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Published in:
Proceedings of the Design Society

Link to article, DOI:
10.1017/pds.2022.121

Publication date:
2022

Document Version
Publisher's PDF, also known as Version of record

INTERNATIONAL DESIGN CONFERENCE – DESIGN 2022
https://doi.org/10.1017/pds.2022.121

To What Extent Is Circular Product Design Supporting Carbon Reduction Strategies? An Analysis of Nordic Manufacturing Firms within the Science-Based Targets Initiative

T. Zomer ✉, T. C. McAloone and D. C. A. Pigosso

Technical University of Denmark, Denmark

✉ tttade@mek.dtu.dk

Abstract

Corporate climate action is critical in supporting the transition towards a low-carbon economy. This paper explores what design practices have been adopted by manufacturing companies that have committed to science-based emission reduction targets and are making progress towards those targets. We contribute to the existing literature by providing empirical evidence of circular economy (CE) actions related to product design supporting firms in reaching their emission reduction targets, contributing to the calls for more research showing evidence between CE adoption and emissions reduction.

Keywords: circular economy, sustainable design, greenhouse gas management, carbon reduction, sustainability

1. Introduction

At the twenty-six session of the Conference of Parties (COP26), approximately 200 countries pledged to pursue efforts to limit the global temperature increase to 1.5°C. To achieve this ambition, the global community must take bold actions: systemic and widespread change is necessary from all actors (Farsan et al., 2018). In addition to the countries' nationally determined contributions (NDCs), which represent the commitments of each country to reduce greenhouse gas emissions and adapt to climate change, a range of actors, including manufacturing companies, are laying out climate mitigation plans.

Corporate climate action is critical for driving the transition towards a low-carbon economy (Krabbe et al., 2015). Corporate climate engagement has enormous potential to reduce global emissions and could result in a "virtuous circle" by spurring further corporate and governmental climate action (Fink, 2018). Companies are urged to reduce their greenhouse gas (GHG) emissions as much and as quickly as possible, across their entire value chain (Farsan et al., 2018). The Science Based Targets Initiative (SBTi) started to call for corporate climate action and is supporting companies in setting greenhouse gas emissions reduction targets aligned with what climate science shows is required to prevent catastrophic climate change (SBTi, 2021). Over 1,000 companies have already joined the SBTi so far, and as of October 2020, around 40% of companies with targets approved by the SBTi had aligned them with 1.5°C (SBTi, 2021). The level of influence and control each company has over its emissions is classified in scopes (SBTi, 2021): i) scope 1 (direct emissions from controlled sources), ii) scope 2 (indirect emissions from purchase of energy and heat), and iii) scope 3 (indirect emissions that occur in the value chain).

Guidance on emission reduction levers at the corporate level has been proposed to support organisations in greenhouse gas management and targets' achievement considering the three scopes

(Farsan et al., 2018). Emission reduction levers are diverse and are related to business model innovation (Pieroni et al., 2021), supplier engagement, procurement policy and choices, customer engagement, product and service design (Pigosso et al., 2014), operational policies and investment strategy (Farsan et al., 2018). Among these levers, product and service design significantly impact emissions across the entire value chain, both upstream and downstream (Farsan et al., 2018). The design process plays, therefore, a crucial role in defining the range of GHG intensity reductions achieved through other reduction measures (Farsan et al., 2018). Greenhouse gas emissions can be reduced by making material flows more efficient and maintaining the utility and value of materials and products for as long as possible (European Environment Agency, 2020), with most of the decisions that will have this effect made during product design (Pigosso and McAloone, 2017). Firms can reduce emissions by designing more efficient products so that lifecycle intensity is lower and by integrating circular economy (CE) principles into product and service design (Rodrigues et al., 2017; Farsan et al., 2018). A circular economy is one that is restorative by design, and which aims to keep products, components and materials at their highest utility and value, at all times (Webster, 2017). CE actions related to product design have been widely acknowledged as essential to tackling climate issues in all sectors (Le Den et al., 2020).

