Master's Thesis – Sustainable Business and Innovation

The environmental rebound effect within the circular economy. A systematic literature review

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Abstract

Introduction: The economic and environmental potential benefits of the circular economy and its corresponding business models are frequently proclaimed, however limited empirical evidence exists on the actual benefits it has for the environment and a critical note in the valuation of these models is still lacking. When negative effects, like rebound effects, are not considered, it would be hard to say how these models differ from traditional linear business, since the environmental benefits are considered the main goal of the circular economy. To open up a debate surrounding this topic, a literature review is conducted to get a more realistic understanding of the potential of the circular economy. This literature review is the first attempt ever to map and combine the existing knowledge and findings on rebound effects in the circular economy. **Theory:** In order to identify which literature is relevant to include in the review, a firm understanding of both topics is needed. Pre-existing theories on the rebound effect originate from the energy efficiency literature, in which there is a strong parallel. Whereas the circular economy is explained on the basis of the circular business models introduced by Bocken et al. (2016). **Methods:** Related search terms to both concepts, including the 3R strategies, are used to search for academic literature in Scopus. After discarding all non-relevant articles, 36 studies remained. These studies are examined on several indicators such as; rebound type, CBM studied, used methodologies, sectors and identified research gaps, which were organized into an Excel spreadsheet. After, a frequency analysis was conducted to categorize findings. **Results:** Rebound effects are studied most in relation to the ‘access and performance’ and ‘encourage sufficiency’ business models because of their relatively large use-phase. 10 different rebound types were identified from which the direct rebound effect is the simplest to quantify with precision. Overall, quantitative studies find rebound effects related to the re-spending of saved income or gained revenue, while qualitative studies find effects related to inadequate consumer behavior. A typology framework places all identified effects according to which actors are involved and what are the driving mechanisms. **Discussion/Conclusion:** A precise understanding of the magnitude of different types of rebound effects is missing due to a lack of empirical evidence and comparability. The scope, region, time period of analysis, product studied and assumptions all differ widely from study to study which makes drawing conclusions impossible. Further research is needed to provide a common methodology on how to measure and interpret these effects. Only then, policymakers can use real comparable data to minimize the rebound effect.

Table of content

1. Introduction 4

2. Theoretical background 7
2.1 Circular Economy 7
2.2 Circular Business Models 8
2.2.1 Access and performance model 10
2.2.2 Extending product value 10
2.2.3 Classic long-life model 10
2.2.4 Encourage sufficiency 10
2.2.5 Extending resource value 11
2.2.6 Industrial symbiosis 11
2.3 Environmental rebound effects 11

3. Methodology 14
3.1 Search and inclusion of studies 14
3.2 Quality assessment and data extraction 15
3.3 Data analysis and expected results 16

4. Results 18
4.1 Descriptive overview 18
4.1.1 Year of publication 18
4.1.2 Sectors 18
4.2 The rebound effect and methodology 20
4.3 The rebound effect and circular business models 21
4.3.1 Access and performance model 22
4.3.2 Encourage sufficiency 25
4.3.3 Extending product and resource value 26
4.4 Research gaps 27
4.5 Typology framework 29

5. Discussion 35

6. Conclusion 37

7. Reference list 40

8. Acknowledgements 46

1. Introduction

The current economy is based on the 'take-make-dispose' principle, which assumes that raw materials are collected, transformed into products and after use eventually discarded as waste. Producing and selling as many products as possible is the ultimate goal of this economic system, and the way how most economic value is created. This principle is fed by a constant expansion of human needs which leads to materialism and ultimately to overconsumption. With global economic development continuing in a business-as-usual mode, and an expected population growth of 30-40% until 2050 (Lutz et al., 2004), the global material extraction will be very likely to keep increasing (Krausmann et al., 2009). At the same time, Leonard (2010) argues that 99 percent of products bought are disposed of within six months. This expected growth in material extractions, enormous production processes and unsustainable consumption patterns result in growing waste streams and pollution on land, air and water and increasing greenhouse gas emissions (Rees & Westra, 2012). This so-called linear economy is becoming less and less attractive as human societies in both high- and low-income countries are becoming more aware of its dangerous impacts on the environment and ecosystems (Lacy & Rutqvist, 2015). Not only is there an environmental need for change, also economically there is much to gain when a transition towards more resource efficient production and consumption is made. Since the price volatility of natural resources is increasing due to the diminishing of non-renewable resources, a linear economy in which mostly natural resources are used for production, will be less attractive in the future (EMF, 2013).

Instead, an economy based on circularity could be promising to achieve this needed transition. A circular economy aims to shift from a linear system to a circular one in which waste no longer exists (EMF, 2013). Ideally, growth in a circular economy is decoupled from using finite resources, and relies on increased product duration, renewability, reuse, repair, refurbishment, sharing and dematerialization (Tunn et al., 2019), and therefore the circular economy is increasingly viewed as a key driver for future business competitiveness and sustainability (Bocken et al., 2016). According to many scholars (e.g. Mont, 2002; Tukker, 2004; Lieder and Rashid, 2016) the highest efficiency within the circular economy can be gained by maintaining products in their current form as long as possible. This maximizes both utilization and lifespan which results in less need for new production. Several approaches to encourage extensive use of materials can be used to maximize utilization. Examples are second-hand sales, selling services rather than products and granting temporary access to private goods between peers (Tukker, 2015). Among scholars, there is a strong belief that these new modes of sustainable consumption lead to a reduction of CO2 emissions, natural resource depletion and other problematic environmental impacts (Warmington-Lundstrom & Laurenti, 2020). The circular economy recognizes the human need for economic growth, however, it is decoupled from resource consumption. Consumers do no longer have to be the owner of products themselves, instead they can make use of the provided service by peers or by businesses (Kjaer et al., 2019). It is this change that potentially leads to environmental benefit.

To make the circular economy work, businesses have to incorporate circularity into their business models. These models are designed to operate on micro-level and aim to close product, material and energy loops while maintaining profitability (Bocken et al., 2014). Circular business models have received increasing interest among scholars and practitioners (Bocken et al., 2016). The positive effects of these new modes of sustainable business models are well-documented and widely acclaimed. However, these models also have unintended negative side effects that are often not directly visible and therefore ignored. A well-documented critical note towards the circular economy seems to be lacking. There exists substantial uncertainty on the potential negative impact that these new circular business models have (Bocken et al., 2016; Lieder and Rashid, 2016) but this is often not recognized. Recent research has shown that there is significant potential for environmental rebound effects (Skjelvik et al., 2017; Warmington-Lundstrom & Laurenti, 2020). An environmental rebound effect can be defined as "the difference between the expected and the actual environmental savings from efficiency improvements once a number of economic mechanisms have been considered, that is, the savings that are 'taken back'" (Font Vivanco et al., 2016, p.60). Meanwhile, resource efficiency does not automatically equal resource conservation. According to Frye-Leving (2012), empirical evidence confirms that rebound effects of efficiency gains overpower their original intention which creates counterintuitive effects at larger scales. This means that even if the intention of a business using circular strategies is pro environmentally, and resource efficiencies are considered, the practical benefits could be less than expected, and in some exceptional cases even backfire. Because of the occurrence of these counterintuitive effects, the backfire is little recognized as a driver of resource depletion.

The efficiency improvements mentioned in the latter rebound effect definition can also apply to circular business models in comparison to linear business models. In this case the efficiency improvements can be recognized in the form of extending product or resource value, durability, upgradability, sharing and prolonging lifespan. These environmental (circular) rebound effects would occur when the initial environmental benefits of these circular business models are partly or fully offset, resulting in a reduction or a cancellation of the expected gains. This reduction of expected gains could either be caused by a failure to substitute primary production because of a growing demand that needs larger production, or this new modes of consumption lead to differences in income gained (supplier) or saved (demander) which can be spend on more goods and services that have an impact on the environment as well (Zink and Geyer, 2017). For example, the sales of second hand items creates a new market that generates revenue for the supplier which can be re-invested in the production of other articles. On the other hand, buying second hand items, which is seen as a pro environmental effort, usually saves money and these savings could be spent on other articles.

