 1995 Decree tyre importers, distributors and producers founded the ‘Vereniging Band en Milieu’ (Association BEM), to implement their obligation under this Decree. This body is formerly responsible for communications with the government. To manage the updated system established by the Car Tyre Management Decree of 2003, the tyre producers and importers founded two other organisations. First, the Stichting Fonds Band en Milieu (Foundation Funds for Tyre and Environment, hereafter known as the Foundation) which is responsible for the financial management of the waste management system, and the collection and management of recycling fees. The Foundation functions to keep individual members financial contributions and market share confidential (Winternitz et al., 2019). The Foundation then established RecyBEM B.V., a private company, which is the collective implementation organization of the Association BEM. RecyBEM B.V. is thus contracted by the Foundation to manage the collection, processing and reporting of the EPR system (see Fig. 1). From 2013, RecyBEM B.V. began setting voluntary processing targets, starting from 70% material and product reuse (R2, R5, R6 and R7) in 2013 to 90% in 2015. The system is thus structured as a third-party takeback where RecyBEM B.V. is the PRP (see Section 2.2).

[3] We contacted the PRO for the data on the final destination of tyres on various occasions, but we were unable to obtain this information.

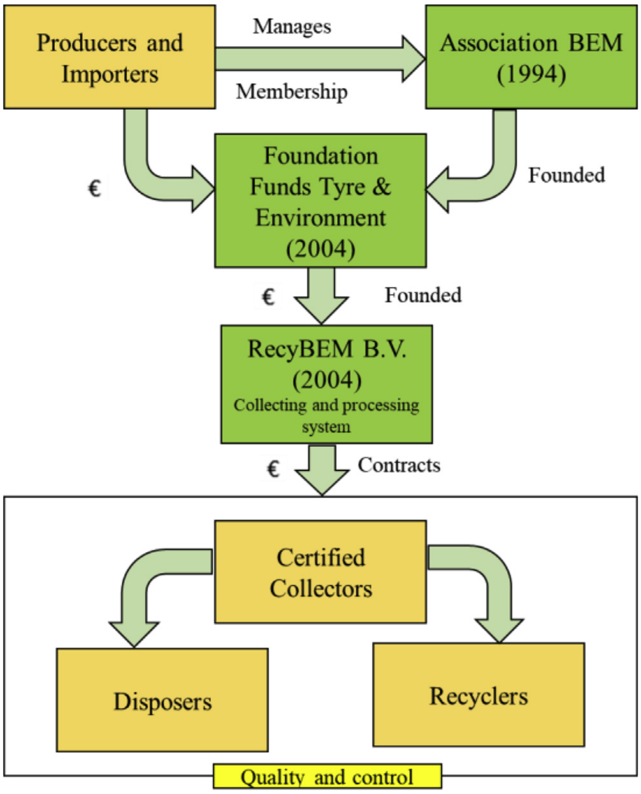

Fig. 1. Organization of the Dutch EPR (Source: RecyBEM B.V., 2019, edited).

To finance the system, all producers and importers of car tyres, caravans and trailers, must pay a waste management contribution fee to the Foundation for every tyre they put on the Dutch market. Between 2004 and 2015 only producers that were members of the Association contributed the waste management fee. In response from protests from the Foundation over free-riders not contributing fees, a 2015 government "general binding statement" (Supplementary material) allowed the PRP to oblige all producers, distributors and importers (both from retail and internet sales) to pay the waste management contribution fee to the Foundation or to establish another EPR system. Non-members can face legal action from the PRP for not contributing.

RecyBEM B.V. is the main operator of the waste management activities, the costs of which are covered by a contribution fee paid to it by the Foundation (see Fig. 2). It uses the fee to contract and pay third party collectors, which are in charge of bringing the tyres to processors, who recover the value from tyres based on the market conditions, RecyBEM B.V. criteria and state targets and regulations. To ensure the quality of the recycling operations, collectors can only operate with recyclers, disposers and processors that have been certificated by RecyBEM B.V., which includes quality management system, as of 2018 following ISO 9001: 2015 standard (RecyBEM B.V., 2019, Supplementary material).

In 2004, the waste management contribution fee, paid by importers and producers per tyre sold, was set at € 2,00 and by 2017 this had been reduced to € 1,30. This fee is internalised in the consumer price of a new tyre. Collectors (garages) are paid from this fee, which in 2004 was € 1,25 per collected tyre and in 2017 had been reduced to € 1,05 (see Fig. 3). The difference between the collecting and the recovery fee is used by the PRP to cover administrative costs and unexpected expenses. Every year, the waste management contribution fee and the collecting fee is revised and updated based on a market study conducted by an independent third-party consultancy: Fact Management Consultants. The system operates with a pay-as-you-go structure where each year, a maximum waste management contribution fee is charged and, at the end of the year, a definitive waste management contribution fee is calculated based on the actual sale and recovery outcomes of the year and any surpluses and/or shortfalls are thus settled.