Despite this recognition from a theoretical perspective, evidence demonstrating that, in practice, firms that are setting science-based targets are adopting CE actions related to product design and which design strategies those firms are employing has not been found in the academic literature. Thus, empirical evidence of how and which product design strategies are effectively supporting emissions reduction at the corporate level is still scarce. There have been studies linking CE strategies and carbon footprint at a city level (Christis et al., 2019) and a range of studies looking at CE adoption in resource-intensive industries and the impact on emissions reduction at a higher level (Ellen Macarthur Foundation, 2021). However, studies linking CE product design actions and showing their contribution to GHG emission reduction at the corporate level have not been identified in the literature. According to the European Commission (2020), the synergies between circularity and the reduction of greenhouse gas emissions need to be stepped up. Therefore, it is relevant to explore which CE actions are effectively supporting GHG emission reduction. Scholars have also called for more research moving from assumptions that CE strategies lead to carbon mitigation to proof that CE strategies are related to carbon emission reductions and quantification of this potential (Cantzler et al., 2020). Thus, this paper explores what design practices have been adopted by manufacturing companies that have committed to science-based emission reduction targets and are making progress towards those targets. More specifically, this paper aims to explore the following questions: *To what extend are manufacturing companies adopting CE product design levers to reach greenhouse gas emissions reduction targets? Which strategies have been used, and where do opportunities remain?* Industry currently accounts for approximately 40% of global emissions, and demand is expected to increase two to four-fold by 2100 (Farsan et al., 2018). Therefore, this study focused on the manufacturing sector, as the manufacturing industry has an enormous contribution to make in tackling the threat.

The remainder of this paper is structured as follows. Section 2 provides an overview of existing literature that provides the theoretical foundation for analysing design strategies adopted by manufacturing companies committed to science-based targets. Then, the research methodology for company selection, data collection and data analysis are presented. The findings on the identified design strategies that have been adopted by firms committed to science-based targets are then presented in Section 4, followed by a discussion of main contributions and remaining opportunities.

2. Circular economy, product design and climate mitigation

In this section, the theoretical foundation is presented in two sub-sections: circular economy and climate change (Section 2.1) and circular product design and emission reduction (Section 2.2).

2.1. Circular economy and climate change

Climate change is a global concern. Keeping climate change below the critical 1.5°C threshold implies a reduction of GHG emissions as well as a migration to a zero-emissions economy by 2050

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(Durán-Romero et al., 2020). The current response to the global climate crisis represents an incomplete picture - the situation requires changes beyond current actions and a transition from the traditional model of production and consumption to a more sustainable one (Ellen MacArthur Foundation, 2021). Current efforts to tackle the climate crisis have focused on a transition to renewable energy or focus on energy efficiency. Although this approach is consistent with a circular economy, these measures can only address 55% of emissions (Ellen MacArthur Foundation, 2021). This shows that CE is indispensable in reducing such emissions by transforming how goods are designed, produced, used and disposed (Ellen MacArthur Foundation, 2021). The CE is at the core of the European Union's strategy for a climate-neutral economy by 2050 (Le Den et al., 2020).

A range of studies has highlighted that the transition to CE can contribute to climate mitigation. There have been studies looking at, for example, circularity metrics and sustainability requirements fulfilled by those metrics (Kravchenko et al., 2020), including GHG emissions (Corona et al., 2019). Other studies have focused on linking the CE with climate change mitigation in specific contexts, such as the built environment (Gallego-Schmid et al., 2020). Existing studies tend to focus on a specific industry and discuss overall recycling, reuse, or material substitution as strategies for climate mitigation. Also, there have been studies adopting other levels of analysis, such as cities or regions (Prendeville et al., 2018). From a micro-level and organisational perspective, Le Den et al. (2020) identified a range of CE-related actions contributing to decarbonisation. Those are related to product design, production process, consumption models and waste management (Le Den et al., 2020). However, as pointed out by Cantzler et al. (2020), most studies so far assume emission savings related to the adoption of CE strategies but do not include proof of the reduction potential. Empirically exploring CE product design strategies adopted by manufacturing companies that are making progress towards reaching emission reduction targets thus provides evidence of CE strategies effectively leading to emission reduction at the organisational level, contributing to existing literature and calls for research on the effective links between CE and climate mitigation (Cantzler et al., 2020).