While there is a growing interest in circular business models and their potential, economically and environmentally, limited empirical evidence exists on the actual environmental benefits or the potential rebound effects these business models entail. When rebound effects are not

considered in the valuation of circular business models, it would actually be hard to say how they differ from traditional business, since the claimed benefits are considered the main goal of the circular economy. Most research on this topic consists of empirical case study evidence, however a systematic review on this topic is still missing. Since knowledge production within the field of the circular economy is accelerating at high speed, it is hard to keep up with the state-of-the art research on this interdisciplinary topic. According to Webster and Watson (2002) conducting an effective review as a research method creates a firm foundation for advancing knowledge and facilitating theory development. It is especially important in this research area that environmental improvements are actually achieved, making a critical review on the different types and size of an environmental rebound effect in the circular economy a necessity.

Accordingly, considering the research gap and scientific and social relevance just explained, the aim of this paper is to conduct a systematic literature review that addresses the following research question:

According to the existing rebound effect literature, to what extent does the circular economy lead to environmental rebound effects?

Generally, the literature states it is difficult to recognize or predict the severity of rebound effects due to several influencing variables (e.g. socioeconomic differences), methodological biases, impacts on the long run and different types of the rebound effect (Maxwell et al., 2011). Therefore, this paper attempts to see if and which circular business models lead to environmental rebound effects by extensively reviewing existing empirical research on this topic. More specifically it will identify several types of environmental rebound effects, and links them to various circular business model strategies, which are defined by Bocken et al. (2016) and shown in section 2.2. Furthermore, it will summarize the sector areas that are studied and commonly used methodologies and outcomes to detect possible methodological biases and provide some clarification. Furthermore, the main research gaps identified in the reviewed studies will provide insights into further research topics. Eventually, this work will lead to a framework to categorize environmental rebound effect types according to which actors are involved and by what mechanisms they are caused.

2. Theoretical background

The literature review brings together the relevant literature on the circular economy and the environmental rebound effect to develop an overview of existing state-of-the-art literature and their outcomes regarding the extent in which a rebound effect is present. Furthermore, this theoretical background section first includes an extensive explanation of what a circular economy entails, the different existing circular business models strategies that exist according to Bocken et al. (2016), and provides some background for the search query used for this literature review. Second, it describes the rebound effect in more detail. The different types of the rebound effect are presented by using examples from the energy efficiency literature, since there is a strong parallel between the rebound effect in the circular economy and in energy efficiency (Zink and Geyer, 2017).

2.1 Circular Economy

The concept of the circular economy has been gaining momentum since its introduction by Boulding (1966), who described the earth as a closed and circular system with limited assimilative capacity. Because of this limited capacity, the economy and the environment should coexist in equilibrium (Geissdoerfer et al., 2017). The concept got recognized by scholars, practitioners, governments and nongovernmental organizations, to appeal for closing material loops, by reusing and recycling materials to maximize value and minimize waste (EMF, 2016; Zink & Geyer, 2017). The circular economy concept is of great interest because it can be viewed as an operationalization to implement the concept of sustainable development (Ghisellini et al., 2016). Indeed, the latter concept has often been called too vague to implement (Kirchherr et al., 2017), or even a theoretical dream (Engelman, 2013). Engelman (2013) argues that nowadays the concept of sustainability could mean literally anything from ‘environmentally better’ to ‘cool’ so there exists a necessity for a concept, in this case the circular economy, that could realize the potential of this vague and theoretical concept of sustainable development.

According to the Ellen MacArthur Foundation, the circular economy is “an industrial economy that is restorative or regenerative by intention and design” (2013, p.14). Within this intentional restorative and regenerative economy, several ‘schools of thought’ exist that focus on different outcomes and implementations. According to Zink and Geyer (2017) some focus on minimizing waste and resource extraction, while others focus on economic growth potential, and others focus on environmental impact reduction. Important contributors to the literature on the circular economy are Geissdoerfer et al. (2017) and Bocken et al. (2016), and they define the circular economy as “a regenerative system in which resource input and waste, emissions, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops”. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling. Similar concepts to the circular economy are ‘industrial ecology’ and ‘cradle-to-cradle’ which also aim at understanding the circulation of materials and energy flows and that regenerate these flows in future processes. Both in industrial ecology and in the circular economy it became increasingly clear that traditional and reactive solutions, such as

“end-of-pipe” solutions, were insufficient to cope with today’s material consumption and production problems (Saavedra et al., 2018).

Various conceptualizations of the circular economy exist in academia. Among those, the R-imperatives distinguish between different strategies to embrace circularity (Henry et al., 2020). These R-imperatives, or R-frameworks vary from 3Rs to 10Rs. While the number of R’s differ throughout literature, most of the lists establish a priority order for approaches to circularity (Henry et al., 2020). However, according to Kirchherr et al. (2017), the 4R-framework (reuse, reduce, recycle and recover) is most commonly used in the circular economy literature. Because this literature review investigates the rebound effect in the circular economy, not all of these R’s are relevant to include in the selection process of relevant literature. Only the R’s that are based on the circulation of material or energy flow are relevant. These include, reuse, reduce and recycle. Recovery (recover) operations are solutions at the “end-of-pipe” and are therefore not subject to the rebound effect. Therefore, the 3R-framework (reuse, reduce and recycle) will be used in the search query in this literature review, along the terms ‘circular economy’, ‘industrial ecology’ and ‘eco-efficiency’ to include most relevant literature.

2.2 Circular Business Models

As described in this research so far, the circular economy remains an abstract concept that needs explanation on strategies and examples on how to operationalize and implement it. It is companies or governments that need to implement certain circular principles and strategies into their ‘business’ model that could potentially lead to environmental benefits. These incorporated circular economy principles are captured in so-called circular business models (CBMs) (Heyes et al., 2018). Kirchherr et al. (2017) define CBMs as circular operations on the micro-level that aim at closing product, material and energy loops and make the concept of ‘end-of-life’ outdated. These ‘closed loops’ have become a trademark of the circular transition. But besides closure, also the utility of material loops can be prolonged or unnecessary material flows can even be prevented by conscious consumer attitude. So these CBMs try to cover all the aspects of the circular economy by aiming to minimize and also keep resources in use for as long as possible by reusing and recycling (Henry et al., 2020). In a CBM the business as usual approach is replaced with business operations that would ideally not lead to maximum production, excessive waste generation and resource depletion. Just as regular business model literature, CBM literature mainly exists around three elements; value proposition, value creation and delivery, and value capture (Bocken et al., 2014). Accordingly, CBMs should create, deliver and capture economic value in order to exist and function while simultaneously contributing to environmental and social sustainability.

A business can use several CBM strategies to either close or slow down the material loop (Bocken et al., 2016). The latter can be a highly effective strategy for reducing the use of resources by extending the utilization period of products or to reuse products. Closing loops are about capturing value from what is considered in a linear business approach, as by-products or

waste. Different frameworks exist to indicate different CBM strategies. These include for instance the R-strategies, explained in section 2.1, which are used by Henry et al. (2020) to make a distinction between CBM strategies. In this research however, the business model strategies introduced by Bocken et al. (2016) are used to distinguish between several strategies. Bocken et al. (2016) came up with a framework to identify different strategies to either slow down the loop or to close it. The six business model strategies for circular businesses, shown below in table 1, are used in this literature review as a coding scheme to identify if and which rebound effects happen within particular CBM strategies. In contrast to the 3R-strategy framework, which only has three variables that can easily coexist within a single business model, the six-variable framework by Bocken et al. (2016) seems more appropriate for a literature review that investigates in which types of business models rebound effects are present. Because of the six variables in this framework, more specific distinctions can be made. Other terms that are commonly used when writing about the CBMs are durability, long-life models, and dematerialization and this is why also these terms are included in the search query for this literature review.