4.3. Performance

The membership of the Association BEM has been rising continuously (Fig. 4), representing over 90% of producers by 2015. The notable rise from 2015 is a consequence of the "general binding statement" of 2015, giving the PRO the power to compel non-compliant actors to pay into their system.

Fig. 5 shows the high collection rates of the Dutch EPR system. The higher volume of sold tyres in 2010 and 2011 are explained by the particularly cold winters of those years, and correspondingly higher sales of winter tyres. The higher collection rates of 2016 and 2017 is explained by the implementation of the "general binding statement" of 2015, which led to new members joining the scheme.

Fig. 6 presents the destination of used rubber tyres managed by the PRP between 2005 and 2017. The red dotted line represents the 50% material and product reuse (i.e. R2, R5, R6 and R7) target established by the first National Waste Plan (2003). The red line indicates the 20% reuse as materials (i.e. R2, R5, R6, R7 and R8) target of the Car Tyre Management Decree of 2003. The dotted black line represents RecyBEM B.V.'s voluntary material and product reuse targets (i.e. R2, R5, R6 and R7): 70% by 2013, 80% by 2014 and 90% by 2015. The solid black line represents RecyBEM B.V.'s voluntary material reuse target (R7): 25% by 2013, 35% by 2014 and 50% by 2015.

Fig. 6 and Table 2 show that the Dutch PRO has continuously met the targets in the National Waste Plan and the Car Tyre Management Decrees, as well as voluntary targets (see Supplementary material). Moreover, our interviews from the public and private sector confirmed that the minimum standard for incineration was also met, meaning no tyres that can be recycled for less than € 175 (2014–2016) or € 205 (2017 onwards) were sent for energy recovery. Therefore, no fines have been given to the organization for violating the rules.

The explicit nature of the recovery outcomes was further investigated and clarified during the interviews (see Supplementary material interviewees). This allowed a better understanding of the implications and complexities of each recovery option. In the case of "product reuse" (R2), representing over 30% of EOL tyres in 2017, interviewees commented that many tyres are sold to countries in Eastern Europe, although the actual destinations are known only to the PRO.[2] Dutch consumers tend to change their tyre before the minimum recommended tread depth in the EU of 1.6 mm, due to the obliged annual car inspection (European Commission, 2019), so many discarded tyres still have a high use value. However, the future EOL and safe recovery of those tyres are no longer guaranteed once they are exported, if they go to destinations without the capacity to process them.

Regarding retreading operations (R5), very few tyres are suitable for retreading due to quality imperatives, hence very few EOL tyres can take this recovery route. Moreover, the Netherlands does not have any retreading plant, so tyres must be exported for this purpose and, once again, their EOL and safe recovery is not guaranteed in the importing country.

[2] Material reuse in the Decree is defined as: reuse of materials for the same purpose for which they were designed or for other purposes (R2, R5, R6, and R7), including energy recovery (R8).

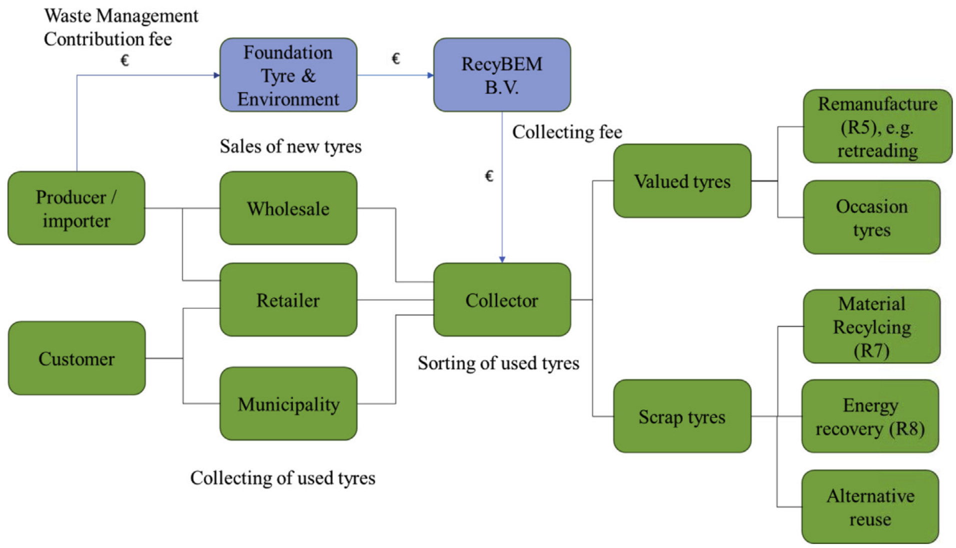

Fig. 2. Financial mechanism of the Car Tyre Management Decree, source: RecyBEM B.V., 2019, (edited).