2.2. Circular product design and emissions reduction

Sustainable product design strategies that respond to climate change have been addressed in the literature for a while (De Los Rios and Charnley, 2017). Usually, design strategies for climate change are found under umbrella terms such as eco-design, design for the environment and sustainable design (Pigosso et al., 2014). Among the tools suggested for quantifying emissions along the product lifecycle, the lifecycle assessment (LCA) is also typically proposed, and sustainability leading indicators are also increasingly used for evaluating the sustainability performance at the early design stages (Kravchenko et al., 2020).

De Los Rios and Charnley (2017) conducted a literature review on existing design strategies for climate change and classified existing design approaches into three main groups: i) whole systems design, ii) design for environment, and iii) design for lifecycle. The whole systems design approach has as its focus radical innovation for sustainability. The design for the environment approach is more preventive and focuses on energy conservation (clean energy consumption) and material conservation (material selection for sustainability). The design for lifecycle approach considers design for extended life (longer lifecycles) and design for end-of-life (multiple lifecycles cradle-to-cradle). From a lifecycle perspective, Bocken et al. (2016) also proposed CE product design strategies. Those consist of design strategies for slowing resources loops and design strategies for closing resource loops (Bocken et al., 2016). The design strategies for slowing resources loops involve designing long-life products and designing for a product-life extension. The design strategies for closing resource loops involve design for a technological cycle, design for a biological cycle, design for disassembly and reassembly (Bocken et al., 2016). Moreno et al. (2016) proposed a taxonomy of design approaches related to circular design strategies, and the authors point out that DfX approaches and systems thinking need to be integrated to change the role of design within the circular economy. Den Hollander et al. (2017) pointed out that circular design is distinct from eco-design following the linear economy of take-make-dispose and proposed a typology of design approaches for circular product design. According to Den Hollander et al. (2017), circular product design encompasses both design for product integrity (aimed at preventing and reversing obsolescence at a product and component level)

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and design for recycling (aimed at preventing and reversing obsolescence at a material level). The design for product integrity involves long use, extended use, and recovery (Den Hollander et al., 2017). For the manufacturing context specifically, Blomsma et al. (2019) proposed a framework with a taxonomy of circular strategies for manufacturing companies engaged in circular oriented innovation (Figure 1). The framework enables mapping the strategies currently applied (including related to product design), and identifying new opportunities. The proposed strategies for the manufacturing context involve i) changing the paradigm of practices, which can be enabled by new technologies (which in the framework is named as 'reinvent'); ii) new business models that are more resource-efficient (named 'rethink'); iii) efficient use of resources and the reduction of harmful impacts (named 'restore, reduce and avoid'); and end-of-use and end-of-life strategies, which involves iv) recirculate parts and products and v) recirculate materials. The framework also contains an 'energy' layer, meaning that all circular strategies should be considered with the intent to reduce overall energy consumption, and the use of clean(er) and renewable sources wherever possible, and a 'logistics layer' that encompasses all the operational process areas. Apart from these theoretical studies proposing circular design strategies and methods, there have been some studies looking at applications of circular design for specific cases, such as electric and electronic equipment (Bressanelli et al., 2021).

