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Review article

The role of product design in circular business models: An analysis of challenges and opportunities for electric vehicles and white goods

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ABSTRACT

Pursuing sustainability implies setting a multitude of open-ended goals to address environmental and socioeconomic issues today as well as those for future generations. The circular economy (CE) paradigm appears more focused regarding goals and agency to address environmental issues by using the economic system. However, companies and governments aiming to operationalize CE in practice, it has been claimed, will face six key challenges limiting the CE "net sustainability impact" potential. This work focuses on the challenges for manufacturers to adopt and operationalize CE for their business. The two key levers for manufacturers to navigate on their path from the linear (take-make-dispose) to a sustainable CE are innovating and designing of the business model and of their products. To date, however, understanding the role of product design in developing circular business models has received little attention in research. This review article builds upon the CE literature foundation, including definitions, challenges, and business modeling frameworks needed to better understand the role of product design. Building on the work of several highly cited CE-centric literature reviews and voices in research and industry, we selected and merged complementing frameworks: Slowing-Closing-Narrowing, Circular Design, and the Circular Business Model Innovation framework. To understand how to put these frameworks into practice, we analyzed CE's links with electric vehicle and white goods research and industry perspectives respectively and collectively. The review and analysis of CE and selected industries' research was supported by a co-occurrence keyword analysis of 5,960 most cited papers in CE as well as the two product categories, electric vehicles and white goods. The analysis indicated limited maturity and linkage of circular business models and role of product design toward a CE in the research literature for the product categories. This result corroborated the knowledge gap and guided our focus in searching for further research and industry clues. We structured the clues of interest that were specific to or common across product categories and industries, using the integrated framework to visualize our Design for X conclusion. The merged framework visualizes how paths toward CE by design and logic of value creation, delivery, and capturing may differ. To conclude, the authors' own experience and literature examples from relevant industry-leading and start-up companies are used to apply the framework and reveal strengths, weaknesses, opportunities, and threats. Future research and industry experiments focused on the circular business models based on product service systems and design for CE strategies identified, will be needed to test and extend the framework to other product categories and industry sectors.

1. Introduction

The circular economy (CE) is becoming more prominent in business organizations (Ferasso et al., 2020; Korhonen et al., 2018). Corporate values (purpose), strategy, and economic opportunities motivate enterprises to explore CE-based value propositions and develop circular business models (CBMs) (Lieder et al., 2018; Bocken et al., 2013; Lewandowski, 2016). A CBM includes and aligns a company value proposition with the creation, delivery, and capturing of value (Bocken et al., 2013). It differs from business-as-usual, linear business models in its focus on high-value and high-quality material cycles (Korhonen et al., 2018). An exam-

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ple of a CBM is connecting product leasing with refurbishment, thereby recovering material value inside an access-based payment model (Sumter et al., 2018). The notion of design is central in creating and transitioning to a CBM (Thomas, 2013), but as Sumter et al. (2018) point out, "In spite of the widespread recognition of the importance of design in a circular economy, there is very little empirical research into the role of design during the development of a circular business model."

In the development of new CBMs, product design plays a fundamental role. If the fundamental logics of value creation and capture must change for CBM innovation to be viable, then product design must also fundamentally change: A product, a service, or a product-service system (PSS) that is designed based on noncircular business models cannot stand as the mechanism for creating value in a CBM. One example can be seen in Sumter et al. (2018) case study on baby strollers. Therefore, this review analyzed the role of product design, opportunities, and challenges for the design of CBMs in practice. "In practice" means considering industry sector–specific challenges such as path dependency or "lock in," design complexity, and maturity in design and companies' value chains. We conducted an analysis of two product categories: electric vehicles (EVs) and white goods (WG). EVs and WG were selected to enable and focus our analysis of both different and shared challenges and performance levers within the design of CBMs and products to shift to- and operationalize a CE in practice, starting from the current state and shifting toward a more circular future.

The automotive sector is one industry that might benefit economically from working toward CE (Groenewald et al., 2017a, 2017b). The immature but potentially huge increase in the EV market and demand for batteries and end-of-life vehicle (ELV) recycling in near future (Gnoni et al., 2017; Planing, 2015) make the electric automotive industry a truly relevant if not urgent product category for CE discussion. Furthermore, industry is already changing. Tesla, Waymo (Google's self-driving car project), and Uber have emerged and challenge dominant business models and design strategies at a mobility system level.

In contrast, the maturity of domestic appliances and WG design is remarkably high, and challengers to the dominant business model for appliance manufacturers are few. The penetration rate of domestic appliances per household in developed markets is saturated. Europeans, for example, use an average of 36 appliances per household (CECED, 2017). But like the automotive industry, the appliance industry in Europe (WEEE, 2020) and Japan (Japan Ministry of Economy, Trade and Industry, 2020) is required to follow evolving end-of-life schemes and targets for recovery, recycling, or preparation for reuse. EVs and WG also share challenges in design: both are electrical equipment and thus share values and potential constraints on energy consumption and efficiencies, given the electric power supply available for users, households, society and its environmental impact. The rise of EVs, the internet of things (IoT), and smart-home households' power electrical systems connected to internet and power grid may also lead to a stronger link between EVs and appliances in design and service-oriented business models (vehicle-to-home or V2H systems) (Lieder and Rashid, 2016; Liu et al., 2013).

Exploring both research and industry literature, we aimed therefore to answer the following three questions:

- RQ1: What characteristics of the product categories electric vehicles (EV) and white goods (WG) clarify the role of design in the context of the circular economy?
- RQ 2: What, if any, possible circular business models (CBM) exist that are suitable for these characteristics?
- RQ3: What are the strengths, weaknesses, opportunities, and threats for EVs and WG to develop such CBMs?

Building on the work of several comprehensive literature reviews and dominating voices of the CE and CBM field, this work assessed CE and CBM's links with key characteristics in product design research, supported by a co-occurrence keyword analysis on "circular economy" and the two selected product categories. To structure the clues of interest we found, we merged three frameworks to connect business model design with product design and subsequently applied this integrated framework for EVs and WG.

The remainder of the article is organized as follows: Section 2 presents the study method and approach; there, readers can also find keyword co-occurrence maps visualizing the overarching features and characteristics for the EV and WG research fields and connection with CE. Section 3 describes our results regarding CE in general and the concept of the CBM. Existing frameworks for circular design strategies and circular business models as proposed by Bocken et al. (2016) and Moreno et al. (2016). Circular business model innovation frameworks based on Guldmann et al. (2019) and Joyce and Paquin (2016) were interpreted and incorporated. Finally, in Section 5, the integrated framework is adapted for EVs and WG as a structure to explore the specific and general role of product design and CBM for these product categories. Identified strengths, weaknesses, opportunities, and threats are presented using two SWOT tables, with examples of specific or common implications for the EV and WG industry that can also guide future research.

2. Method

The previous section introduced the key terms and scope of this review and suggested its importance, due to the limited research attention to the role of product design for the CE and CBMs. This section describes the method and iterative process by which this literature review was conducted, as well as some examples of the visualizations used to guide our analysis and uncover linkages.

As illustrated in Fig. 1, we employed snowballing as a literature review technique, as recommended by Wohlin (2014) and used in CE research (Geissdoerfer et al., 2017). We used VOSviewer software for bibliometric analytical purposes (Van Eck and Waltman, 2010). We conducted a co-occurrence keyword analysis on the 2000 most cited papers in each of the CE, EV, and WG fields (5960 unique papers). VOSviewer has the benefit of being easily applied and suitable for visualizing overarching features and characteristics of a bibliometric dataset (Van Eck and Waltman, 2017), which allowed for a guided iterative analysis of RQ1.

The main research literature input was collected using Scopus database first in 2019 and updated January 2021, searching for the following keywords and search strings (Table 1).

The analysis and visualizations from VOSviewer are based on a co-occurrence keyword analysis combining the 2000 most cited documents (articles, books, or conference papers) resulting from searches 1, 2, and 3 in Table 1, respectively (5960 unique documents). Exported data from Scopus was processed, adding a thesaurus to merge synonyms and highly related concepts before using the VOSviewer to generate interactive visualizations like Fig. 2, which shows the most used keywords and co-occuring keywords linking different (sub)clusters of research. Fig. 2 and Fig. 3 are two examples of many visualizations analyzed. VOSviewer's density visualization, shown in Fig. 2, provides a quick overview of keyword co-occurrence and linking five clusters of co-occurring keywords: domestic appliances (white goods) in blue; circular economy in red; electric vehicles in green; energy, air, electricity, and fuel-handling systems, including economic analysis, in yellow; and an EV subcluster regarding lithium-ion batteries and their chemistry (purple).