Business Model Strategies	Definition	Examples of cases
Business model strategies for slowing loops		
1 Access and performance model	Providing the capability or services to satisfy user needs without needing to own physical products	• Car sharing • Launderettes • Document Management Systems (e.g. Xerox, Kyocera) • Tuxido hire • Leasing jeans • Leasing phones
2 Extending product value	Exploiting residual value of products – from manufacture, to consumers, and then back to manufacturing – or collection of products between distinct business entities	• Automotive industry – remanufacturing parts • Gazelle offering consumers cash for electronics and selling refurbished electronics (gazelle.com) • Clothing return initiatives (e.g. H&M, M&S' Shwopping)
3 Classic long-life model	Business models focused on delivering long-product life, supported by design for durability and repair for instance	• White goods (e.g. Miele's 20 year functional life span of appliances; [4]) • Luxury products claiming to last beyond a lifetime (e.g. luxury watches such as Rolex or Patek Philippe)
4 Encourage sufficiency	Solutions that actively seek to reduce end-user consumption through principles such as durability, upgradability, service, warrantees and reparability and a non-consumerist approach to marketing and sales (e.g. no sales commissions)	• Premium, high service and quality brands such as Vitsœ and Patagonia [7] • Energy Service Companies (ESCOs)
Business model strategies for closing loops		
5 Extending resource value	Exploiting the residual value of resources: collection and sourcing of otherwise "wasted" materials or resources to turn these into new forms of value	• Interface – collecting and supplying fishing nets as a raw material for carpets • RecycleBank – providing customers with reward points for recycling and other environmentally benign activities (recyclebank.com)
6 Industrial Symbiosis	A process- orientated solution, concerned with using residual outputs from one process as feedstock for another process, which benefits from geographical proximity of businesses	• Kalundborg Eco-Industrial Park (http://www.symbiosis.dk/en)

Table 1. Business model strategies by Bocken et al. (2016).

2.2.1 Access and performance model

According to Bocken et al. (2016) this model is concerned with providing services to satisfy users' needs instead of individuals owning the physical product. The value proposition is focused on delivering a service through access and performance rather than ownership and this could incentivize the producer to increase the products' durability since value is captured by pricing per unit of service (e.g. time, number of uses). Regarding the 'access and performance model' some commonly used examples in practice and increasingly investigated in literature are product-service systems, sharing and exchange platforms. In these examples, products are used, leased, hired or shared without the possibility to own the product. This can either be consumer-to-consumer, or business-to-consumer based. Because these examples of CBMs are commonly known in the circular economy literature, these terms are also used in the search query to include relevant literature in this review.

2.2.2 Extending product value

This model plays a role in extending product lifetimes by reversing product obsolescence. Companies that use this BM capture value from used products by either one or more of the four strategies: recontextualising, repair, refurbishing, and remanufacturing (den Hollander et al., 2017). In this way they contribute to product life extension and by this slowing down resource flows. According to Bocken et al. (2016) the value proposition is focused on manufacturers exploiting residual value of used products and delivering remanufactured and affordable products.

2.2.3 Classic long-life model

This model is also concerned with a long-product life, but instead of repairing, refurbishing or remanufacturing residual products, this model is supported by design for durability in the first place. Also, free repair options are mostly offered. The value proposition focuses on high-quality, long lasting products. The original price of the product is often relatively high as this typically covers warranty and long-term service. Examples of these products are Miele washing machines or luxury products. However, a critical note can be set for luxury products since they are in principle not about slowing down resource flows.

2.2.4 Encourage sufficiency

Also, the model 'encourage sufficiency' is about long-lasting products. However, this business model uses a non-consumerist approach to sales according to Bocken et al. (2016). It seeks to actively reduce end-user consumption. In contrast to the 'access and performance model', 'extending product value' and 'classic long-life model', this model does not benefit from high sales or providing as many services as possible. It actually encourages customers to buy products that last and allow them to hold on to them without additional sales tactics or hidden 'built-in obsolescence'. The premium prices justify 'slower sales' and higher service levels.

2.2.5 Extending resource value

This business model is about closing resource loops instead of slowing down resource loops. It is about the collection or sourcing of otherwise ‘wasted’ materials to turn these into other forms of value. Classical examples are large-scale recycling programs, such as aluminium recycling where re-melting uses less energy than creating new aluminium. The overall product price, and material costs are reduced which makes the product more appealing to certain customers. The difference between this business model and the ‘extending product value model’ is that not exactly the same products have to be refurbished or repaired, but the entire resource is reused.

2.2.6 Industrial symbiosis

The last CBM described by Bocken et al. (2016) is ‘industrial symbiosis’. This model is concerned with using waste outputs from other production processes into feedstock for new products or processes. The difference with the ‘extending resource value’ model is that this often happens at the process and manufacturing level and therefore is centered on a smaller (geographical) scale. This model captures value through cost reductions. Often it has a collaborative agreement with closely related firms and it creates joint cost reductions and further opportunities for new business based on former waste.

2.3 Environmental rebound effect

The concept of rebound effect was first proposed by Jevons in 1865 when he recognized an increase in energy consumption from burning coal. At that time, burning coal was considered to be more energy efficient than burning other fossil fuels, which he thought would result in less energy use. However, the energy consumption went up. This led to the concept being labelled as ‘Jevons paradox’. Much later, the concept became relevant again when academics investigated global oil shortages and increasing concerns on climate change (Font Vivanco et al., 2016). Another related term is ‘Khazzoom-Brookes postulate’ (Broberg et al., 2015). Like Jevons Paradox, the Khazzoom-Brookes postulate explains an efficiency paradox, mainly in energy use, that is largely counter-intuitive. Zink and Geyer (2017) explain the rebound effect as a phenomenon where increased efficiency makes consumption of (some) goods relatively cheaper and as a result, people consume more of it. The increase in use leads to a reduction in the original environmental benefit of the efficiency increase. Eventually this could even lead to a ‘backfire’ which occurs when the net impacts are even higher because of increased use. A commonly used example is the case of a car driver, who buys a more fuel-efficient model, only to benefit from the cheaper running costs and with this savings to drive further or more often.

According to Zink and Geyer (2017) there are two possible ways in which circular strategies can lead to a rebound effect. The first is via the re-spending or income effect, which originates from price reductions. Typically, reused or recycled products have a lower price and logically lower expenditure results in buying additional goods and services. Second, a circular strategy could be failing to effectively compete with primary production, which is called imperfect substitution. Zink and Geyer (2017) highlight certain misconceptions regarding circular activities such as

recycling, refurbishing and reusing that cause imperfect substitution. They state that a 1:1 displacement of raw materials by secondary ones is impossible due to technological limitations and because of consumer behavior. According to Makov and Font Vivanco (2018) firms and governments like to believe that the sales of used products cannibalizes sales of new ones, however such replacement is likely limited and therefore production simply increases. Because of this imperfect substitution, reusing old resources could just 'grow the pie'. Both ways eventually result in an overall increase in supply and demand, which leads to heavier environmental burdens.

In the literature, different typologies exist around the concept of rebound effects. The most cited typology of rebound effects is from Greening et al. (2000) and has led to a four-part categorization. It refers to traditional literature on rebound effects which imply changes in energy efficiency measures, and in this research helps to place boundaries on definitions during the examination of the size of the rebound effect in the circular economy literature. Greening et al. (2000) expand the microeconomic view on the rebound effect with a less predictable macroeconomic view, which is harder to recognize but important to understand. The just explained possible rebound effects of circular strategies can be grouped into categorizations which differ in the way this re-spending or income effect and imperfect substitution are expressed. Below this four-part typology (Greening et al., 2000) is explained, from which the last two are subject to the macroeconomic view.