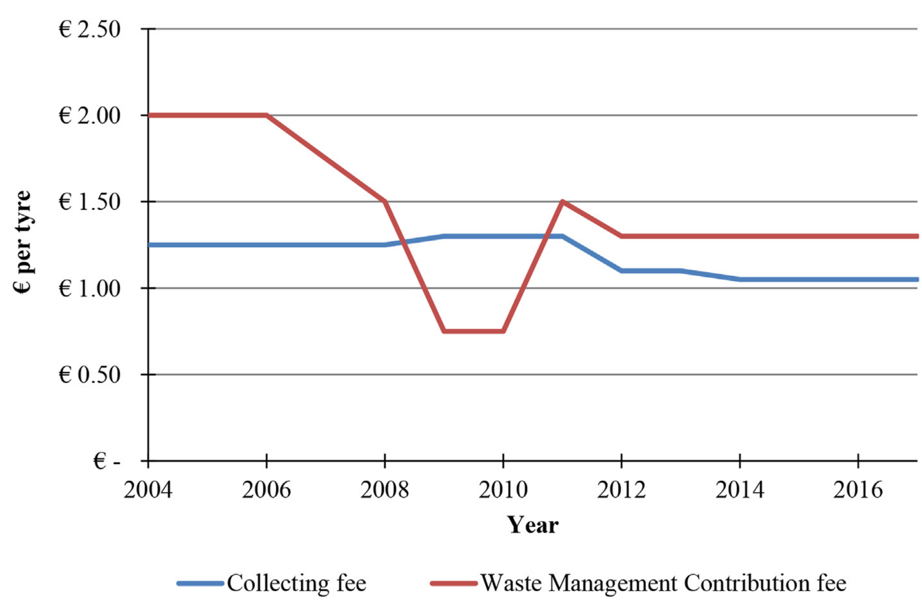

Fig. 3. Collecting and waste management contribution fee 2017 (own work, source: annual reports Supplementary material).

Repurposing (R6) represents a very small fraction of EOL tyres and concerns punctual and limited uses such as cart-track protections, and bumpers on quays and waterways.

Finally, recycling (R7), the most common recovery operation for EOL tyres, is carried out through granulation, which is used in a multiplicity of lower value outcomes, such as insulation materials, engineering applications (mainly for road construction), filling for artificial sports fields etc. Due to energy efficiency, safety and quality imperatives, new tyres currently contain about one to five per cent of granulated rubber from EOL tyres.

Most interviewees reported a high level of satisfaction with the EPR system in the Netherlands. Tyre producers and distributors value the low cost of tyre recovery operations and the “hands-off” approach that this third party take back structure gives them. The PRO enjoys a great level of legitimacy due to its track record of compliance with government targets and low recovery costs. Producers and importers thus give a significant amount of autonomy to the organization (and PRP) and let it manage collection and recovery operation. Producers, importers, collectors and processors are not directly connected and don’t collaborate, nor share information to improve tyre recycling outcomes or increase the uptake of recycled rubber in new tyres. There is little evidence that the Dutch EPR system provides an incentive for eco-design, rather it incentivizes producers and importers to outsource recovery operations at the lowest possible cost. While the PRO has financed several research and development projects on devulcanization, this

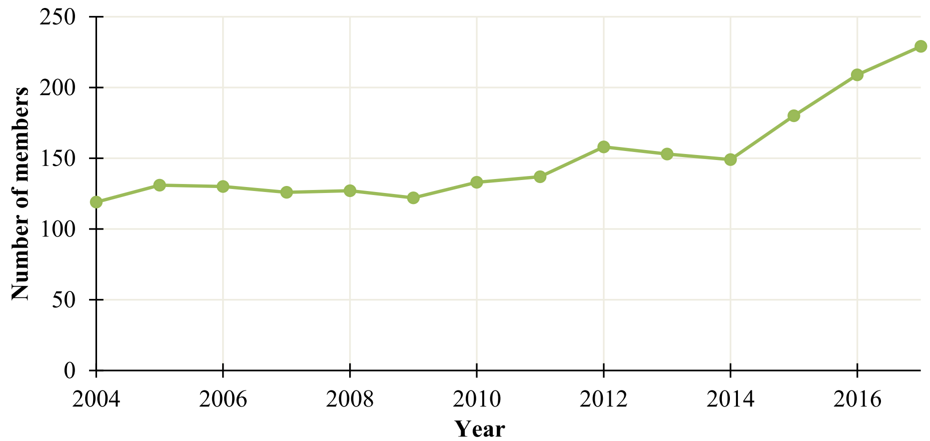

Fig. 4. Association BEM Members between 2004 and 2017 (own work, source: annual reports Supplementary material).