Fig. 3 is another example of our analysis using VOSviewer, visualizing the dominant keywords that link (co-occur between)

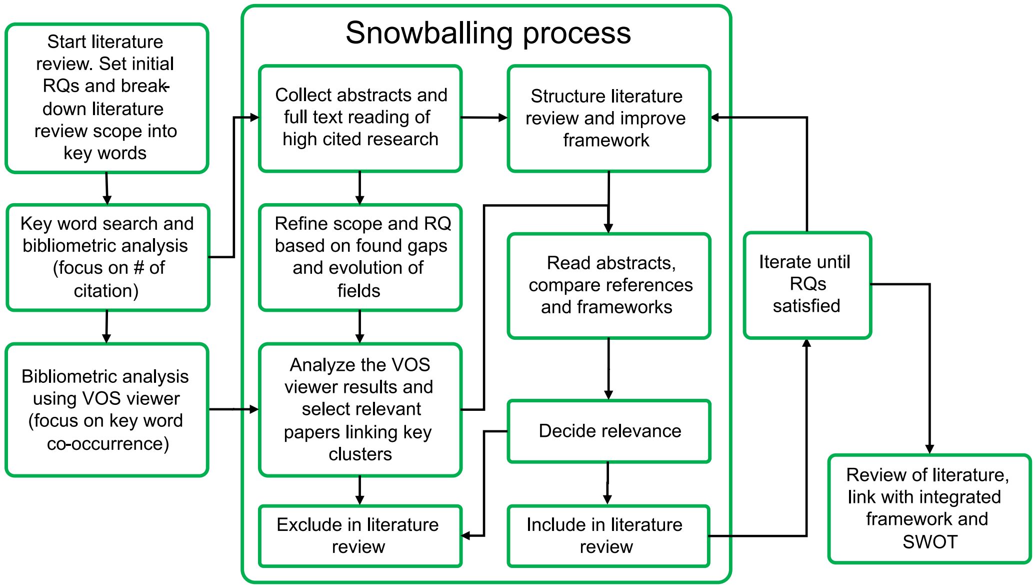

Fig 1. Literature review process.

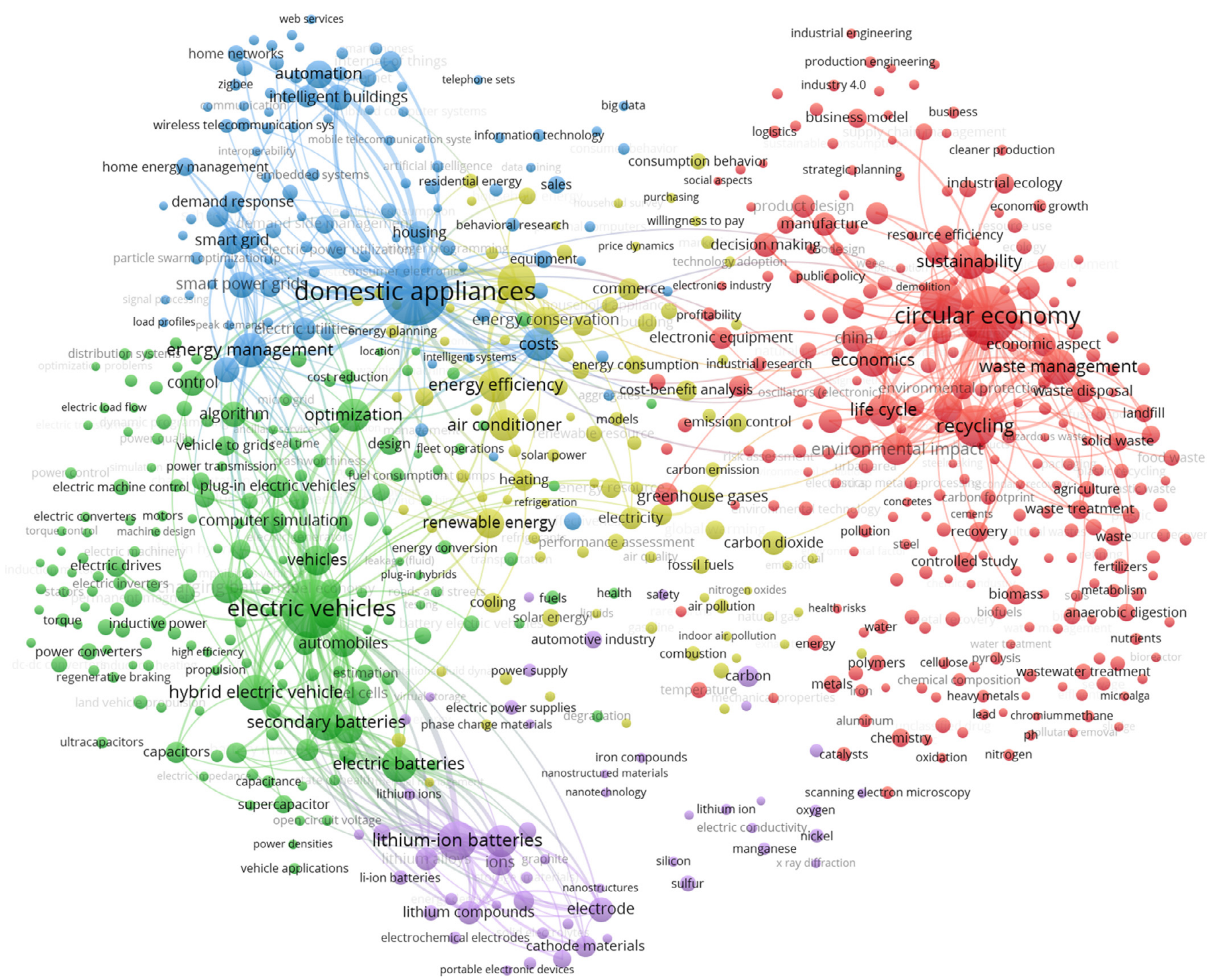

Fig. 2. Density visualization from VOSviewer indicating five clusters of keyword co-occurrence: domestic appliances (white goods) in blue; circular economy in red; electric vehicles in green; energy, air, electricity, and fuel-handling systems, including economic analysis, in yellow; and an EV subcluster regarding lithium-ion batteries and their chemistry (purple).

Table 1
Initial Keywords and Search Strings Used in Scopus Search.

#	Search string	Results
1	TITLE-ABS-KEY ("circular economy")	8790 documents
2	TITLE-ABS-KEY ("electric vehicle*")	71,349 documents
3	TITLE-ABS-KEY ("domestic appliance*" OR "white good*")	10,889 documents
4	TITLE-ABS-KEY ("circular economy" AND "electric vehicle*")	77 documents
5	TITLE-ABS-KEY ("circular economy" AND ("domestic appliance*" OR "white good*"))	25 documents

Table 2
Additional Keywords and Search Strings Used in Scopus Search.

6a	TITLE-ABS-KEY ("circular economy" AND ("electric vehicle*" AND ("domestic appliance*" OR "white good*")))	0 documents
6b	TITLE-ABS-KEY ("circular economy" AND ("business model*" OR "product design"))	933 documents
7	TITLE-ABS-KEY ("circular economy" AND ("electric vehicle*" OR ("domestic appliance*" OR "white good*")) AND ("business model*" OR "product design"))	20 documents