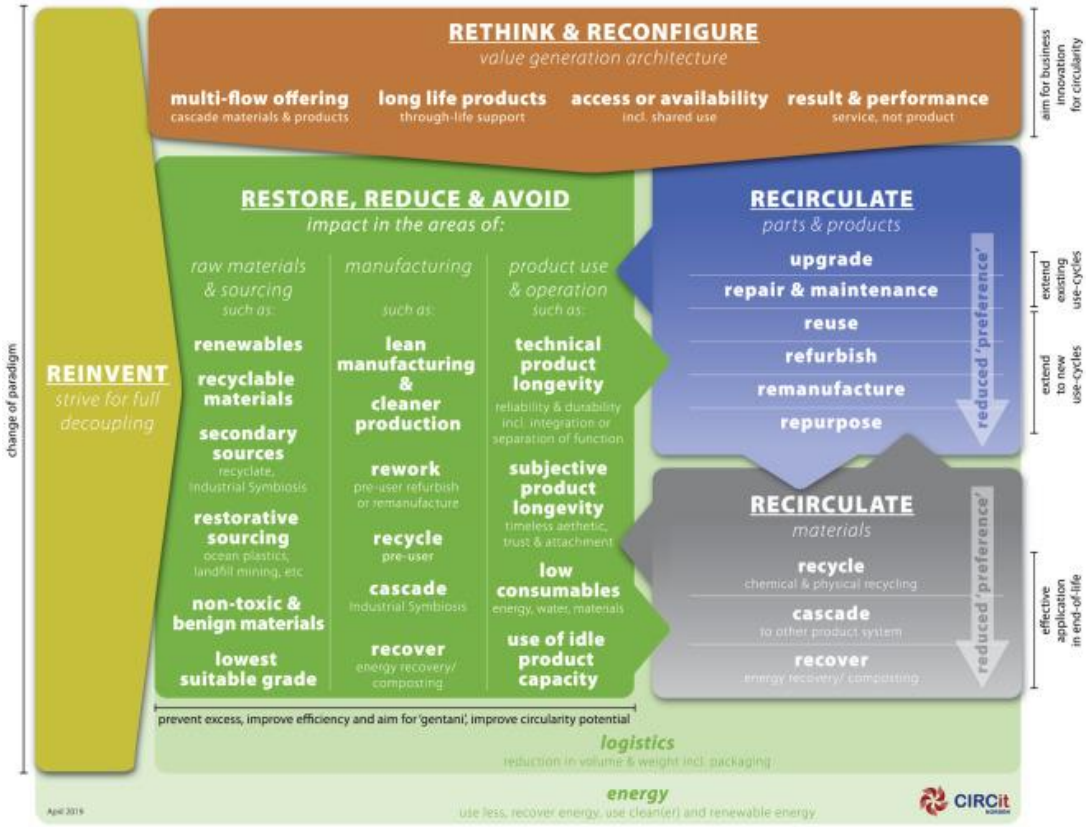

Figure 1. Circular strategies scanner for manufacturing firms. Source: Blomsma et al. (2019).

Regarding the link between circular product design and GHG emission reduction, Le Den et al. (2020) proposed a list of CE actions related to product design that contribute to decarbonisation. The proposed actions are the design for the use of less material in a product, the design of products to extend their lifetime, the design for adaptability and flexibility of products to changing markets, use layering principles to ensure entire products or product-service lives are utilised of the different components/layers, design products with reused parts, design products with recycled material, design for product/packaging reuse, repair, refurbishment, remanufacture, disassembly and (as a last resort) recycling, design to substitute abiotic (fossil/mineral) with bio-based materials, and design products to enable local material-sourcing and manufacturing (e.g. near-sourcing). However, despite the theoretical assumptions that circular product design leads to emission reductions (Farsan et al., 2018),

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empirical studies demonstrating that the design of circular products is actually leading companies to achieve their emission reduction targets were not found in current literature. Nevertheless, such studies are relevant to provide evidence of the links between CE and climate mitigation. The circular product design strategies and methods adopted by manufacturing firms committed to science-based targets and are making progress towards such targets are investigated in this study, aiming to build empirical evidence of such links.

3. Methods

A case-based approach was adopted to explore how manufacturing companies that have committed to science-based targets are innovating in their product and service design strategies to meet the established targets.