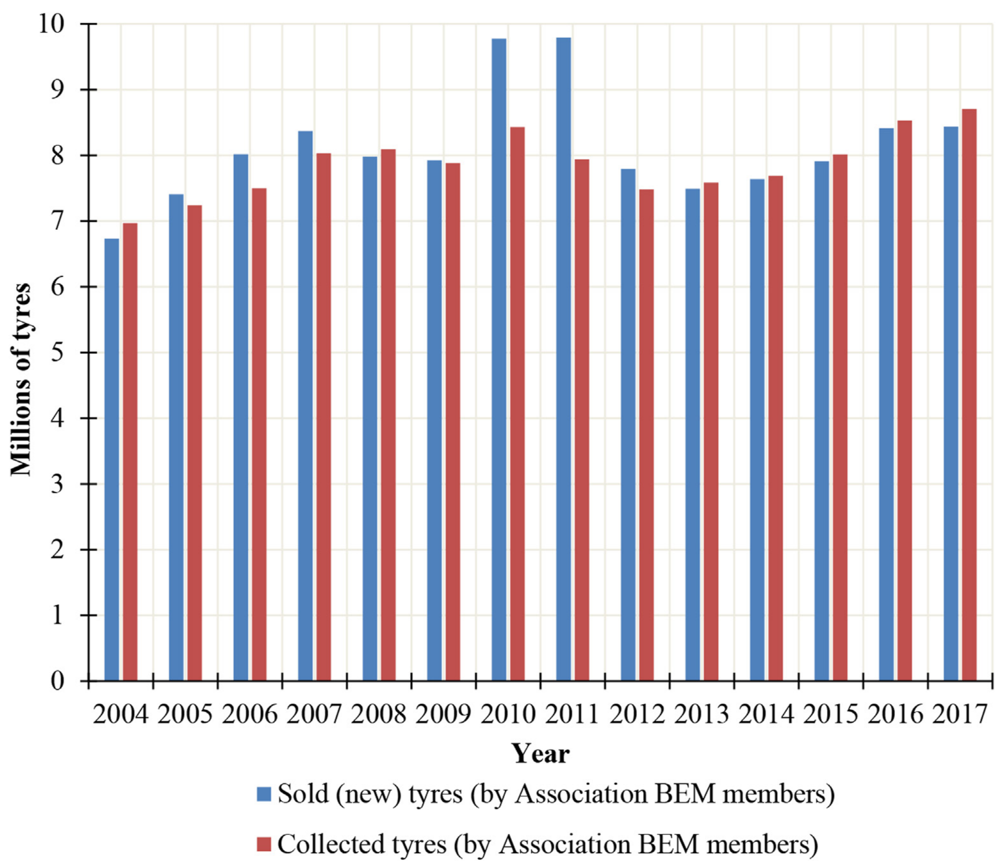

Fig. 5. Sold tyres vs. collected tyres between 2004 and 2017 2017 (own work, source: annual reports Supplementary material).

is not enough to foster lifecycle thinking and a full closure of resource loops.

Despite this apparent success, there has been a recent backlash against recycled rubber and the EPR system in response to public concerns over the human and environmental health impacts of artificial sports fields made with recycled rubber granulate (Zembla, 2016). This led to a government inquiry on the topic and a series of reports were commissioned. In line with recent academic research (Bleyer and Keegan, 2018; Peterson et al., 2018), and evaluations of the European Chemicals Agency (ECHA, 2017), the Dutch government report on human health has found no evidence of cancer risks related to artificial turf fields made with recycled rubber (RIVM, 2017). However, other government reports evidenced important environmental impacts, especially for aquatic life (STOWA, 2018; Verschoor et al., 2018). This demonstrates the complexities of a circular system, which aim to narrow, slow, shrink, and close material cycles, but do so in ways that do not affect human and environmental health. This is often complicated,