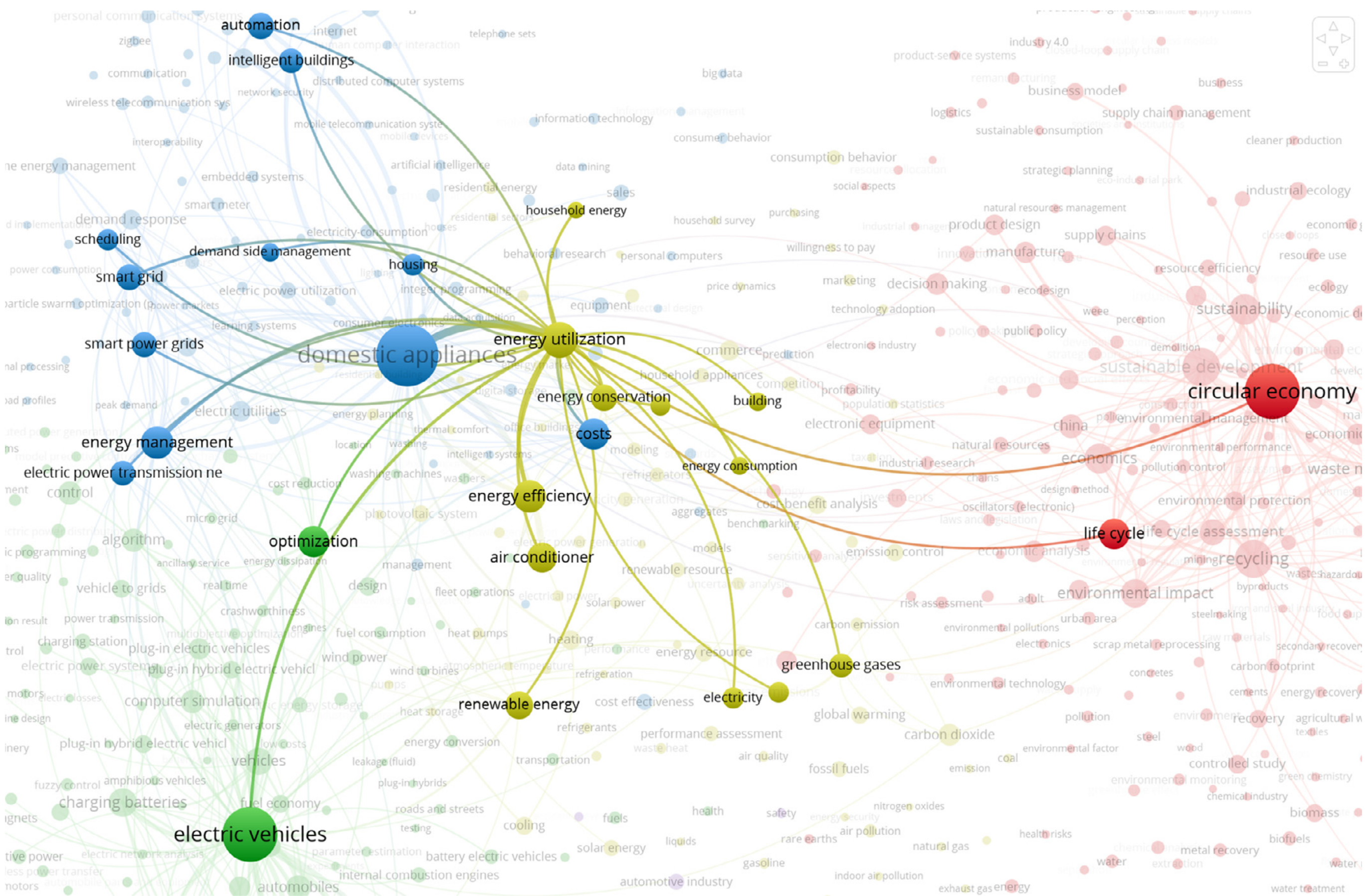

Fig. 3. The main keywords (co-occurring) connecting circular economy, electric vehicles, and white goods (domestic appliances), based on the 5960 most cited documents in Scopus, using VOSviewer density visualization.

the main clusters circular economy, electric vehicles and white goods (domestic appliances), based on 2000 most cited documents for each (5960 unique). These links suggested which product characteristics to study and documents to review to clarify the role of design in the context of the circular economy for the two studied categories.

Different visualizations consistently revealed the weak link of CE with these product categories in the main body of research in general, and a very weak link on the role of design and circular business models. Search results 4 and 5 (see Table 1) provided input for the review of product category–specific CE research. Additional searches in Scopus were done (see Table 2), using all documents (instead of the 5960 most cited) to check the research gap assessment and retrieve additional literature for review for more specific examples on the role of design and or (circular) business models in the context of CE for these product categories.

3. Results

The following results are based on insights from our iterative literature review process. Section 3.1 aims to clarify the concept of CE in relation to sustainable development, limitations, and driving forces from research and industry perspectives. Section 3.2 introduces the perspective of a business model, sustainable business model archetypes (Bocken et al., 2014), and framework to link a CBM with design strategy: Slowing-Closing-Narrowing (Bocken et al., 2016). Sections 3.3 and 3.4. review our findings related to the larger concept of CE and sustainable development from the EV and WG perspectives. Section 3.5 returns to CE and sustainable development but takes a more practical "how to" perspective by complementing and merging circular business model innovation, circular design, and strategy frameworks. Section 3.6 builds on the CBM innovation framework by mapping product design op-

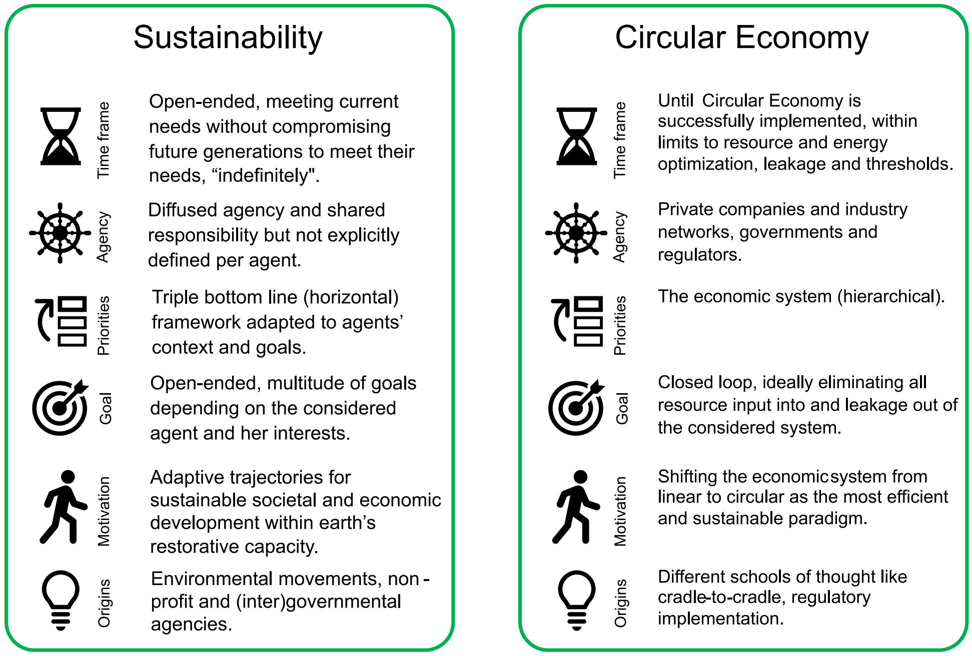

Fig. 4. Selected differences between the sustainability and circular economy concepts.

tions and key partners (value chain stakeholders) to align with value proposition, value creation, value delivery, and value capture in the context of a CE.

3.1. What is the circular economy?

Over 100 CE definitions exist (Kirchherr et al., 2017), indicating that CE as a concept has ambiguous boundaries resulting from the perspectives of different CE actors. We have reviewed both research and industry perspectives.

The research literature suggests there is no commonly accepted definition of CE (Yuan et al., 2008). But in brief circular economy can be said to be a logic for operationalizing the global political position of sustainable development, encapsulated in the now famous statement by the Brundtland Report: "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (UN, 1987). Fig. 4 provides some key differences between sustainability and the circular economy based on Geissdoerfer et al. (2017) and our own literature review.

Following Geissdorfer et al.'s (2017) comparison, the circular economy paradigm appears more focused in goals and agency to address environmental issues by using the economic system. The origins of CE, as presented by Geissdorfer et al. (2017), can be traced back to the late 1960s and 1970s, when a circular economic system was suggested as a closed system, necessary to sustain life on Earth, but also as a general systems theory and part of industrial ecology (IE). Uniting these influential schools of thought is the aim to describe and grasp economic systems, as well as how such systems are controlled or regulate each other. IE includes a proactive perspective for companies or governments to use these systems concepts to build their roadmaps for sustainable development. Here CE builds upon IE's foundation, scaling up to economy-wide system for sustainable development. The question is how governments and companies are to apply the CE logic for operationalizing sustainable development. This operationalization question is, as Korhonen et al. (2018) state, "what the entire circular economy research field is about." And answering these questions may be a precondition for sustainable development (Geissdoerfer et al., 2018). Considering the literature reviewed and implementation examples found CE appears be too immature a concept to define CE conclusively this review adopted Korhonen et al. (2018) suggested definition of CE as:

"an economy constructed from societal production-consumption systems that maximizes the service produced from the linear nature-society-nature material and energy throughput flow. This is done by using cyclical materials flows, renewable energy sources and cascading-type energy flows. A successful circular economy contributes to all three dimensions of sustainable development. Circular economy limits the throughput flow to a level that nature tolerates and utilizes ecosystem cycles in economic cycles by respecting their natural reproduction rates" (page 39).

A crucial aspect of CE stressed by Korhonen et al. (2018) is the "global net sustainability" contribution that any CE effort might have, and that this is the single gold standard to assess an effort against. Korhonen et al. (2018) identified six limits challenging the implementation of CE and its "global net sustainability" contribution:

- Thermodynamic limits,
- System boundary limits,
- Limits posed by the physical scale of the economy,
- Limits posed by path dependency and lock-in,
- Limits of governance and management,
- Limits of social and cultural definitions.