These four categories of market responses to efficiency changes are: (1) direct rebound effects, which can be explained by an immediate increase in consumer demand due to lower prices from increased efficiency. An example in the circular economy could be that, due to the increased sales of second hand clothes, people tend to buy more clothes than needed. (2) Secondary effects, which can be defined by an increased demand of *other* goods due to savings from the initial product. In this case, buying second hand clothes saves up money and these savings are spent on other products that would originally not have been bought. (3) Economy-wide effects, which refers to larger unpredictable effects that increased efficiency has on prices and demand of other goods. In the case of the circular economy, this could mean for instance an increased supply and demand on second hand clothes that affects the demand of regular clothing. Indeed, regular clothing could get less expensive, resulting in higher sales and a smaller environmental benefit related to the sales of second hand clothing (by reusing). (4) Transformational effects, referring to the potential of energy efficiency increases to change consumer preferences, social institutions, regulations or other large-scale effects. Greening et al. (2000) explain that the effects in this fourth category are extremely difficult to identify and quantify. Even if these detailed data were available, it would be uncertain that these large-scale changes would be fully explained by these transformational effects only. Because of these reasons, this fourth category is not being considered in this research.

The degree in which a rebound effect can occur also differs. Five possibilities come forward in this regard. These are respectively; super conservation (RE<0), zero rebound (RE=0), partial rebound (0<RE<1), full rebound (RE=1) and backfire (RE>1). Super conservation is supposed to have the best benefits for the environment and backfire the worst. The actual savings vary from higher than expected (the effect is negative), to negative resource savings (the effect is higher than 100%) (Zink & Geyer, 2017).

3. Methodology

Davis et al. (2014) present a summary of steps for undertaking a systematic literature review, defined by the Berkeley Systematic Reviews Group at the University of California. This summary involves the following steps.

1. Formulate focused review question
2. Comprehensive search and inclusion of studies
3. Quality assessment of studies and data extraction
4. Synthesis of study results
5. Interpretation of results and report writing

This methodological section goes through all steps one by one. The first step is disregarded, since it has already been addressed in the introduction.

3.1 Search and inclusion of studies

A web based Boolean search of scientific literature has been conducted, utilizing combinations of search terms related to ‘circular economy’ and ‘rebound effect’. The related terms have been explained in previous section 2, and table 2 below shows the definite search terms.

Topic	Search terms (OR*)		Topic	Search terms (OR*)
Circular economy	“Circular economy” “Industrial ecology” “Eco-efficiency” “Product service system” “Sharing economy” “Reuse” “Recycle” “Reduce” “Dematerialisation” “Durability” “Long-life model”	**AND***	Rebound effect	“Rebound” “Jevons paradox” “Khazzoom-Brookes postulate” “Income effect” “Substitution effect”

Table 2. Search terms for web query constructed by the author.
*including search terms: industrial symbiosis, cradle-to-cradle, circular business model, bounce-back effect, take-back effect, re-spending effect and imperfection substitution, do not provide any additional results so these have been left out of the search.

The literature collection is made based on a search using search-engine Scopus. The focus is on all peer-reviewed journal articles that were available before the end of July 2020. Potential limitations to this approach are acknowledged. As only papers written in English are considered,

further sources in other languages have not been considered. Furthermore, the scope of search terms that is used could have excluded other articles of relevance which do not name both search terms simultaneously, but which could have been relevant for this literature review. This latter limitation is minimized by including not only the title, but also keywords and the abstract in the search. A total of 2002 papers was identified. Discarding the search term ‘reduce’ reduces this total amount to 149 papers. A considerable amount of these 149 articles seem relevant, however, discarding the term ‘reduce’ may leave out other useful articles that do include the circular economy in combination with rebound effects. So, the original search terms were used and manually all papers that do not contain any circular business model strategy were disregarded.

3.2 Quality assessment and data extraction

All 2002 articles were downloaded in Mendeley, a computer program that helps academics automatically referencing and organizing large quantities of articles in a simple way. The decision whether an article was considered relevant was based on respectively; the title, keywords, abstract and content. Another requirement to be included in the literature collection is the presence of one or more CBMs in which the article can be categorized. After discarding all non-relevant articles, only 36 articles, mostly case-studies, are considered relevant to base the literature review on. Besides these 36 articles, there are more studies that comprise both concepts but do not include a specific circular business model into their study. These articles are used throughout the research to elaborate on certain statements and give background information.

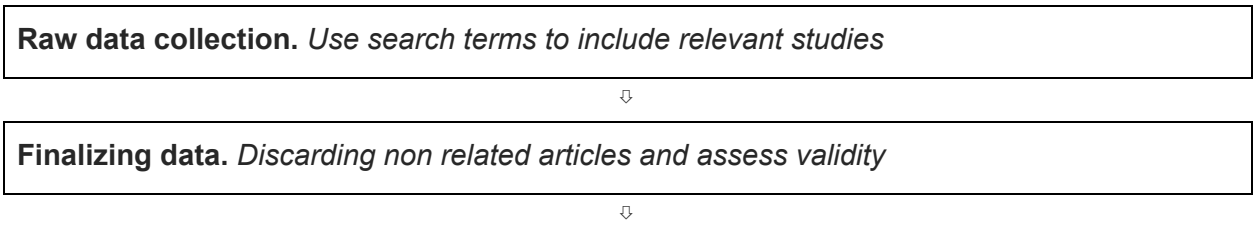
In order to allow for a systematic analysis, the articles were organized in an Excel spreadsheet. In this spreadsheet, relevant characteristics and parameters were listed to briefly describe and categorize the sources. The following parameters were used:

- Author
- Citation
- Year of publication
- CBM strategy
- Methodology
- Type of sector
- Type of rebound effect
- Unit in which the rebound effect is measured
- Keywords
- Focus of the article
- Research gaps derived from the article
- Notes (comments or citations that summarize the content or that could be of use in a later stadium)

The unit in which a rebound effect is measured could be either in energy savings, GHG emissions/GWP or material/resource use. In addition, an assessment of the validity of the findings of the included studies is undertaken by the author. This helps to lower the risk of biases (Tranfield et al., 2003). According to Messick (1995) writing a literature review can have two goals, either a) to provide a neutral representation of the literature or b) to take a non-neutral stance to support a position. In this literature review a neutral representation of the existing literature is given by figuring out if there are any hidden incentives for authors to support a non-neutral position. In other words, what is the purpose of writing their article, by whom the research is funded and do the conclusions naturally derive from the findings.

3.3 Data analysis and expected results

Especially in this research, it would be challenging to perform a meta-analysis because of different methodological approaches and different characteristics studied in each case-study (Tranfield et al., 2003). Therefore, a frequency analysis was performed to measure a quantitative count of the different parameters. This will assign a relative significance of the CBM strategies present in the literature and at the same time it shows the distribution of the other variables to get a descriptive overview of the literature. Furthermore, it is noted for every article if, what type and to which degree there is a rebound effect present. This shows the relationships between the CBM strategies, the variables and the outcome and by this sheds a light on most predictable outcomes, patterns, under researched areas and conflicting areas of research. The measures are shown in graphs and overviews to visualize the results. Finally, a framework is constructed that places the different types of rebound effects, identified by the authors, in perspective according to actors involved and causes that trigger a rebound effect. This can be used for future research and policymakers. Figure 1 shows the methodological procedure that is followed to conduct this research.



Coding.

CBM strategies

- Access and performance model
- Extending product value
- Classic longlife model
- Encourage sufficiency
- Extending resource value
- Industrial symbiosis

Other parameters and characteristics (shown in section 3.2)

⇩

Frequency analysis. *Measurement of the quantitative counts of the different codes*

⇩

Identification of relationships, results and framework.