A search for companies that have disclosed climate-related data publicly was performed to identify manufacturing companies that have set up science-based targets for GHG reduction in the last four years and that are making progress towards the defined targets. Information was collected for manufacturing companies that submitted climate change reports on the Carbon Disclosure Project (CDP) website for the current year (2021). CDP is a not-for-profit charity that runs the global disclosure system for investors, companies, cities, states, and regions to manage their environmental impacts (CDP, 2021). Data on corporate climate change submitted by companies in form of reports is publicly available for registered users. Previous studies looking at carbon management practices at the corporate level have also performed analyses based on CDP data (e.g. Li et al., 2018).

The defined focus was on European companies, as in June 2021, the European Union (EU) adopted a European Climate Law, establishing the aim of reaching net-zero greenhouse gas emissions in the EU by 2050 (European Commission, 2020). European firms have then started defining science-based targets. They are adopting a range of emission reduction levers, including those related to the design of products, representing a relevant population to identify design practices adopted for greenhouse gas emission reduction purposes. More specifically, the focus was on companies in the Nordic region - the Nordic countries have a shared vision of becoming the most sustainable and integrated region by 2030 and recently signed a declaration on carbon neutrality (Nordic Co-operation, 2019). Thus, manufacturing companies in the Nordic region were selected as they are implementing a range of levers to achieve the targets of carbon neutrality and could provide evidence of effective design-related levers.

The selected sample consisted of 112 manufacturing firms in the Nordic region, from different sectors and sizes - Denmark (20 companies), Finland (30 companies), Norway (21 companies) and Sweden (41 companies). Those firms were identified by searching for keywords (e.g. "manufactur*, product*) in their business' descriptions. Sixteen companies were afterwards eliminated from the sample, as although the searched keywords were included in the description of their activities, they were not manufacturing firms. This process resulted in 96 manufacturing firms in the final sample.

The data analysis consisted of a content analysis regarding the description of companies' business strategy and how climate-related risks and opportunities have influenced their products and services (section C.3.3 on how climate-related risks and opportunities have influenced their strategy) (CDP, 2021). The data reported by the companies for which climate-related risks have impacted their product and service strategies were analysed aiming to identify what circular product design strategies those companies are implementing and have been effective in supporting them in reaching the targets. The circular strategies scanner framework proposed by Blomsma et al. (2019) (Figure 1) was adopted to classify the strategies. The framework was selected because it allows the mapping of current strategies, it builds on previous classifications of CE product design strategies (e.g. Bocken et al., 2016) and it is focused on the manufacturing sector. Thus, the descriptions of how climate-related risks have influenced and changed companies' product strategies were analysed in the light of the Blomsma et al.'s (2019) framework and the strategies firms are adopting and that are helping them to achieve their emission reduction targets were classified as strategies focused on i) restore, reduce and avoid impacts, ii) recirculation of parts and products, iii) recirculation of materials, iv) rethink and reconfigure value delivery and v) reinvent

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(functional replacement or new practices which can be enabled by new technologies) (Blomsma et al., 2019), as described in the following section.

4. Results

Climate-related risks and opportunities have influenced manufacturing companies' strategies in multiple ways, including the product and service-related strategies for most firms (93 firms in the sample) that have committed to science-based targets and have submitted climate change reports in 2021. Few of them (three) has not provided a description on how their product strategies have changed or stated that climate change has not influenced the product strategy yet - e.g. a pharmaceutical company in Denmark has stated that pharmaceutical products must follow strict medical regulation and neither their products nor the packaging materials are allowed by existing regulation to change due to climate risks or opportunities. Regarding the remaining companies in the sample, around 35% did not describe precisely how climate risks have changed their product strategy or provided details of which design strategies/methods they are adopting. Twenty-five companies mentioned changing their product design in response to climate risks but provided only a high-level description.