Three of these challenges are to be considered unmanageable limits (thermodynamic, system boundary, and limits posed by the physical scale of the economy). Presenting at the Royal Institute of Technology (KTH) on the CE topic in February 2019, Korhonen further stated that the remaining three challenges are very difficult, in some cases impossible, to manage. Cultural values, social acceptance, and behaviors are known to delay, redirect, or undermine the uptake of any new or innovative circular business models (Singh and Giacosa, 2018). Limits of governance and management (Korhonen et al., 2018) include sectoral alignment of interests, technology investments, and implementation challenges to realize and sustain new business models. As a CBM includes and aligns a company value proposition, value creation, delivery, and capturing

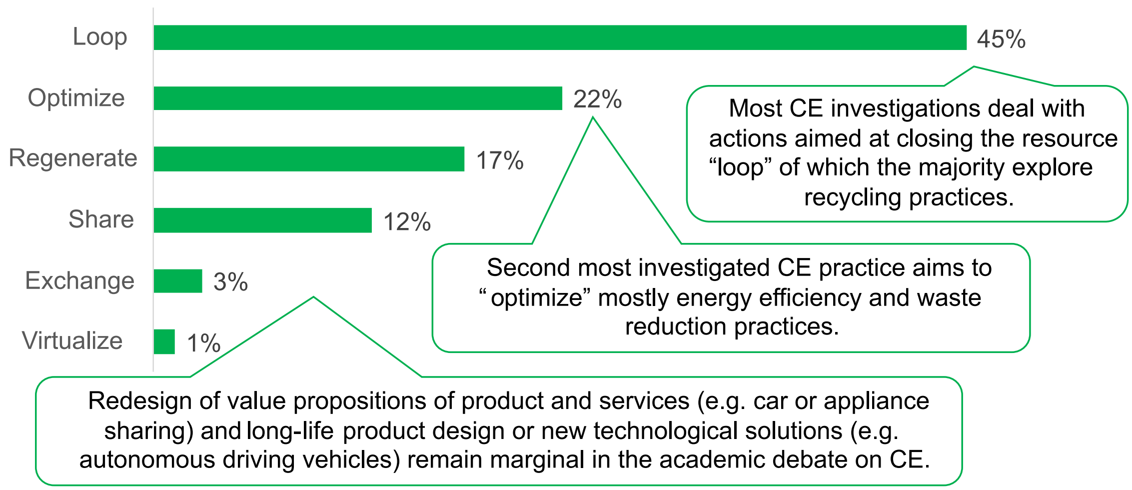

Fig. 5. Merli et al., (2018) review of the circular economy literature classified in pillars of the ReSOLVE model.

of value (Bocken et al., 2013), operationalizing such CE logic will require more parties and collaboration at various intra- and inter-organizational levels than a more traditional (linear) product sales model.

Regarding the general features of the CE research field, Merli et al. (2018) structured a review of over 500 articles into analytic categories, classifying the state of CE research into three main areas of interest: changing social and economic dynamics at the macro and administrative levels; supporting firms in circular process implementation at a micro level to spread new forms of consumption and product design; and discussing meso–level industrial symbiosis experiences. The ReSOLVE model dominating in industry publications on CE, promoted strongly by the Ellen MacArthur Foundation (2012, 2015, 2019) and McKinsey Report (2015), was used by Merli et al. (2018) to categorize reviewed CE research literature. When classifying circular economy research literature in the ReSOLVE categories (see Fig. 5) Merli et al. (2018) found a strong focus on closing the resource loop, with optimization a distant second with only half as many occurrences. Among the "Loop" and "Optimize" categories, waste reduction, recycling, and energy efficiency appear to be dominating the academic debate. Examples of business models that impact value propositions, those involving long-life or upgradable product design, or using new technology to "Virtualize" parts of the product delivery experience remain marginal in the academic debate.

3.2. Doing business in the circular economy – a research perspective

Business models describe the rationality of a company, how it creates and captures value in economic, cultural, social, or other contexts (Singh and Giacosa, 2018). A company designs its products and services based on its business model. For example, in a cultural context where people prefer to use new products, companies tend to adopt a business model based on introducing new products frequently with a shorter lifespan. In contrast, in a context where people seldom buy new products or rather prefer to use second-hand products, companies' business models are based on producing long-lived products that survive fashion and keep their value in the market. In other words, product design and business models are interrelated, and a business model is considered a blueprint of the company's operation (Singh and Giacosa, 2018).

Bocken et al. (2014) assert that a business model framework shall distinguish value proposition, value creation, value delivery, and value capture. Based on their framework, three groups of business innovation form a comprehensive set of sustainable business model archetypes: technological, social and organizational innovation (Bocken et al., 2014). A later study by Bocken et al. (2016) proposed a framework covering both design and business model strategies for CE in the following three overarching dimensions:

- Slowing resource loops
- Closing resource loops
- Narrowing resource loops

"Slowing" concerns creating longer-life products and establishing product reuse practices. "Narrowing resource flows" is about resource efficiency and aimed at using fewer and less resources per product, as successfully applied also in most linear economy business models, but in itself not addressing the speed nor looping of resource flows. "Closing" focuses on creating value from what would traditionally be seen as "waste," a concept that some argue no longer exists in CE (Bocken et al., 2014; Sumter et al., 2018). Others (e.g., Korhonen et al., 2018) argue that a dynamically changing societal temporal construction of the waste concept will strongly influence how material resources are perceived and managed in the design of CBMs. The next two sections aim to provide a review of the state-of-art industry perspective and dominant research identified for the two chosen product categories. Mindful of the CE literature debate, as well its business model archetypes and strategy framework mentioned above, we reviewed the research and industry literature looking for key characteristics of electric vehicles and white goods respectively and collectively that might clarify the role of design in the context of the circular economy.

3.3. State of the circular economy – An electric vehicles perspective

Given that (1) the automotive sector has been pointed to as one industry that might benefit economically from working toward CE (Groenewald et al., 2017a, 2017b), especially in relation to remanufacturing (Benoy et al., 2014; Rizos et al., 2016), and (2) in the near future a huge increase in end-of-life EVs (End-of-life vehicle statistics, n.d.) and batteries from EVs will be generated (Groenewald et al., 2017b; Richa et al., 2017) the electric automotive industry is a relevant product category for CE discussion. The European Directive on ELV treatment has heavily influenced policies in many countries and encouraged car manufacturers to reconsider their product design and platform strategy to enable better ELV treatment. EVs are highly complex mechatronic systems that functionally and spatially (at lower system levels) integrate heterogeneous system components into their design (Kumar et al., 2017; Janschek, 2011). They are high-value and highly complex products, although very standardized, with little deep unit customization: they typically use the same chassis, motor, battery platform, wheelbase, etc. Research on EV technology has focused on a few areas according to Yong et al. (2015):

- Battery technology (Groenewald et al., 2017b; Speirs and Contestabile, 2018), especially LiPo batteries as the primary locked-in battery technology in the EV market (Kurzweil, 2015)
- Charging and power grid infrastructure (Poullikkas, 2015)
- Power train.

The power train is the categorization scheme based on a vehicle's hybridization ratio, ranging from hybrid electric vehicles (HEVs) to plug-in hybrid electric vehicles (PHEVs) to battery electric vehicles (BEVs). HEVs supplement an internal combustion engine with a battery that is solely charged by the car's operation, not the power grid, which distinguishes it from PHEVs. EVs are powered only by their own batteries and electric motor(s) (Yong et al., 2015). Among them, Kumar et al. (2017) argue that PMBLDC (permanent magnet brushless direct current) motors are state-of-the-art.

Despeisse et al. (2015) points out how today's ELV management mainly focuses on recycling the metal fraction of ELVs because the technology exists and is well-established. However, the evolution of material technology and the diversity of materials used in newer vehicles also makes the recycling and recovery processes more challenging. With current trends in material substitution for fuel efficiency and safety, the percentage of electronics, plastics, composites, and other nonmetallic parts is increasing. This trend is heightened by the exponential increase in EVs. Zhang et al. (2018) found an increasing stream of hazardous material, namely rechargeable batteries containing the poisonous materials nickel, cobalt, and lead. Batteries are generally not designed for recycling or reuse, making the processes hazardous and costly, as well as yielding impure or lower-value recycled materials. This further emphasizes the need for integrating end-of-life strategies at the product design stage.

Our keyword search for publications on electric vehicles and circular economy resulted in only 77 out of over 70 thousand publications relating only to EVs until January 2021 (See Table 1, search #4). Among this literature, design and or business models issues relating to EVs and Circular Economy (See Table 3, search #7) are very few. Here the focus is on the battery design, battery chemistry and charging. Nonetheless, strong indirect connections exist, especially based on the sustainability logic in both research fields and their respective interests in energy efficiency, as shown by the VOSviewer visualizations (see Fig. 3) discussed in the Section 2 (method).

An EV is only an operation-zero-emission transportation option if the power generation infrastructure that charges it has zero emissions, which is termed "well-to-wheel efficiency" (Poullikkas, 2015; Yong et al., 2015). This is in line with the argument that the global net sustainability contribution should be the baseline assessment, both in an absolute and a comparative sense (Korhonen et al., 2018). As such, much of the research on CE motivated by environmental sustainability directly relates to energy policy and energy grid research (Kempton and Tomić, 2005), and especially research on possible interactions and energy transfers between vehicles and the power grid (V2G, G2V). Charging schemes and infrastructure is thus important for the future sustainability of EVs, particularly irrational charging behavior and its power-demand impacts (Poullikkas, 2015).