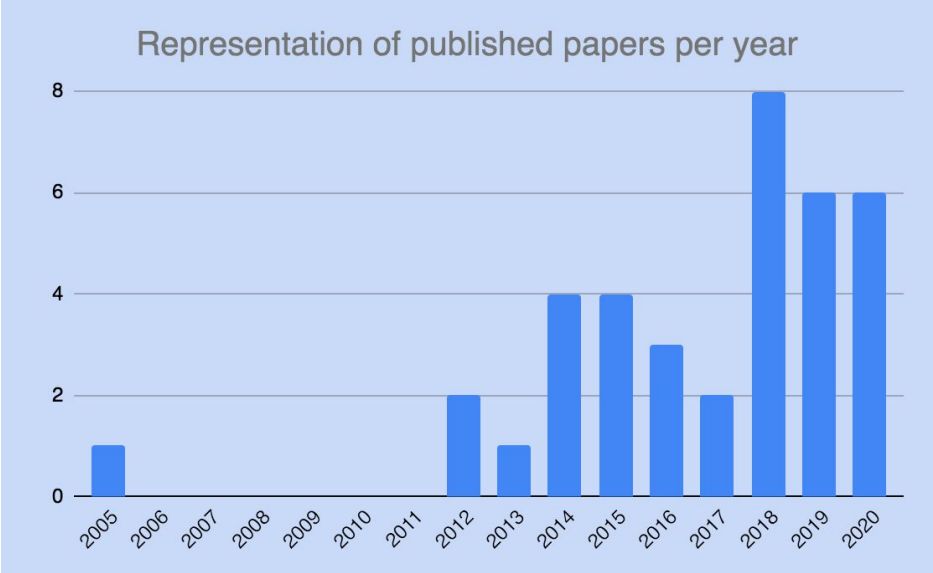
Fig. 1. Methodological procedure followed. Constructed by the author.

4. Results

4.1 Descriptive overview

4.1.1 Year of publication

The graph (1) below shows a representation of the included 36 studies and the years in which the papers were published. It clearly shows that the subject is relatively novel and at the same time an upcoming phenomenon. Only one encountered paper was published before 2012. This paper from Briceno et al. (2005) was the first to include the rebound effect in their study in order to calculate the real benefits of car-sharing including re-spending patterns of their research subjects. All other encountered studies were conducted in or after 2012, with a peak in 2018 and a growing interest in the last couple of years.



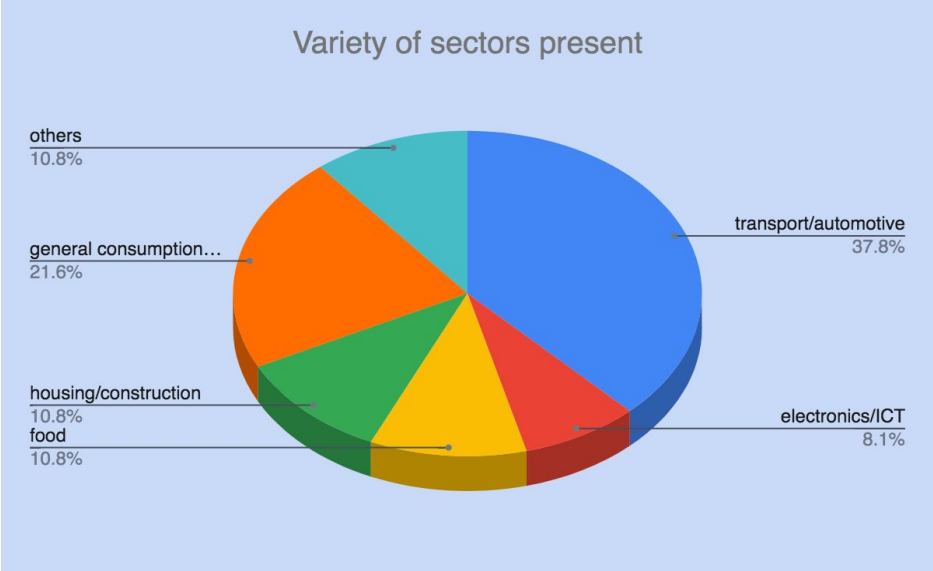
Graph 1. Overview of the included literature by year.

4.1.2 Sectors

The graph (2) below shows the variety of sectors in which the studies are carried out. More than one third of the literature on the rebound effect in the circular economy is written about the transport sector and especially the automotive industry. Most of these studies are involved in the subject of reduced ownership of cars and in more detail about ride-sharing or car-sharing. Also ride-hailing, which is similar to personal taxi services like Uber, boat-sharing and the increased use of public transport are research topics in this sector.

A first explanation for this large share could be that the transport sector was one of the first industries in which the circular economy was brought into practice and therefore a more mature sector and easier to study. Secondly, the majority of studied transport innovations are cost-reducing, which liberates money that will be spent on extra consumption, thus creating conditions in which rebound effects are like to occur (Font Vivanco et al., 2015). Finally, Petrides et al. (2018) explain that rebound effects are heavily linked to product use after

manufacturing, and since personal vehicles, which have a rather long use phase, are now used in circular strategies, rebound effects are likely to occur and therefore studied frequently.



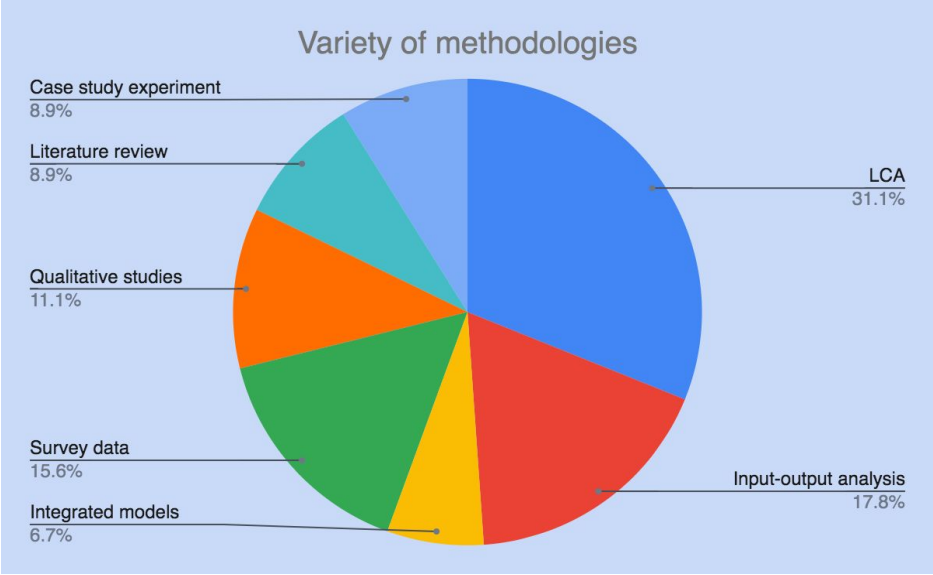
Graph 2. Overview of the sectors that are involved in the literature

The second largest sector (21.6%) present in literature is here called ‘general consumption’. This sector includes topics on (household) consumption, consumer behavior and lifestyle related changes. For instance, Chitnis et al. (2014) estimate direct and indirect rebound effects on household level for driving behavior, food waste reductions and indoor temperature for different socio-economic groups in the UK. And Vita et al. (2019) research the environmental impact of ‘green’ consumption and several sufficiency lifestyles scenarios across Europe. Furthermore, there are four other sectors distinguished which are housing/construction (10.8%), food (10.8%), electronics/ICT (8.1%) and ‘others’ (10.8%). The housing and construction sector include papers that assess smart buildings or homes that reuse materials. The food sector articles are involved in the reduction, prevention or recovering of food waste. Salemdeeb et al. (2017) highlight the importance of avoiding food waste and the significant environmental benefits it can have. Electronics and ICT articles assess for instance the rebound effect of multiple site conferences, which promises a substantial reduction of GHG intensity by a reduction of international flights (Coroama et al., 2012). Furthermore, the role of technological change in the sustainability transition is assessed when it turns out that electronics/ICT can have a positive, as well as a negative impact on a rebound effect. A product or service can become faster or more convenient to access which could result in an increase in demand of that particular product (direct demand-side rebound effect), or it may save time or money which is then spent on more energy intensive products (indirect rebound), which in the end may balance out the favorable effects of the implemented circular strategy (Pouri and Hilty, 2018). The last group includes studies based on the circular economy in combination with the use of resources

such as water (Li and Zhao, 2018), gold (Figge and Thorpe, 2019) and also a single study based on sustainable tourism (Scheepens et al., 2016).