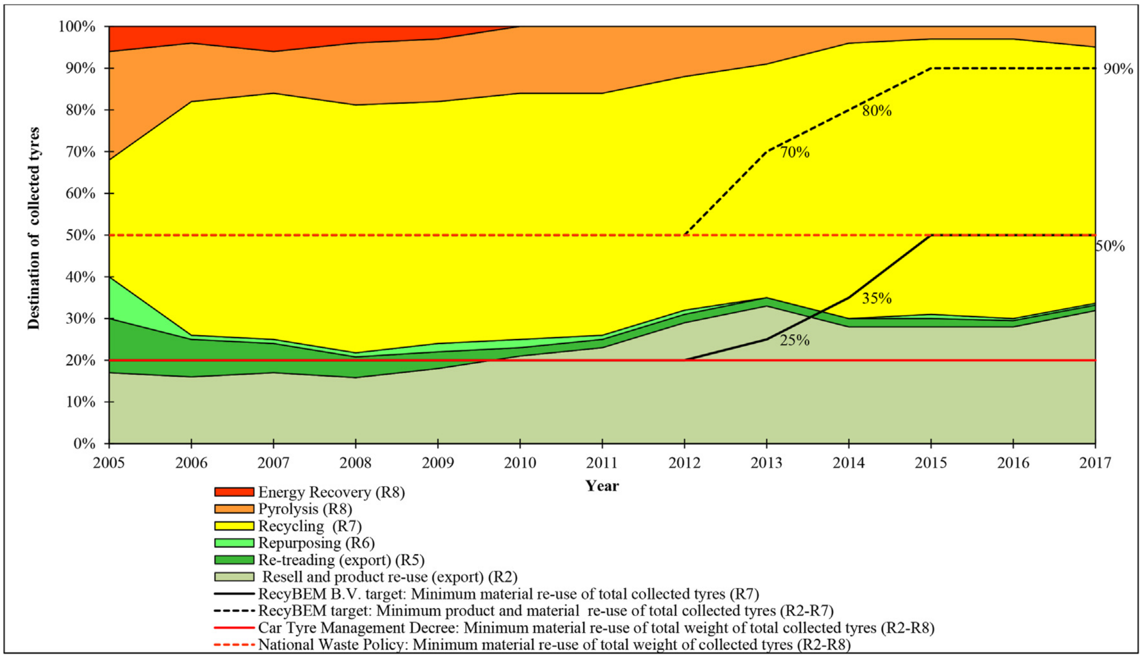

Fig. 6. Destination of collected used rubber tyres by RecyBEM B.V. between 2005 and 2017 (own work, source: annual reports Supplementary material).

Table 2
Recycling Targets and results.

Target	RecyBEM B.V. target: Minimum material re-use of total collected tyres (R7)20% (2005−2012)25% (2013)35% (2014) 50% (2015−2017)	RecyBEM target: Minimum product and material re-use of total collected tyres (R2-R7)50% (2005−2012)70% (2013)80% (2014)90% (2015−2017)	Car Tyre Management Decree: Minimum material re-use of the total weight of total collected tyres (R2-R8),20% (2005−2017)	National Waste Policy: Minimum material re-use of the total weight of collected tyres (R2-R8)50% (2005−2017)
Result	2005−2012: 54% average2013: 56%2014: 66%2015−2017: 64,8% average	2005−2012: 82% average2013: 91%2014: 96%2015−2017: 96% average	2005−2017: 100% average	2005−2017: 100% average

especially when dealing with complex recycling processes and materials containing a mixture of often unknown or toxic chemicals. This complexity poses the main obstacle to tyre management in the Netherlands.

5. Analysis and future implications

Since the initial experiments in 1995, the Dutch EPR system for passenger car tyres has reached 100% collection rate, with low energy recovery levels (5% in 2017) and zero landfilling. Interviewees viewed the system as stakeholder friendly, financially efficient, and effective at preventing the widespread illegal dumping of tyres, which occurred before the 2003 Decree. The system meets the minimum standards and targets set in the 2003 LAPs and the PROs voluntary targets. However, it also has many key obstacles, weaknesses and limitations both from the perspective of CE 2.0 and of CE 3.0. This section outlines these challenges, and proposes recommendations, which, after careful adaptation, could also provide useful insights for new and existing EPRs in the global North and South alike:

Recommendations from a CE 2.0 perspective:

1. *Promoting higher-value recovery*: Fig. 6 and Table 2 demonstrate a high focus on recycling, yet the recycling of tyres currently produces low quality granulate that cannot be used in large quantities in new tyres. This focus on material recovery is thus a form of downcycling, which does not allow for the closing of resource loops. Instead, greater priority should be given to other recovery options such as retreading, reuse and repurposing. Moreover, eco-design must be encouraged so that EOL tyres are easier to remanufacture and recycle and so that new tyres can contain higher quantities of granulated rubber without compromising on their quality. In this regard, further investment in R&D would be necessary and could be implemented by an obligation to use a percentage of the waste management contribution fee to finance it. An autonomous or government established fund can be established to manage this part of the fee to finance transformative and disruptive innovations, which can challenge incumbents. Another option is to establish a differentiated fee based on the sustainability of tyres (durability, recyclability, percentage of recycled content etc.) to incentivize eco-design and innovation in the marketplace.
2. *Managing exports and leakages*: A large percentage of EOL tyres are exported for reuse and retreading (about 33% in 2017). While these are high-value recovery options, in theory, the lack of monitoring on the destination of these tyres does not guarantee an environmentally safe recovery. It is thus key to set up mechanisms to prevent exports from happening and to have greater oversight over the export destination and final disposal of tyres. This is a critical concern since tyres can significant adverse human and environmental health impacts if they are

not properly recycled (Li et al., 2010; Verschoor et al., 2018). However, controlling exports and following tyres through their multiples uses and owners is a complex process. A possible solution to this problem would be to raise consumer awareness and improve the annual car inspection process so tyres are not discarded before they reach the minimum tread depth. This would keep tyres in use for longer, improve their value for customers, and prevent them from being exported, thus reducing transport emissions and impacts oversees. The above measure would have to be combined with strong controls on the export of second-hand tyres so that tyres with a tread depth under the minimum standard are not exported for direct re-use. Moreover, enforcement of EOL tyre export controls should be reinforced so they are not exported to countries that do not meet Dutch social and environmental standards.

Recommendations from a CE 3.0 perspective:

1. *Aiming for sufficiency to reach the highest value retention options (R0, R1)*: Having longer-lasting tyres is perhaps one of the most important strategies, which can lead to significant sustainability improvements, as it directly reduces overall tyre consumption (R1 - reduce). The current EPR system has so far done nothing in this regard, and tyre consumption has increased between 2004 and 2017 (see Fig. 5). The PRO could directly work with rubber tyre manufacturers and importers to design tyre in a way that guarantees their durability. This has the added benefit of reducing the number of resources spent dealing with EOL tyre management further down the product lifecycle. Awareness campaigns among consumer can also increase the lifespan of tyres and be done through a combination of product labels and media campaigns. This R1 strategy is second in the value retention hierarchy, leading to considerable environmental benefits, thanks to the reduced pressure on natural resources (rubber, iron, fibres etc.) and the avoided impacts from production, use and disposal of tyres.

An even more effective strategy would be to reduce tyre consumption by reducing the need for tyres in the first place (R0 – refuse). This could be achieved through effective urban and regional planning, as well as transport policies that encourage public transportation, rail, cycling and walking. However, these policies are beyond the concern of a PRO and can thus only be established by national, provincial and municipal governments. This shows the limitations of EPR systems in general, especially with the highest value retention options: R0 and R1. To implement these measures, a percentage of the waste management contribution fee can be given to a government agency or an autonomous institution responsible for reducing the overall domestic material consumption and ecological footprint through sufficiency strategies. This agency could thus develop innovative transportation solutions which work towards reducing the need for rubber tyres such as improved national rail networks, and sustainable urban planning solutions.

2. *Collaboration and multi-stakeholder governance*: The existing EPR system lacks effective connection and collaboration between tyre producers and recyclers. This inhibits product innovation concerning the application of reclaimed rubber. The EPR system for tyres in the Netherlands could hence be improved by further integrating recyclers, disposers and processors members with the BEM Association. This would reinforce collaboration across the whole value chain and ensure that the EPR system does not just incentivize low-cost recovery options.

Socially inclusive governance considerations have been disregarded by the Dutch EPR system. Various scholars have pointed out the importance of these aspects to construct a fair and fully sustainable CE (Hobson and Lynch, 2016; Kirchherr et al., 2017; Merli et al., 2018; Millar et al., 2019; Moreau et al., 2017), which tackles questions of intellectual property, technology transfer, ownership, production methods, benefit sharing and participation in decision-making processes. While the Dutch EPR does have a successful governance structure that includes all the relevant producers and importers (see Section 4.2), it is not particularity inclusive beyond direct industry members. This reduces the capacity for democratic oversight, transparency and accountability, leading to suboptimal outcomes in terms of recovery options and human and environmental health (see Section 4.3). To improve this, it is key to foster greater participation of civil society and public authorities in the governance, oversight and management of the EPR system. This can be achieved by forcing the BEM Association to include a certain percentage of civil society members, which represent the interests of citizens and the natural environment. This would force the EPR system to consider wider social and environmental concerns and improve the overall transparency and accountability of the system.