An overview of specific cases of EV development in relation to their business models was conducted by Bohnsack et al. (2014), covering most of the big automotive actors making EVs at that time, but without a strong presence of either CE or sustainability logic. Instead, the dominant analytical categories were luxury car versus budget car and large-car/small-car polarities. As such, their business model archetypes (Bohnsack et al., 2014) cannot be said to be CBMs but may be suitable for linking to them or applied in a CE context.

In the electric vehicle case, Tesla has explored remanufacturing and refurbishing strategies they presented in 2013 by enabling the swapping of battery packs for the Tesla S and testing a battery swap station as a complement to their charging stations during 2015–16 (Lambert, 2016). Swapping of battery packs was later rejected by Tesla (Lambert 2021) and design for long life and module-level refurbishing now appears to be the company's chosen design strategy (Lamber 2019a). Using high-end components and manufacturing appears to have contributed to the fact that only a very limited number of Tesla batteries have actually reached end of life (Lambert, 2019a). While the company uses third-party recyclers to recover high quality recycled components and dispose of other components with environmental responsibility. Tesla's "Gigafactory 1″ in Nevada, USA, cooperative endeavor with Panasonic, is said to be developing a "unique battery recycling system" of its own (Lambert, 2019b; Tesla, 2018, 2019). The company believes that closing the loop will result in significant savings over the long term (Lambert, 2019b; Tesla, 2018; 2019). These reports suggest Tesla is pursuing several CE strategies, such as intensifying, narrowing, and closing resource loops to ensure long-term economic performance and meet stakeholders' interests in sustainability.

Focusing on environmental and ecological net sustainability, Tesla, Volkswagen, Toyota, and Nissan each introduced V2G and G2V technology with the aim of allowing owners and stakeholders to optimize electric supply and demand. A project initiated in Denmark (the Parker project) has demonstrated V2G possibilities, including the economic and environmental benefits of using the technology (Graham, 2017).

To conclude, both researchers and the EV industry have many sustainability-related research interests, but most of these are specific to engineering design and economic questions, not the overarching issues facing CBM design and innovation. "Firms often took their existing business model for conventional cars as a starting point to incrementally adjust it to compensate for the downsides of EVs for customers, suggesting path-dependent behavior" (Bohnsack et al., 2014). It might be the case that smaller entrepreneurial actors in the automotive industry are the only ones structurally capable of transitioning to a CBM for an EV business (Bohnsack et al., 2014). Tesla may be such an actor (though now large and still growing). Earlier mentioned Tesla lithium-ion battery plant "Gigafactory 1″ can be considered as an candidate for operationalization of a business model and design strategy close to the idea of a CBM.

3.4. State of the circular economy – A white goods perspective

For the white goods part of the domestic appliances industry, which business model(s) and design approach(es) appear most promising in the transition to a circular economy? To answer this question, we have considered both the voice of industry and research. Publications by industry, consultancies, and other organizations supporting CE are typically easy to digest and to the point, but their factualness or scientific method may be questionable, unclear, or somewhat "greenwashed." Research papers can be assumed to be more methodical and objective, yet frameworks, models, and cases are conceptual, not (fully) realized or possibly contextually out of date, due to the fast pace of industry and technology developments.

A 2017 report by the European Committee of Domestic Equipment Manufacturers (CECED, 2017), the European Committee of Domestic Equipment Manufacturers, in collaboration with the United Nations University and based on Eurostat data, states the

Table 3
SWOT Analysis of the Two Product Categories in Relation to a Product-Service System Business Model.

PSS CBM	Electric Vehicles	White Goods	Common
Strengths	Service and leasing business already established in the automotive industry	Rental business of appliances emerging for high quality and long-life products	
Weaknesses	Dealership model lock-in, service infrastructure system scale of change	Fixed mounting in private home/kitchen limiting sharing platforms	Product sales path dependency in channels and manufacturers
Opportunities	Sharing economy and ridesharing trend reduce the need for vehicles per capita	Pay per use enabled by IoT / smart homes and new revenues from consumables	
Threats	Privately owned, autonomously driving and perceived "zero-emission"	Competition from linear paradigm and poor economies of scale	Recycling/recovery cost, consumer acceptance
	EVs may increase total traffic and resource use	Policy counteracting reverse and remanufactured flows	
	Culture/mindset and social status symbol		

penetration rate of domestic appliances per household in Europe is saturated. Of an average 36 appliances per household in use, seven are large appliances including refrigerators (2.6 per household) and washing machines (0.9 per household). Production of new home appliances uses 6 million tons of raw materials, of which the main components are steel (50%) and plastics (18%). The installed base of appliances in use is estimated at 8 billion products (67.3 million tons). Again, the bulk of this material is steel (30 million tons) and plastics (12 million tons). Similar to the European directive for ELVs, a product responsibility was first introduced in the EU in 2002. Industry recycling schemes currently collect and treat about 1.7 million tons of appliances annually, but the total of discarded appliances is estimated at 5 million tons, 50% being large appliances (white goods) and 24% refrigeration products. No EU data is available on the fate of discarded appliances outside industry schemes, though a UK study European Committee of Domestic Equipment Manufacturers (CECED, 2017) found that 80% or 3.6 million tons of all discarded appliances are collected for recycling. The rest, 20% or 1.4 million tons (mainly small appliances), ends up in waste treatment or unknown destinations in about equal amounts.

Based on our finding that recycling is one of the main research topics in literature linking domestic appliances with CE, together with the CECED annual quantities of undocumented discarded product, we first explore the CBM and design options to improve the recycling rate of appliances. This means closing the loop with the producers or cascading circular supplies (downcycling), so no discarded appliances are lost as e-waste to unknown treatment and undocumented destinations. To achieve a better closing of the loop by recycling and reuse of end-of-life appliances with a circular business model, the product service system (PSS) model has been studied using system dynamics modeling (Gnoni et al., 2017). Switching from traditional purchase of a machine to monthly payments enables consumers to obtain a higher quality machine than they would have considered if traditionally. Such washing machines can pay off with a 55% lower operating cost for the washing location. The producers retain ownership control of the machine to ensure efficient operation and maintenance as well as controlled replacement with new best-in-class machines and reverse flow of used machines for efficient reuse, recovery of reusable materials, and treatment of non-reusable content. Another study (Bressanelli et al., 2017) suggests that the adoption of such a PSS scheme, if incentivized and widely adopted, could also save 0.6% and 1% on the electricity and water consumption at a national level, when calculated for France, UK, Germany, and Italy. Bressanelli et al., (2017) account for the differences in energy and water cost, as well as the washing habits and equipment performance per country. From a design approach point of view, any and all combinations of the Slowing-Closing-Narrowing framework proposed by Bocken et al. (2016) can be considered, as well as the opportunity of IoT, but their paper does not detail if there is any trade-off or additional benefits for users, producers, or other stakeholders. Also, business model variants are mentioned but not quantified as a net benefit. One CBM mentioned is sharing of machines and even washing cycles, to improve the current average utilization of 4% of available time and 2.5% of theoretical washing capacity. Another option is providing a more "full-service" PSS offer, including detergent, water, and energy. Aside from potential new revenues for the producer, more intelligent machines could optimize their consumption and cycle based on sensor inputs, machine learning, and variable rates for utilities. Despite challenges due to the system boundary or limits of governance and management as argued by Korhonen et al., (2018), one can envision intelligent and connected appliances playing a role in smart-homes energy management and wastewater quantity and composition, to realize further "net sustainability impacts." The washing machine case, in different forms and extent, has been found in industry literature though with little or no changes to its design. Bosch offers a "full service" leasing scheme that includes warranties over the contract term (Ellen MacArthur Foundation, 2012), but more recently also introduced machines that, similar to competitors Miele and Samsung, manage their own dosing of detergent. Miele was recognized by start-up company Bundles as a superior performing and long-lasting product to build up a pay-per-use business model using the existing Miele washing machines, tumble dryers, and dishwasher equipment along with a "smart plug" and connected device to measure the energy use and calculate the usage to be invoiced (Bundles, 2019; Ellen MacArthur Foundation, 2019). The Bundles founder however also stated that Miele is the only washing machine designed for 100% reuse or recycling. Electrolux also tested the service business model for the consumer market on the Swedish island of Gotland (Electrolux, 1999) but this initiative appears to have halted due to the utility Vattenfall discontinuing smart metering service (Ellen MacArthur, 2012) demonstrating earlier mentioned system boundary or governance and management limits (Korhonen et al., 2018). Panasonic was said to be planning to start fixed-rate rental service of appliances like refrigerators for household use as soon as 2020 (Kawai and Suzuki, 2018). In the Panasonic case, the motivation is a strategy to "lock in" customers and secure recurring revenues as it faces tough competition from Chinese and Korean appliance producers, rather than sustainability or CBM. Similarly, Panasonic offers TV rental services, which it uses to gather data on TV channels users watch as input to tailor promotions and develop new products and services. Panasonic's examples of design and business model innovations may very well open doors for sustainable and circular design strategies as we will show in the next section, but presently seem not to be driven by CE logic.