4.2 The rebound effect and methodology

The 36 included studies follow a great variety of methodologies. Some papers make use of mixed methods. In these cases, multiple methodologies are counted for one study. It becomes clear that calculating an exact size of the rebound effect is mostly done applying a life cycle analysis (LCA) or input-output analysis. Almost half of the used methodologies belong to one of these two types. Graph 3 shows the distribution and variety of the methodologies that are used in the assessed literature.



Graph 3. Overview of the methodologies used in the literature.

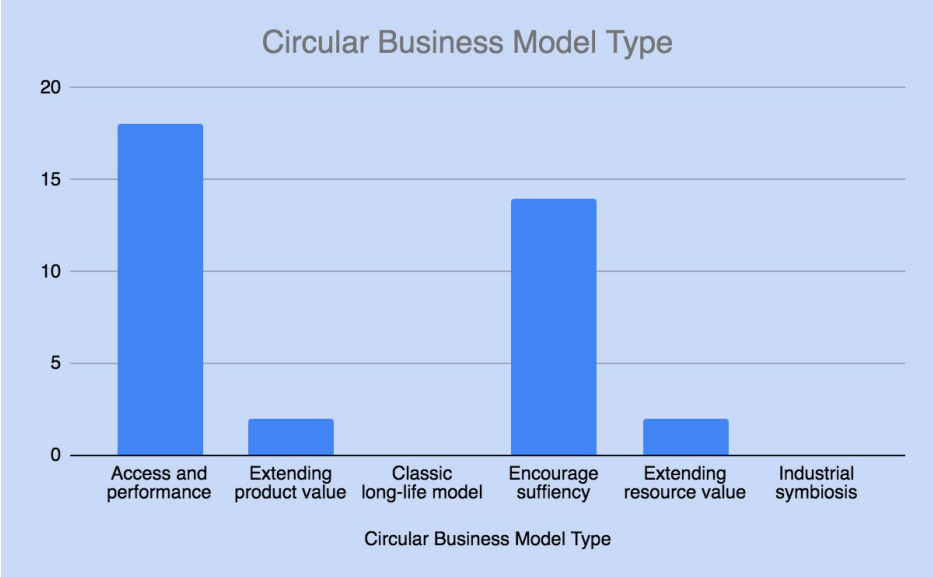
Furthermore, it can be stated that studies which make use of rather qualitative methodologies, including case study experiments, surveys and literature studies, find different rebound effects compared to studies using quantitative methodologies. The qualitative methodologies describe the common direct and indirect rebound effects but also other effects such as behavioral rebound effects (Dorner, 2019), spillovers, time-use rebounds (Sorrell et al., 2020) and informational rebounds. Furthermore, qualitative methodologies are used to get a better understanding of the rebound effect and look for differences between different socio-economic groups. Chitnis et al. (2014) find for instance, with the help of surveys, that high-income households have higher embodied GHG emissions, while lower-income households have higher operational GHG emissions which are more subject to rebound effects. Sorrel et al. (2020) and Grabs (2015) share this opinion and conclude that rebound effects tend to be larger for low-income households and for households in emerging economies because these groups tend to re-spend saved money on more environmentally intensive goods, while high-income households more inclined to reinvest in energy efficient products like renewable energy or

housing insulation. These findings can be of important notice when implementing policies aiming to decrease to the rebound effect.

The quantitative studies, including LCAs and input-output analyses mostly deliver exact numbers on the size of the direct and indirect rebound effects. In contrast to qualitative studies, that have a more descriptive character. Shao and Rao (2018) justly state that despite the different classifications, the direct rebound is much easier to estimate than the other effects. Hitherto, no widely accepted methods exist on how to calculate the economy-wide effect and to a lesser extent also the indirect effects. This is why many studies give a wide range of the size of these effects, if calculated at all. When only the direct rebound effect is considered, an underestimation of the total rebound effect can be the consequence of that. Furthermore, certain specific modelling techniques such as GEM-E3 equilibrium modelling (Skelton et al., 2020) and integrated land-use transport modelling (Yin et al., 2018) are combined in a group called ‘integrated models’. The paper that uses this GEM-E3 equilibrium model is one of the only two papers that assessed an economy-wide rebound effect, since this models’ strength is to measure interactions between the economy, energy systems and the environment. The other paper that illustrates macroeconomic effects, by Laurenti et al. (2016), makes use of a causal loop diagram to visualize how different variables in the system are interrelated. To do this, they make use of broader system boundaries than other studies. This also has its implications for the findings since there is more uncertainty when broader system boundaries are used.

4.3 The rebound effect and circular business models

Only four out of the six predefined CBMs are found within the selected relevant literature. Most common are the ‘access and performance model’ and the ‘encourage sufficiency’ model. 18 out of the 36 papers are considered studies that research a type of ‘access and performance model’, 14 papers research ‘encourage sufficiency’. Both ‘extending product value’ and ‘extending resource value’ are researched twice. The ‘industrial symbiosis’ and the ‘classic long-life model’ are not found at all within the considered studies. Graph 4, below, gives a visual representation of these findings.



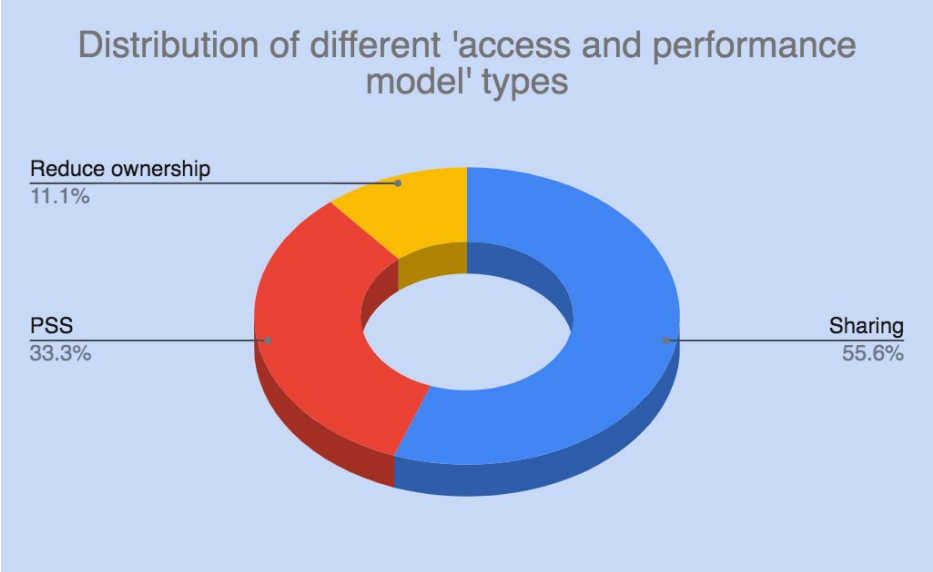
Graph 4. Overview of the different CBMs that are studied in the literature.

It becomes clear that a rebound effect can occur at different stages along the supply chain, from design and production phases towards the use phase. The highest impact on the environment however is during the use phase and that could explain why most papers include CBMs that have a large use phase. Scheepens et al. (2018) explain that generally 80% of the environmental impact of products, such as cars, is generated in the use phase by the combustion of fuel and because of that the environmental impact reduction of sharing the physical product is insignificant at best. Petrides et al. (2018) as well share the idea that rebound effects are heavily linked with customer behavior and the potential product use after manufacturing. Efficiency measures taken in the manufacturing phase could lead to minor savings, however the use phase still takes the greatest part of the total environmental impact. Following that in both the 'access and performance model' and the 'encourage sufficiency' model the use phase is important because the models are focused on the consumer/user mainly. In contrast, by 'industrial symbiosis' the use phase is not important because it is more of an end-of-life strategy which does not involve users. The 'classic long-life model', too, is completely focused on the design which does not involve users. In general products in a 'classic long-life model' are more expensive than regular products and this would logically not result in a rebound effect.