3. *Effective monitoring and continuous improvement of the EPR system*: Considering that collection targets have not been adjusted since 2003, and remain vaguely defined, it is key to update targets and explore the future direction for the sector. In fact, not only are the established recovery targets not ambitious enough but they were already met in the year they were set (see Section 4.3).

Setting renewed goals is particularly important as the current system promotes a standard and generally low waste management contribution fee, which has incentivised low-cost and low-quality recovery options over higher-value-retention ones. Moreover, the existing monitoring system reports only collected volumes and treatment processes. This leaves data gaps regarding how recovered materials are used and what is the final fate of exported EOL tyres, all of which can hide unsustainable practices.

The careful regulation and monitoring of the EPR system through effective government policy, civil society oversight, and continuously improving targets and incentives for higher-value retention options (especially R0-R6) is thus key. Moreover, it is necessary to overhaul the ways by which the best processing options are chosen (including the selection procedure for waste management operators) and the ways by which investments are carried out to achieve continuous improvements in new recovery options (e.g. R&D in devulcanization or pyrolysis). Better monitoring, transparency, oversight and civil society participation in these processes is key to ensure the continuous improvement of the EPR system and to promote socially and environmentally sustainable design and recovery practices.

4. *Improving overall social and environmental outcomes beyond EOL tyres:* The consequences of potentially socially and/or environmentally harmful uses of granulated rubber shows the weakness of focusing on recovery alone rather than actual sustainability outcomes. It also raises the question regarding extended value chain governance, whether producers should have continued responsibility beyond the first EOL processing of the product. Such expansions of capacities must be done only after an impartial, non-conflicting, regional LCAs aimed at maximising circularity, social fairness and sustainability. In fact, in such complex situations, having clear research and data at hand is vital to plan the best possible recovery options with

human and ecological health in mind. Furthermore, a plan to improve the sustainability outcomes of the entire tyre supply chain should be established and implemented in coordination with a more democratic and inclusive EPR structure. This can ensure that the EPR system doesn't just recycle EOL tyres but also leads to tangible improvements in terms of socio-ecological outcomes, and raw material demand. The overall aim of a CE is not just to close resource loops, but to reduce the pressure of human activities on the planet to ensure the well-being of current and future generations (Kirchherr et al., 2017; Korhonen et al., 2018). An EPR system should thus be understood as a component of a broader policy objective, which aims to sustainably and equitably reduce a country's overall environmental footprint.

5. *Circular business models*: Circular service or leasing business models based on the performance of tyres, rather than selling large quantities of tyres could be encouraged to incentivize higher-value maintenance for producers and consumers (Stahel, 2010). Indeed, under the right conditions, PSS can lead to a sustainable CE, since industries which keep ownership of their tyres have a direct incentive to develop long-lasting and easily recyclable products (Camilleri, 2018; Kjaer et al., 2019). It could thus improve reduce, reuse, retreading and quality recycling within the Netherlands, henceforth reducing the overall consumption and export of tires whose fate remains unknown once exported. However, this necessitates careful government oversight and regulation to prevent rebound effects and ensure that PSS lead to reduced overall resource use and create positive social and environmental sustainability outcomes (Hobson and Lynch, 2016).

The identified gaps and these proposed solutions provide an opportunity for the EPR organization to transform from being an EOL tyre management entity to a true driver of circularity, playing a transformative role in addressing prominent contemporary social and environmental challenges. In this transition, the system must be more inclusive, democratic and adaptive to continuous improvements. The existing fragmented systems of isolated EOL tyre management must be integrated into a value chain governance approach and high-value maintaining targets must be envisioned together and collectively worked towards with greater transparency.

The abovementioned recommendations are in line with those of the updated EU waste directive, which calls for EPR systems to include eco-design requirements to reduce environmental impacts as well as to improve transparency, reporting, monitoring and collaboration with civil society. There is thus now a unique opportunity to overhaul the Dutch EPR system through holistic CE 3.0 strategies, leading to both improved human well-being and ecosystem functioning.

However, a possible limitation of the above recommendations is the small size of the Netherlands in the global market for tyres. Indeed, the country imports most of its tyres and can hardly force large tyre producers oversees to significantly change their design and production processes. EU-wide directives with ambitious targets for tyre recycling, retreading, repurposing, and percentage of recycled content in new tyres is necessary. Indeed, while the EU has established a new CE action plan with various new policies, it has not taken further action on tyres or rubber recycling. Further action from a holistic CE 3.0 perspective is hence needed both nationally and internationally. Another key limitation of the above recommendations is that they are directed towards the unique social, historical, political, economic and technical circumstances of the Dutch EPR system for EOL tyres. Therefore, further research is needed to validate and apply our insights and commendations to other case studies and waste streams.