3.5. Toward a more circular economy by design

Despite the many possible archetypes for business model innovation, designing and implementing a viable new business model is challenging in practice, particularly for circular business models. Rizos et al., (2016) identified six basic obstacles to establishing CE as a regenerative and restorative business model, complimenting, and partially reinforcing earlier mentioned (Section 3.1) obstacles to CE operationalization and "net sustainability impact" by Korhonen et al., (2018):

- Cost
- Raw material availability
- Cultural differences
- Stakeholders' interests
- Policy and practice related to the economy
- Business environment.

Guldmann et al., (2019) noted these obstacles and introduced a circular business model innovation framework where they have addressed the economic, supply chain, and stakeholder impact of being circular by slowing, closing, or narrowing resource loops. However, to be sustainable, the framework needs to be three-dimensional, addressing economic, social, and ecological impacts. Addressing the dimensional issue, Joyce and Paquin (2016) proposed a framework widely known as the triple-layered business model framework or canvas. For this paper, a simplified framework for circular business model design is proposed, based on Guldmann et al., (2019) and Joyce and Paquin (2016) (see Fig. 6). Based on our literature review on business models, we will consider this framework as the suitable model for developing and evaluating CBMs across product categories. The framework consists of earlier introduced themes or principles: value creation, value proposition, and value delivery and value capture whereby each of the themes establishes an economic, environmental, or social layer to the business model.

The framework themes' economic, environmental, and social layers can be summarized as follows. We defined the value proposition as a quantity of product or service offered in relation to the functional or experience value served. Value creation includes all forms of resources (sustainable inputs) utilized by design to provide this value. Value delivery is where and how the business model interacts with its customers and utilizes society, time, space for the forward, reverse, and end-of-life flows of resource and energy to generate revenues. To emphasize this wider customer perspective, we used the term *extended customer relations* and segments. A CBM aims for the highest value utilization from products or services, which means value capture is to account for the "triple-layered" exchange and balance of sustainable values served, resource and energy captured, and lost per unit of time. This results in an economic, social, and ecological cost–and-benefit perspective, based on the logic proposed by Joyce and Paquin (2016).

Companies may initiate different strategies when designing sustainable circular business models. As introduced earlier (Section 3.2) Bocken et al., 2016 structured main strategies to slow, close, and narrow resource loops. Geissdoerfer et al., (2018) emphasize "intensifying" and "dematerializing" as key sub-strategies worth separating out from "slowing". "Intensifying" is defined as the use of resources and products through more intense usage, such as sharing services and "dematerializing" a resource loop involving substitution of physical products and material resources by services and software solutions.

These strategies may be attained using both product and business model design as a starting point (Bocken et al., 2016), but they should be evaluated and balanced as each may face its challenges or obstacles in the four themes and three layers of the framework. Sustainable inputs are separated to emphasize sustainable sourcing of energy and virgin, recycled and recyclable material inputs, but we will consider sustainable input to be an integral part of the value creation design strategies and its operation or consumption in value delivery.

3.6. Integration of design for circularity into business model frameworks

Emphasizing the Circular Business Model Innovation framework concept, Lieder et al. (2016) and Bocken et al., (2016) suggest that a CBM should integrate environmental and economic value delivery and capturing strategies in the value creation process by design. Only this way can product, supply chain, and life cycle management (recovery) systems successfully implement a continuous flow of reused products. Considering the strategies' impact on product design requirements (Bocken et al., 2016), obstacles and challenges, enabling or even enhancing the relationship between circular business models and product design activities as discussed is worthy of exploration. Two supportive approaches to do this are suggested (Pieroni et al., 2018):

- Combining a backcasting approach to business model development with eco-design (Mendoza et al., 2017)
- Introducing circular strategies of CBM and product design (Bocken et al., 2016, 2018; Korhonen et al., al.,2018).

Pieroni et al., (2018) found the adoption of such frameworks as an add-on to the business model development process to be most common. Pigosso and McAloone's (2017) review of design literature aimed to reveal how design science can contribute to the circular economy. Pigosso and McAloone (2017) scanned across a range of topics including management and organization of design, design methods and tools, information and knowledge management, and design education. They conclude that design science should focus on product, services and systems design and product-service systems (PSSs), in particular "Design methods and tools" and "Design for X, design to X" (DfX). They also identified the need for business model research and a gap in "design information and knowledge management" to enable the transition to a circular economy (Pigosso and McAloone, 2017). Moreno et al., (2016) present a "circular design framework" based on the evolution of DfX that considers not only business model and design but also governance through policy and regulation. Bocken et al., (2016) use the example of Miele's long-life design strategy for its washing machines and modest growth ambitions at the company

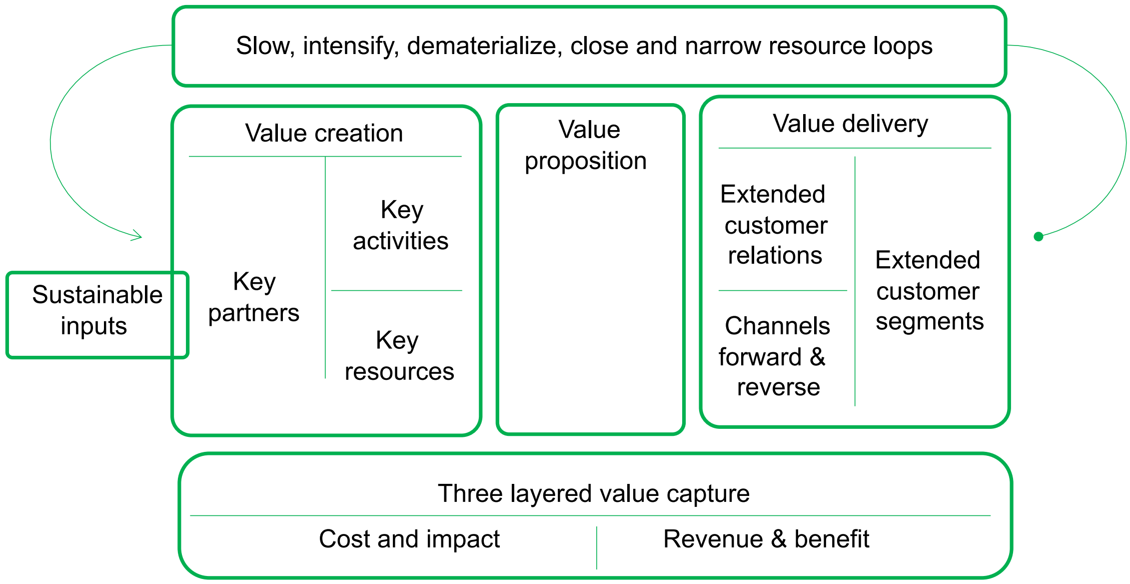

Fig. 6. Triple-layered circular business model innovation framework.

level to demonstrate the fit with a "slowing" and "sufficiency" business logic. Moreno et al., (2016) find that several business logics support a long-life design strategy ranging from supporting services and the refurbishment business, building more emotional and long-lasting customer relations, to enabling product-as-a-service or sharing models. Such differences underline the expression, "all models are false or at least imperfect, but some are useful." Concluding this section, we find there are many models and frameworks to support aligning circular economy business with design strategy (RQ 2). By merging these frameworks and models into a proposed Integrated Business Model framework (Fig. 7), a more explicit, cross functional, framework emerges featuring the key circular value proposition and creation strategies to apply in design and business models and how these may be implemented in value delivery and capture.

4. Discussion

Combined researcher and industry perspectives on CE and CBM reveal a growing field of environmentally focused sustainability and business logic. The academic debate on CE is dominated by investigations into closing the loop of resource flows as far as possible or optimized and sustainable energy and waste management, also referred to as narrowing. Industry CE perspectives appear fueled by human ingenuity, technology, and emerging policy to bring economic advantages for companies as part of a larger social and economic dynamics toward sustainability at the macro level.

The frameworks and archetypes for business model innovation proposed in CE research are useful both for reviewing and structuring the growing CE research, linking product category–specific and industry literature as well as adapting frameworks for CBM development to be suitable for our selected product categories EVs and WG (RQ 2). However, categorizing and selecting business models according to product category from a manufacturer perspective is considered a top-down, inside-out approach. In many cases, such top-down approaches run a high risk of nonacceptance by consumers, due to cultural, social, or individual bottom-up and external (outside-in) factors (Singh and Giacosa, 2018). In many cultures, usage of brand-new products or services is embedded in a cultural belief in high power distance. Society undermines the concept of recycling and reuse when possession and ownership holds psychological essentialism and encourages individuals to consume (Singh et al., 2018). Some consumers will prefer temporary ownership in the short term and sacrifice more durable economic life in the long term, following a "bird in the hand is worth two in the bush" mindset (i.e., not calculating net present value of future product upgradability). In addition to these cognitive biases, additional nonacceptance risks of CBM were identified by Planing (2015), such as the conflict of interest within companies and misaligned profit-sharing along the value chain. The latter can also be a result of a lack of governmental policy for products at their end-of-life phase. These factors involving non-acceptance of CBM may be more manageable in environments where society and business organizations are genuinely concerned about environmental degradation and governments are determined to formulate and execute CE-friendly policy, whereas other environments will be much more locked into a linear value delivery and capturing paradigm with value propositions. The "bottom line" and bottom-up constraints visualized in the lower sections of the integrated framework (see Fig. 7) should not be underestimated. These will need further attention as well as contextualization in future research.