4.3.1 Access and performance model

From the 18 papers that assess a possible rebound effect in relation to the 'access and performance model', 10 papers consider rebound effects in the 'sharing economy', 6 papers look at a 'product service system' and 2 papers research the rebound effect specifically in relation to reduced ownership. Below, graph 5 shows the distribution of these different types. An explanation for this ratio could be similar as to the occurrence of sectors within the found literature. The sharing economy is brought into practice more often than PSS models or models

that solely focus on reduced ownership, and that could be a reason why a rebound effect in the sharing economy is studied more often.



Graph 5. Distribution of different ‘access and performance model’ types.

Most of the papers that assessed an ‘access and performance model’ found direct and/or indirect rebound effects. Only two papers (Skelton et al., 2020 & Laurenti et al., 2016) tried to assess an economy-wide rebound effect, and this was in combination with a study conducted towards a PSS. Skelton et al. (2020) warn that the ‘win-win’ circular economy rhetoric in a product service system model, that entails both environmental and economic wins, is not always the case. In their study, they look at material, energy and product-service efficiencies. They assume a reduction in demand for vehicles because of the product-service, which at the same time implies material efficiencies because less cars need to be produced. However, improvements in resource/material efficiency have the potential to offer a great GDP growth stimulus which in return causes an economy-wide rebound effect. So, according to them, products that seem to have the best improvements in resource efficiency are also likely to carry the greatest rebound effects. In their simulation the rebound effect was as big as 85% of the originally saved GHG emissions. Despite the rebound effects identified, all considered scenarios resulted in emission savings so no ‘backfire’ occurred. Besides that, both Laurenti et al. (2016) and Skelton et al. (2020) admit that researching an economy-wide rebound effect is subject to great uncertainty since the assumptions made determine the results for a great deal.

Furthermore, Figge and Thorpe (2019) propose another less common rebound effect while investigating a product-service system model, namely a “symbiotic” rebound effect. A symbiotic rebound effect implies that opportunity costs drive a higher than expected use of resources in a circular economy. This implies that for example the choice for recycling comes at the cost of having to discard the option of reusing. A resource cannot simultaneously be recycled and

reused. The optimal decision, the one that encourages the most efficient use of resources, can only be made in the context of knowing the implications of all options.

While all 18 studies found a rebound effect, not all of them came up with percentages or ranges on the magnitude of this rebound effect. Where most of the outcomes measured a partial rebound effect (>0% and <100%), some did not give an exact percentage or gave a relatively wide range because of the assumptions made. Amatuni et al. (2020) state for instance that, in the case of carsharing, the rebound effect is highly dependent on which other transportation mode is used, other than a car, and the available infrastructure in a particular place. It is hard to tell how much GHG emissions would have been saved by full sharing, since full sharing practically does not exist. Demyttenaere et al. (2016) state that rebound effects linked to consumer behavior are influenced by a shift in ownership. If consumers are no longer the owner of a product, they might exhibit careless behavior which results in an eventual increase of resource consumption.

Additionally, Ottelin et al. (2020) report that consumption choices can potentially have a strong impact on environmental footprints. However, they conclude that circular consumption choices related to an ‘access and performance model’ do not necessarily lead to a lower material footprint. According to them, making use of sharing, hiring or repair services does not decrease the material footprint. In the study of Junnila et al. (2018) also reduced ownership did not have a noticeable influence on the overall material footprint of individuals due to rebound effects, and it only has a slightly positive influence on the carbon footprint. They identify a new type of circular related rebound that relates to products with a long life cycle, which they call ‘life cycle rebound’. This implies that owners of products with a long life cycle (e.g. housing) invest in the performance of these products, while sharers (or tenants) are more prone to spending money on services and particularly leisure travel because they do not feel responsible for the performance of long life cycle products that they do not own. This corresponds with the findings by Demyttenaere et al (2016) as just explained. Scheepens et al. (2018) share these thoughts as well by stating that it depends on consumer behavior whether ‘sharing’ actually has environmental benefits. They provide an example about car sharing and state that people either drive less kilometers because they have to pay for every kilometer, or people who are normally not used to driving a car start using it for convenience reasons and actually drive more than they did before. The environmental impact clearly depends on consumer choices, but a lack of understanding of rebound effects may negatively influence the environmental footprint while consumers think they are making the right choices. According to Junnila et al. (2018), just offering products as a service does not automatically reduce the total environmental impact. Full benefits from an ‘access and performance model’ are more realistic when simultaneous change on both the production and consumption sides are emphasized. This means that producers must stick to offering environmentally friendly service products, while consumers should spend their saved money in energy-efficient investments.

4.3.2 Encourage sufficiency

Similar to the papers that assessed an ‘access and performance model’, the direct and indirect rebound effects were found and studied most within the literature that examined the ‘encourage sufficiency model’. No economy-wide rebound effect is studied in relation to the ‘encourage sufficiency model’. The reason for this is that this type of rebound effect refers to larger unpredictable effects which are extremely difficult to identify and quantify, and specifically for consumer or household behavior related sectors in which the ‘encourage sufficiency model’ is assessed most. Besides, some other rebound effects were found which are basically the same as the direct or indirect rebound effect but focused on a more in-depth subject within a rebound effect. These are a behavioral rebound effect (Dorner, 2019), spillovers, time-use rebounds (Sorrell et al. 2020) and informational rebounds (Qi & Roe, 2017). The behavioral rebound effect suggests that: “reductions in pro environmental effort contributes to the overall rebound effect, and could have further implications for environmental damage beyond the standard rebound effect (Dorner, 2019. P. 16)”. These reductions in pro environmental effort can be caused by technological changes that foster moral licensing. This means that people license themselves to behave in a less pro environmental way because they think that a certain technological change will be enough or fix the current problems. Murray (2013) concludes that for demand-side environmental policies to have pay-offs, the adoption of ‘green’ consumption choices in the absence of any changes to technology is key. Better targeted nudging of consumer preferences could in this case improve the pay-off of such policies. Findings by Polimeni & Polimeni (2006) show that along the variables; percentage change in GDP, percentage change in population and percentage change in energy intensity, the latter has the most significant impact on energy consumption. This indicates that technological changes or advancements are the main driver for increasing energy use, which supports the existence of an environmental rebound effect.

Spillovers and time-use rebounds are types of rebounds commonly found in energy sufficiency literature. Sorrell et al. (2020) describe in their literature review that spillovers have to do with consumers that may feel they have ‘done their bit’ for the environment and subsequently spend money on more energy- and emissions-intensive products and activities. This differs from the behavioral rebound effect in the way people license themselves to take a step back because of previous pro-environmental behavior. The behavioral rebound effect includes technological change as a license to reduce pro-environmental behavior. An example can be that a person who changes their diet to lower the carbon footprint, license themselves to go on a plane for holiday. On the contrary side, positive spillovers exist too, in which less carbon intensive actions such as cycling may reinforce a personal commitment to avoid carbon intensive actions in the future. This phenomenon was also recognized by Csutora (2012). She found that there is no significant difference in the environmental impact of conscious and non-conscious consumers as eco-friendly products are consumed more because of the perception they do less harm to the environment. Furthermore, time-use rebounds also exist in a positive and negative way. Time-use rebounds suggest that consumers may save or spend more time by taking part in

more energy sufficient actions so that they can spend more or less time on activities that also require energy or resources (Sorrell et al., 2020).

Qi and Roe (2017) propose a type of rebound effect that they called informational rebound. This suggests an effect in which promoting policies that mitigate environmental damages may unintentionally undermine policies meant to encourage individual consumer initiatives to reduce the waste of resources. Their study looked at food waste reductions and recycling policies implemented separately or jointly. They found that these policies implemented jointly lead to little reduction in consumer food waste behavior compared to recycling-only policies, and that both policies implemented jointly significantly lead to more food waste than reduction-only policies. This implies that when consumers are informed about an ongoing recycling program, this largely offsets the achievement of food waste reduction strategies in the first place. Practically this means that people tend to take larger portions of food when they know a recycling policy is in effect.