6. Conclusion

This paper examined and evaluated the structure, organisation, performance and potential limitations of the Dutch EPR system as a case study to explore how this older CE 2.0 systems can be adapted to fulfil the broader societal concerns embedded in the current CE 3.0 debates (i.e. concerns over resource supply, planetary limits, waste generation). It adds a practical understanding of the relationship between EPR and CE, and the former's capacity to contribute to the latter.

Despite this representing a successful example of CE 2.0 initiatives and fulfilling the obligations of the national legislation, our analysis outlined seven limitations and issues, which, we argue, can be the basis of modifying and creating an EPR that meets the needs of the existing CE 3.0 debate. Current EPR systems of CE 2.0 can achieve high recovery rates, but they do not reduce overall resource consumption and promote full circularity, in line with CE 3.0. Thus, our paper suggests strengthening the EPR system by proposing a long-term transformative perspective, which can address issues concerning transparency, inclusion, sufficiency, sustainability and continuous improvement. These lessons could be applied to different contexts and waste streams with careful research and adaptation. Moreover, we examined the internal consideration of the Dutch EPR system. As Circularity in the Netherlands is inherently is tied to a European and global circularity, any exports should be strictly controlled and regulated to ensure high-value retention and sustainability.

This research further illustrates the limits of recycling and traditional recovery operations. CE is often characterised as a tool for closing resource loops and turning wastes into resources. However, low-quality recovery options complicate this as a closed-loop for tyres cannot simply be established with current technologies. Whilst devulcanization could potentially improve recovery outcomes, it is not commercially operational on a large scale and only enables the use of up to 30% secondary rubber in new tyres; still far from a closed-loop. This shows the limits of R3-10 and the importance of sufficiency strategies, especially R0-1 to reach a CE with tangible results in terms of reduced material demand and ecological footprint. The above points are beyond the scope of this paper and demonstrate the complexity of the CE, and the need for specific case studies to improve its governance and implementation.

Moreover, the insights and recommendations learned from our paper are limited to the recovery of tyres in the Netherlands, and further research is needed in other contexts to develop specific and culturally adapted recommendations. In particular, transdisciplinary research with key actors and stakeholders could be an effective manner to build solutions for a sustainable, circular, and participatory overhaul of EPR systems.

Future comparative analysis of EU EPR systems is also needed to uncover how they interfere with each other in the context of the single market. A broader study could also provide further insights into structural issues and challenges for EPR systems in general and uncover other possible best practices for EPR systems from a CE perspective.

Author contribution

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Martin Calisto Friant[a]: Conceptualization, Methodology, Formal analysis, Investigation, Visualization, Writing - original draft, Writing - review & editing.

Kaustubh Thapa[a]: Conceptualization, Methodology, Formal analysis, Investigation, Visualization, Writing - original draft, Writing - review & editing.

Dirkjan Lakerveld[a]: Investigation; Formal analysis, Visualization, Writing - original draft

Walter J.V. Vermeulen[a]: Conceptualization, Funding acquisition, Project administration, Supervision, Resources, Validation, Methodology, Writing - review & editing

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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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2020.122042.

Appendix

A: 10Rs from Reike et al. (2018).

R-principles	Description
R0 Refuse	For consumers to buy less. Also for producers who can refuse to use specific materials or designs.
R1 Reduce	Linked to producers, stressing the importance of concept and design cycle, e.g. less material per unit of production (dematerialisation).
R2 Reuse	Second consumer of a product that hardly needs any adaptation and works as good as new.
R3 Repair	Bringing back into working order, by replacing items after minor defects. This can be done peerto-peer or people in the vicinity.
R4 Refurbish	Referring to large multi-component product remains intact while components are replaced, resulting in an overall upgrade of the product.
R 5 Remanufacture	Full structure of a multi-component product is disassembled, checked, cleaned and when necessary replaced or repaired in an industrial process.
R6 Repurpose	Popular in industrial design and artistic communities. By reusing discarded goods or components adapted for another function, the material gets a new life.
R7 Recycle materials	Processing of mixed streams of post-consumer products or post-consumer waste streams, including shredding, melting and other processes to capture (nearly) pure materials. Materials do not maintain any of their product structure and can be re-applied anywhere. Primary recycling occurs B2B, whereas secondary recycling takes place post municipal collection.
R8 Recover	Capturing energy embodied in waste, linking it to incineration in combination with producing energy.
R9 Re-mine	Landfill remining.

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