Some companies (25%) also highlighted some of the reasons why they have been innovating their product strategies. Among the reasons, companies pointed out that they have been innovating their products because customers are setting requirements regarding phase-out of hazardous substances; customers are asking for the CO2 footprint of products; customers are putting higher demands on reduced energy consumption and CO2 emissions during the use phase, and the use of renewable and recycled materials; and the need to adapt to new legislation. Companies see the innovation of their products as an opportunity to remain competitive - one organisation mentioned that future carbon taxes will increase customers' focus on energy-saving products and more energy-efficient solutions to reduce their carbon emissions, and by innovating their products, they become competitive suppliers.

Few companies (12 organisations) explicitly mentioned that they are innovating their products to be adapted for a circular economy or that their products have been designed to be ‘fit for purpose’ according to new circular business models that they might be adopting (e.g. Ambu, H&M, Novo Nordisk). Actually, the analysis of the current strategies adopted by manufacturing firms following the circular strategies scanner revealed that companies are mainly focusing on designing efficient products and restoring, reduce and avoiding impact in the areas of raw materials and sourcing, manufacturing and product use and operation instead looking at the whole life cycle and considering, for example, design for slowing and closing resources loops. Around 60% of the companies are focusing on restoring, reduce and avoiding impacts related to the operational phase, 10% are focusing on the recirculation of parts and materials (extending existing use cycles or extending to new use cycles), and 30% are focusing on the recirculation of materials or the end-of-life of materials to capture (residual) value or reducing value loss from continued use of materials. Figure 2 provides an overview of the distribution of strategies adopted by the companies. Additionally, 10% of the companies are applying the previously mentioned strategies focusing on product packaging only, instead of their products.

Regarding the reduce, restore and avoid strategy, most manufacturing firms (60%) have focused on improving efficiency in product use through low consumables of energy and resources, improving energy efficiency and using cleaner sources of energy. Examples include firms establishing energy consumption targets during the use phase of their products to be at least 25% lower than current regulation. Product design focused on use phase efficiency is critical in some sectors, such as vehicle manufacturers. Vehicle manufacturers have a crucial role in enabling a transition to low-carbon transport, as most of the emissions happen during the use phase and are generated from fossil fuel combustion or, in the case of electric cars, from electricity generation. This focus for the majority of the firms may also be related to meeting current legislation - there are EU directives regarding energy-using products and energy efficiency (e.g. "EN 50598-3 Eco-design for power drive systems, motor starters, power electronics & their driven applications - Part 3: Quantitative eco-design approach through life cycle assessment including product category rules and the content of environmental declarations), and organisations might be focusing on strategies that address such directives, given that they perceive such directives as driving customers to focus on energy-saving products and more energy-efficient solutions, and thereby increase the demand for their products and

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solutions and create new market opportunities. The focus on efficiency during product use due to existing legislation was, actually, mentioned in the reports (e.g. Danfoss). Still, regarding the restore, reduce and avoid impact strategy during the product use phase, 12% of the companies reported focusing on enabling product longevity through design for durability and high robustness. Extending the utilisation period of products reduce the use of new resources and consequently the emissions related to them, i.e., the emissions from the embodied energy of materials used to create new products and the processing of those materials. To develop long-life products, firms have reported that engaging more with customers is essential to understand how products are used, so the design can be optimised to allow for a longer lifetime given use patterns.