4.1. A design for X framework for electric vehicles and white goods

The use of an integrated business model framework is recommended for our two chosen product categories. To elaborate and evaluate the proposed integrated framework (Fig. 7) for the chosen product categories (EVs and WG) we studied selected papers from the keyword co-occurrence analysis, websites of manufacturers for CE-related strategy statements, implementation cases resulting in a more focused Design for X framework shown in Fig. 8. The Design for X framework is intended to capture shared vision, guide understanding and help explore scenarios of how a CBM may be enabled and challenged along the value chain from value proposition, -creation, - delivery and -capture given a case context, including product design category, sector situation, and key stakeholders.

The Design for X framework uses all business model canvas elements but centers on value delivery instead of value proposition. The framework does not impose a specific order of work, and an iterative approach across the elements is recommended. Based on the challenges and obstacles presented in this review, we believe

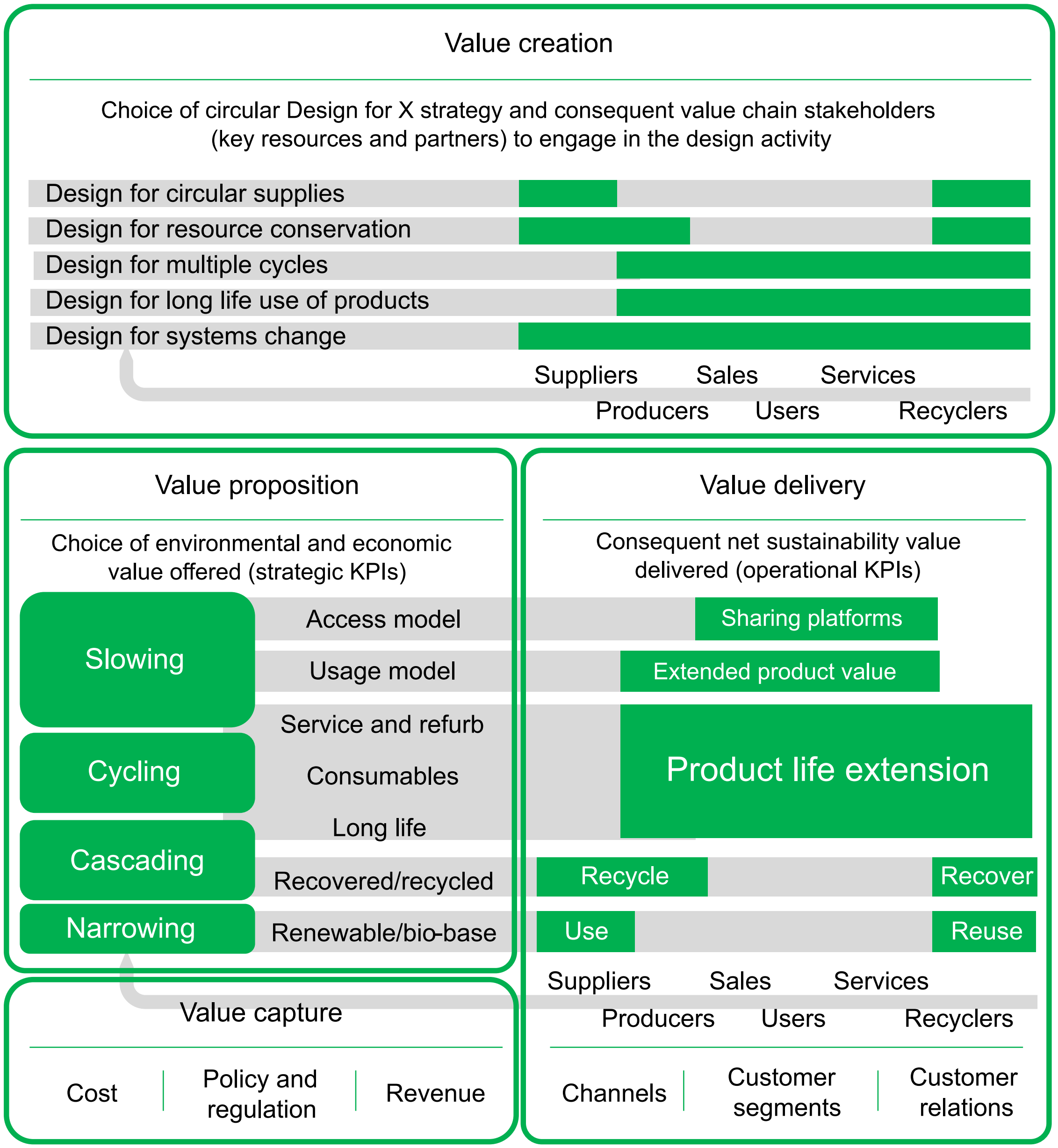

Fig. 7. Integrated framework for circular design strategies connecting with circular business models, applied on the circular business model innovation framework. Adapted from Guldmann et al., (2019) and Moreno et al., (2016).

value delivery to be the critical bottleneck for a successful implementation of a CBM, at least for the studied product categories. A manufacture is likely to serve multiple customer segments and channel configurations facing different cultural challenges or stakeholder conflicts of interest. We recommend separate sheets to define segments and channels to explore customer relations and assess multiple value delivery options for the same or similar value creations.

Notice how the boxes in Fig. 8 form an “X”. Reading from the top of the model, following Bocken et al., (2018), a company-specific “Value purpose and proposition” should state why the organization exists and state why “Slowing resource loops” and “Cycle products for as long as possible” makes business sense and guide design strategies and KPIs for value creation and delivery. Reading from the bottom of the “X”, Bocken et al., (2016) and Lewandowski (2016) suggest an access- and performance-based business model for complex products like EVs. This corresponds with value delivery through sharing platforms and extended product values such as regular upgradation, maintenance, and refurbishment at subsystems or module-level to prevent premature obsolesce. A design for system change and multiple cycles of use, reuse, and reconfiguration will be challenged by the dominant vehicle ownership model, but necessary to avoid an unsustainable rate of new EV production. On the other side of the “X” spectrum, white goods are very mature and low-complexity products, less frequently demanding upgrades or maintenance. The more profitable domestic appliances are those that are “built-in” part of a larger more complex system: homes and commercial real-estate. Considering these segments home/households, facility management, real-estate, construction companies KPIs for value delivery in product life extensions (sustaining real estate value) and hassle-free operation corresponds with design of long-life products, with consumables and services as “integrated” parts of the value proposition. It is therefore interesting to observe the industry cases on subscription/rental models for both EVs and WG. These appear to be growing and successful in at least some customer