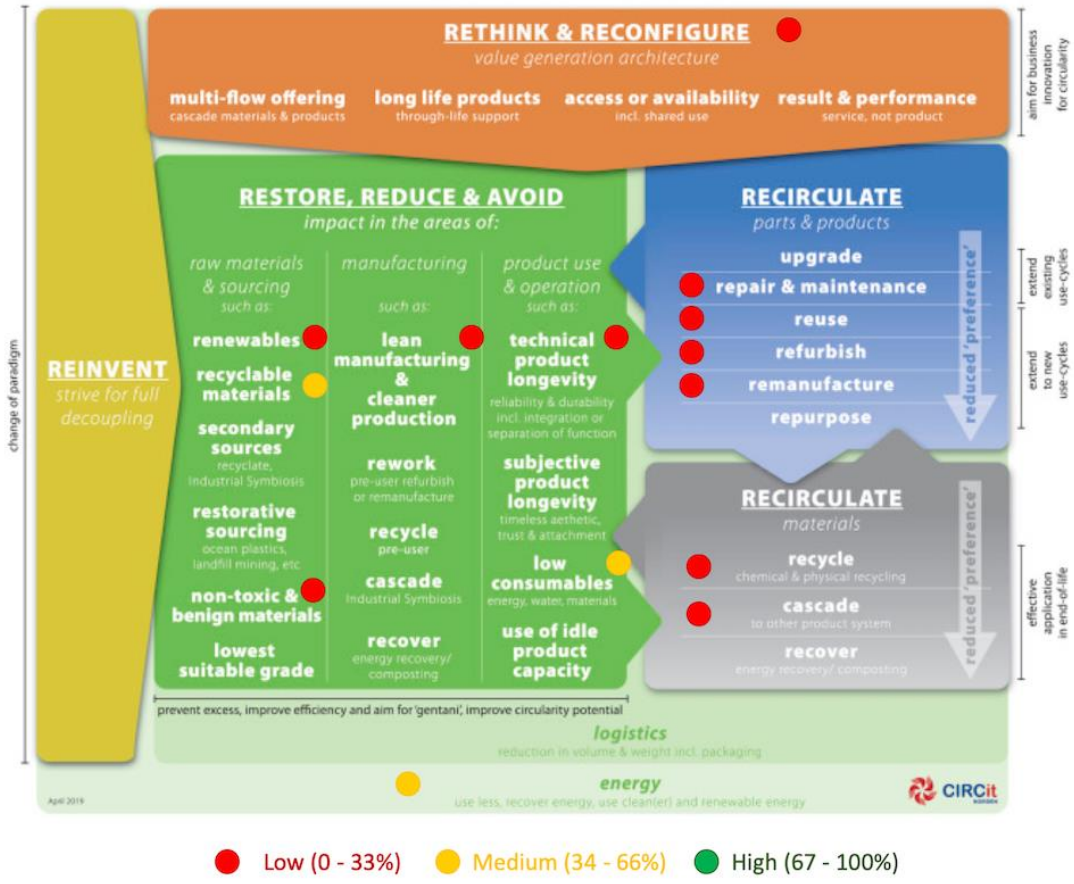

Figure 2. Strategies adopted across the sample, according to the CE strategies scanner (adapted from Blomsma et al., 2019).

Other areas of application proposed in the framework to restore, reduce and avoid impact during product use and operation (i.e., through increased subjective product longevity and/or use of idle product capacity) were not identified. No mentions to designing products to increase customers' attachment and trust, for example, were found in the descriptions of climate influence on product strategies, although it could be an effective design strategy to extend the life use of products. Regarding restoring, reducing and avoiding impact in manufacturing or improving process efficiency during product manufacturing, only 5% of the companies reported focusing on consuming fewer natural resources or energy (e.g. Swedish Match). No mentions were found related to finding uses for manufacturing waste or energy recovery or recovery of biological nutrients, for example. Finally, a huge focus has also been placed on reducing and avoiding impact regarding sourcing and raw materials. 60% of the companies reported being focusing on improving efficiency in the sourcing process. Around 15% are investing in sourcing renewables and bio-based materials, 40% reported

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focusing on recyclable materials, and 25% are using non-toxic or benign materials (to facilitate re-absorption in natural cycles). Companies reported focusing, for example, on materials that could transform the product from a CO2 source to a CO2 sink and introducing low carbon/carbon neutral materials (e.g. LEGO). These strategies seek to achieve the same outcomes with the use of fewer resources or less-intensive resources. Other areas of application proposed on the framework, such as reserving the highest-quality resources for the most demanding tasks and using used resources further down the chain, were not identified.