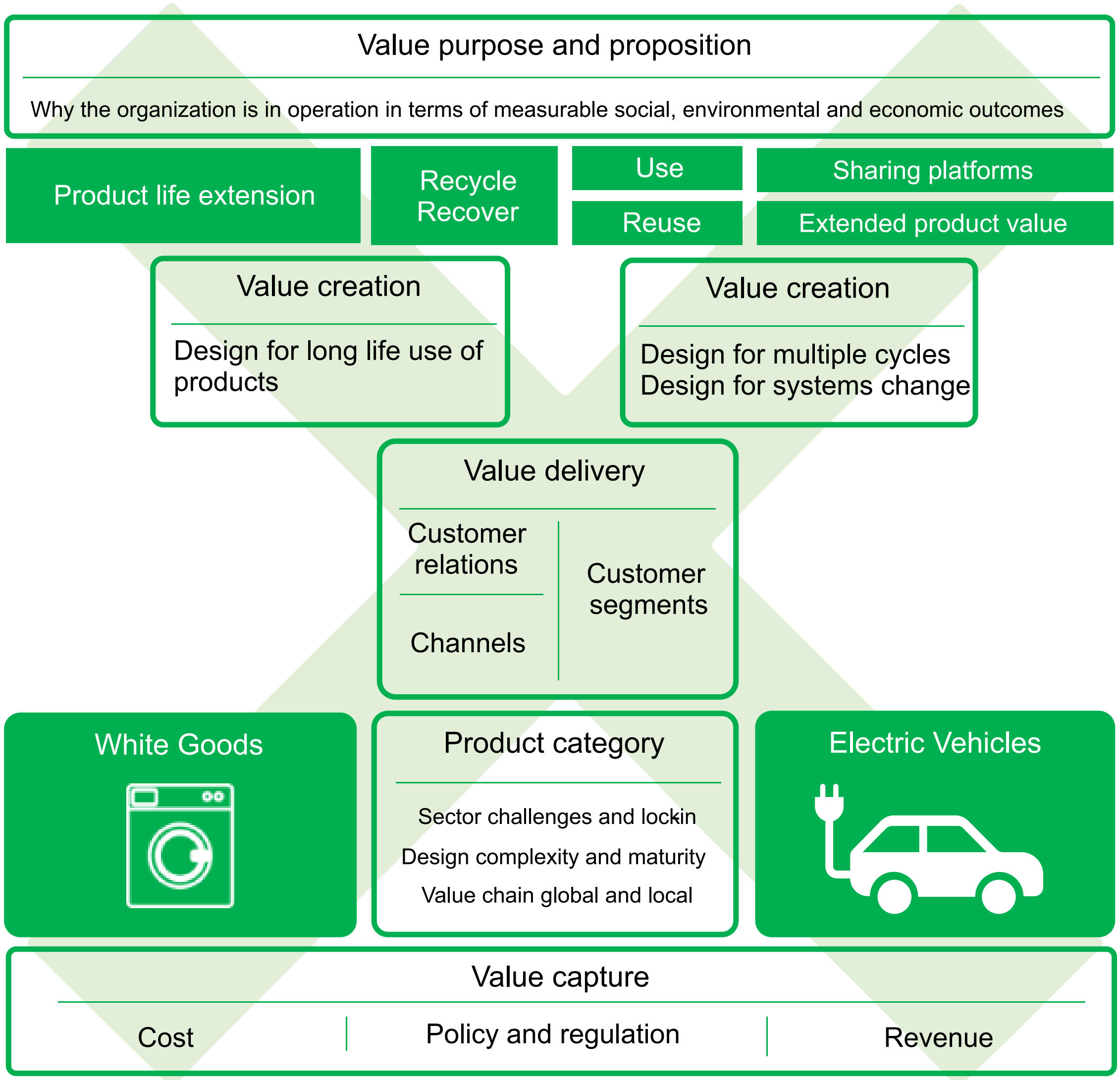

Fig. 8. Design for X framework for our chosen product categories.

segments, and coexisting with more traditional product sales and leasing, if quality (long life) and modularity (upgradation, refurbishment and configurability) is properly considered in design. For example, premature obsolescence for styling or new technological features, may be less frequent or decoupled by design of style- and upgrade modules. In that case, a combination of long-life durable products and life extension "modules," such as EV battery module refurbishment or upgrades or WG self-dosing/cleaning and energy metering modules can deliver value to suit the needs of different customer segments, but even channel partners (in forward and reverse flow).

Across the center vertical axis of the "X", we find the current state of CE strategies dominating our bibliometric research co-occurrence analysis and industry cases. These are focused on the narrowing of resources (energy, consumables, and materials), waste management, and recycling, which are a good complement and increasingly driven by policy and regulations, but not sufficient by themselves. These apply to both WG and EVs. Effectively closing the loop of materials will depend on the predictability and control of the forward supply chain in receiving quality supplies. These supplies may come from recycled, remanufactured, or reusable content of used products, but this in turn will also require designer choices on material and design for disassembly, in line with recycling process capabilities, overall life cycle energy cost, availability and cost of virgin material, and a feasible, two-way supply chain infrastructure. These challenges capture the challenges and obstacles identified by Korhonen et al., (2018) and Rizos et al., (2016). These highly depend on which policies and regulations apply, which is therefor place between costs and revenue in the bottom value capture theme of the framework. Policy certainty and global sustainable development rules can incentivize further circular business model innovation and design of electric vehicles and white goods, which for now may not be economically viable or limited by stakeholder conflicts of interest or linear business "lock in".

The current state analysis and the resulting integrated frameworks and recommendations we presented answer research questions 1 and 2, we believe. It should be noted that firstly, as the keyword co-occurrence analysis and literature review confirmed, CE and CBM are still a limited priority topic in the academic debate and product design for these product categories. And secondly, consistent with the literature (Camacho et al., 2018; Cherry and Pidgeon, 2018; Haines-Gadd et al., 2018; Korhonen et al., 2018), we assert culture, consumer behavior in general and acceptance in particular at present may play a greater role than product design to determine the suitability and boundaries of discussed CBMs, par-

Table 4
SWOT Analysis of the Two Product Categories in Relation to Design for Circular Economy.

Design for CE	Electric Vehicles	White Goods	Common
Strengths	Modularity of EVs enabling upgrading and life extension	Mature technology, long life, and predictable wear	
Weaknesses	Battery range/weight Technology change rate Infrastructure-related design	Low-end, design for cost leadership path dependency	Path dependency and cultural focus on stand-alone product level efficiencies rather than system net sustainability impact
Opportunities	Charging, power storage, and supply system change by design	Consumables and energy management optimization	Modularity-enabled remanufacturing and product life extension Material cost saving from circular supply
Threats	Rare-earth elements availability, End-of-life processing cost and waste	Consumer perception of hygiene issue, inhibiting reuse and recycled materials or parts use.	IoT/connectivity content, increased complexity of e-waste and end-of-life treatment, and longevity

ticularly PSSs. This does not contradict there is great untapped potential for product design to realize CBMs but the value proposition and value delivery to customers and by stakeholders along the value chain deserve to be centric in product design, rather than the economic and environmental value captured (or lost) and related challenges stated as limits and obstacles for the operationalization of CE.

4.2. Strengths, weaknesses, opportunities, and threats for electric vehicles and white goods

Significant uncertainties remain on how to best shift to a circular economy. Experimentation in markets and product categories where circular economy and sustainable development are maturing will be needed to validate our recommendations. In order to answer RQ 3, we conclude with a more speculative analysis of strengths and weaknesses, opportunities, and threats (SWOT). A SWOT analysis was conducted both from a product-service system CBM perspective (Table 3) and Design for CE strategy perspective (Table 4). The columns exemplify some key clues of interest specific of common for two chosen product categories EVs and WG. These examples are based on the accumulated understanding from the literature review and authors own industrial experience.

The integrated framework for design and business model innovation, elaboration on its application for EVs and WGs using the Design for X framework and SWOT example is intended as a useful and easy-to-replicate starting point for companies and researchers to reflect upon a more specific set of opportunities and challenges. For this purpose, the Supplementary Material Information provides a blank template (Fig. 9). This template does not presume a product category but leaves space to evaluate two definitions of value creation side by side or combination of interacting value creations, as well as allowing the choice of any combination of circular value delivery types. The choice, amount, and consistency of value delivery types (green boxes) is intended to provide a clear classification and guide selection of appropriate sustainability metrics. The value delivery space is layered, encouraging the user to assess multiple customer segments independently. Other spaces may also benefit from exploring as design alternatives and scenarios, but this remains to be further studied in future research.

5. Conclusions

Despite much research on CE and CBM alone, the connection between these topics with new innovative product design of EVs or WG is very limited. Following a review of the literature, we identified the gaps and trends in research and accentuated the importance of developing business models considering cultural and behavioral aspects of value delivery within a CE logic. Our review showed that thermodynamic and system boundaries may limit EV and WG (as well as other) companies from recovering and looping materials without losses, but strategies focused on design and circular business models have been recommended. Furthermore, we found evidence that researchers struggle to provide more detailed recommendations on the operationalization of these strategies and circular business models. Identified key characteristics linking EVs and WGs with circular economy, and innovation frameworks clarify how product design and business models trade-offs relate to a company's value purpose (reason for being) and value proposition (versus competitors in a market). Obstacles to create, deliver, and capture CE value will differ due to the product or industry sector-specific challenges or “lock-in”, product maturity and complexity, global and local value chain structure, applicable policies, and regulations. Product design characteristics and strategies brought together in this review aim to guide EV and or WG companies toward a more holistic CE strategy evaluation. We conclude the integrated- and Design for X framework suits not only the selected product categories (WG and EV) but most likely also other products with similar characteristics as well as combined value propositions linking EVs and appliances in design and business models (vehicle-to-home systems). Observations and reflections from the provided SWOT analysis or other product case self-assessment can provide a valuable input to experiment with the use of the integrated framework and Design for X framework. Only through repeated practice in using such models, assessing their case-by-case implications, experiments, and observation of outcomes can we accelerate our understanding of the role of design and validate circular business models as suitable or unsuitable given a set of product design characteristics. Finally, authors would like to conclude that the concept of circular economy is still growing such that recurring literature reviews and benchmarking product categories on CE topic should be captured reusing a consistent literature review method(s) such as presented in this review, to gain understanding of trends, design for CE or CBM principles and best-practices.

Declaration of Competing Interest

The authors declare that there is no conflict of interest.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.spc.2021.03.030.

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