Regarding extending existing use cycles to capture residual value or reduce value loss from continued use of parts and products (recirculation of parts and products), only 10% of the companies reported engaging in designing products for repair and maintenance refurbish and remanufacture. A higher proportion focuses on capturing residual value or reducing value loss from continued use of materials by either extending materials lifespan through processing them to obtain comparable quality (15% of the firms) or cascading to a subsequent use (8% of the firms). One firm mentioned started exploring upcycling, which is concerned with improving the properties of materials (e.g. Amer Sports). To support recycling, they have mentioned focusing on ensuring that products and parts can be separated and adopting design for disassembly.

The use of multiple strategies simultaneously (i.e. restore, reduce and avoid, recirculate parts and products and recirculate materials) was identified only for 20% of the companies. The most used strategies are restoring, reducing and avoiding impact in the areas of raw materials and sourcing and product use while organisations focus on recycling. Firms scarcely reported focusing on slowing resource loops and closing resource loops simultaneously (i.e. evidence was found for less than 10%), indicating that opportunities remain in improving their product design strategies to support their emission reduction targets by adopting an entire lifecycle perspective. Moreover, a small number of companies (around 10%) explicitly mentioned innovating their products and adding services to their offerings to enable circular business models. This might be because they might have reported innovations related to business models in another section of the report not covered in the analysis, but it might also be an indication that few companies are adopting circular business models

5. Conclusion

Corporate climate action is critical in supporting the transition towards a low-carbon economy. Among the strategies that have been identified as critical for firms to reduce their GHG emissions in alignment with science-based targets is the design of their products and services. Although this is acknowledged theoretically, there is still a lack of empirical evidence looking at how firms innovate their product and service strategies to cope with climate risks and which design levers support firms to achieve their GHG emission reduction targets. This paper explored how firms are changing their product and service strategies in response to climate risks and which design strategies/approaches have supported achieving the targets. The analysis of a sample of manufacturing firms committed to and making progress towards targets for emission reduction showed that firms had adopted some CE product design levers. However, the focus has been mostly on improving efficiency in the sourcing process and during product use, with less focus on the entire lifecycle. While most of the strategies proposed in the circular strategies scanner (Blomsma et al., 2019) were mentioned in the analysed reports, none of them have been extensively applied across manufacturing firms. There are, furthermore, remaining opportunities to cut emissions related to use of new resources by extending existing use cycles through recirculation of products and parts, and manufacturing firms can still take advantage of this strategy. Combining multiple strategies is another opportunity has not been widely adopted and companies can take advantage of GHG emission reduction enabled by the combination of multiple strategies.

Providing evidence of which design strategies have been used and are supporting companies to achieve the defined emission reduction targets contributes to literature and practice. First, understanding which practices have been adopted by other manufacturing firms is relevant to designers and strategic decision-makers in businesses that plan to set up carbon emission reduction targets in the future. Second, from an academic perspective, this study shows evidence of CE actions related to product design supporting firms in reaching their emission reduction targets, contributing to

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the calls for more research showing evidence between CE adoption and emissions reduction (Cantzler et al., 2020). Scholars have called for more studies moving from theoretical assumptions that CE initiatives lead to climate mitigation to showing those relationships more explicitly. This paper contributes to the gap by showing empirical evidence that firms making progress towards established targets adopt circular product strategies, which strategies have been adopted and where the opportunities remain.

The analysis is limited to manufacturing companies in the Nordic region. Moreover, just one section of the climate change reports submitted by those firms in one year (2021) was analysed; it is possible that descriptions of how CE strategies are supporting them in managing climate risks have been provided in other sections of the reports, not covered in the analysis. A further study will look at manufacturing firms across Europe and perform in-depth analysis of the entire reports to streghten the preliminary findings across entire European manufacturing industry, including potential differences among regions/countries. Further research will also conduct a longitudinal analysis to identify changes over the years and how those changes have influenced the progress towards emission reduction targets. Moreover, future research will focus on exploring approaches to quantify the contributions of each CE strategy for emissions reduction. Understanding the contribution of each CE strategy for GHG emission reduction is useful for companies to understand better which strategies can be used and how to combine them in order to make progress towards their targets.

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