For these ‘behavioral’ rebound types of rebound effects the size of the effect depends greatly on the metric used, which sector is researched, what kind of household type or behavioral attitudes consumers contain. For these reasons, the authors do not give exact percentages on the size of the particular rebound effect, or do not measure the size at all. On the other hand, some authors that did research a direct and/or indirect rebound effect gave exact percentages which lie between 0 and 100%. This is called partial rebound and means that ‘encouraging sufficiency’ still has a positive effect and therefore reduces resource use or GHG emissions. However, this effect is not as big as thought in the first place. The only study that did not find a rebound effect is from Paloheimo et al. (2015). They reported that in the trial performed on crowdsourced deliveries, no rebound was found, even though it was searched for. Crowdsourced deliveries affect an absolute reduction of inefficient driving by private cars. This initiative suggests that consumers take and deliver packages to other consumers when they pass by a dropping point and head the same way as where the order needs to be delivered. This form of delivery reduced an average of 1.6 km driven by car, despite 80 per cent of the deliveries being made within less than a 5-km distance. Within the ‘encourage sufficiency’ business model, this is the only example so far that reported no rebound effect, all others described a rebound effect in one way or another.

4.3.3 Extending product and resource value

Both the ‘extending product value’ and ‘extending resource value’ models are present only twice in the rebound literature on the circular economy. The two ‘extending product value’ business models study both the direct and indirect rebound effects, where the ‘extending resource value’ business model only studies the direct rebound effect. A logical explanation for this distinction is that refurbished, remanufactured or reused ‘products’ are usually less expensive than new products, and because of that consumers have more money to spend on other goods, which is the definition of an indirect rebound effect. On the contrary, used ‘resources’ are commonly

turned into energy or used as secondary resources to produce ‘new products’. These recycled products are likely to have the same costs so no income is saved and in return, studying an indirect rebound effect is not applicable. Makov and Font Vivanco (2018) highlight the existence of a rebound effect that can be caused by reuse strategies, namely imperfect substitution. When reused products do not replace the production of new products on a 1:1 basis, overall production increases. In their study they found that this failure of reused products (smartphones in this case) to fully substitute new units does indeed lead to a noteworthy reduction in the expected GHG emission savings.

The ‘extending resource value’ model is the only model that covers the ‘closed loop’ aspect of the circular economy instead of the ‘slowing down’ aspect. While little research investigates this particular model in relation to the rebound effect, Horvath et al. (2019) found out that the EU bases the circular index of EU member states on recycling performance only. An interesting finding by Horvath et al. (2019) is that the EU even encourages their member states to have high amounts of waste because then the circular index numbers positively increase. Although circularity is in popular opinion mostly associated with recycling, according to Cramer (2017) it is of higher importance to prevent the generation of waste. One can better lengthen material loops by extending product lifespan or narrow them by refusing consumption. Measuring circular efficiency in line with unfavorable actions such as recycling lead to deadweight losses. This can be linked to the symbiotic rebound effect proposed by Figge and Thorpe (2019) where there is a trade-off between different circularity strategies.

Similar to the findings in the other two CMBs, the size of the rebound effect is not unambiguous per study. For example, Makov and Font Vivanco (2018) studied the rebound effect regarding refurbished and reused mobile phones. They found that the rebound effect differs between for instance phone models and regions consumers live in. The iPhone 6 in China even backfires (>100% rebound effect), while other models in the UK only have a relatively small rebound. While Ingrao et al. (2018) research a completely different topic, namely the anaerobic digestion of food waste, they also explain that their results are highly affected by the methodological choices and assumptions that are made as part of their environmental assessment. In their review they compare the anaerobic digestion of food waste to win energy with conventional treatment of food waste like incineration or landfilling. They highlight that the circular anaerobic digestion treatment has negative climate change impacts, just like the conventional ones. The problem however is how to compare them since the reviewed studies all show different results.

4.4 Research gaps

The final dimension considered by this review are the research gaps proposed by the authors. The identified research gaps show which information is still missing to develop a common understanding about the real benefits of a circular economy while also considering rebound effects. First, a frequently mentioned gap in this research area regards consumer behavior, and in particular the insufficiency of data to measure the impact of behavior on the rebound effect.

Warmington-Lundström and Laurenti (2020) recognize the need for a behavioral framework for analyzing sharing behaviors and related spending intentions. Why do people engage in sharing platforms and how do they spend their freed/saved money? Furthermore, they mention that “an increase in understanding is needed to address whether, to what extent and, under which conditions rebound effects undermine environmental gains of resource-optimization platforms (p.7)”. Lastly, real-world data from field experiments should be generated according to them. Junnila et al. (2018) also state that real-world data would be useful and mention that it would be necessary to understand the consumption behavior of affluent consumers in particular since they have the highest personal environmental footprint and usually play a central role in strategic decisions in western societies. Dorner (2019) identifies a gap in his own experimental design that would be the testing of order effects for moral licensing since moral licensing only has moderate statistical support right now. Ottelin et al. (2020) as well state that it is important to know how consumers spend their saved money, since for now mostly standard data is used that corresponds with existing consuming patterns which does not include lifestyle changes or circular consumption behavior. In addition, “it would be helpful to collect longitudinal expenditure data in order to study causal relationships (p. 15)”. Detailed data on the frequency and motivations to buy for instance second-hand products, green label products or recycling habits could help to deeper analyze the impacts of circular consumption.

Second, research gaps were identified that surround topics concerning the research type or tools that are used to measure the rebound effect. According to Sorrell et al. (2020) there is a need for more standardized measures of the environmental impact in order to compare results. Qualitative research mostly identifies behavioral related rebound effects and causal links but lacks the ability to measure these effects, while quantitative research fails to deliver context. Laurenti et al. (2016) propose that quantitative analysis should be used, that follows the conceptual modelling process indicated by causal loop diagrams, in order to further reveal the strengths and weaknesses of opposing modes of behavior of unintended environmental consequences. Furthermore, several authors (Chitnis et al., 2014, Sorrell et al., 2020 and Chan et al., 2020) mention the need for Computable General Equilibrium (CGE) modelling tools in order to fully capture mechanisms that both quantify outcomes and make use of behavioral input. These modelling studies can explore indirect rebound effects and economy-wide consequences that include price effects and supply constraints which may lead to ideas for effective policy and tax structure changes (Sorrell et al., 2020). These CGE tools can make use of household level data and for instance explore rebound effect scenarios for households that have actively chosen to downshift. Walzberg et al. (2020) propose a modelling technique called agent-based modelling (ABM) as a relevant tool to incorporate both human behavior and a rebound effect in LCA studies. This technique makes it possible to consider human behavior at an individual level, and future research should focus on implementing the decisions that lead to re-spending of saved money into this ABM tool. Other types of the rebound effect could be modelled with ABM as well,such as irrational household behaviors or moral licensing. This could help to better estimate the magnitude of the rebound effect in the circular economy and

help to design better policies to avoid them. These modelling techniques predominantly focus on a macroeconomic approach.

On the other hand, there are authors that propose a different approach which focuses on the impact of local policies (Tirachini, 2019) or at a finer geographical scale (Vita et al., 2019). The latter also plead for real life demand-side solutions and a focus on views of non-academic stakeholders instead of resource-assessment scenarios and hypothetical trajectories. The reason for this is that in order to reach real life targets (1.5°C climate target) the focus should be on mainstreaming sustainable lifestyles. To identify and support environmentally sound and socially accepted lifestyles that can mitigate current challenges, several scenarios have to be constructed and tested on a smaller geographical scale. Other identified research gaps were related to the indicator that is used to measure environmental impact. Several authors mention that energy and GHG emissions are measured most but that these are only a subset of potential indicators. Grabs (2015), Bourelle (2014) and Makov and Font Vivanco (2018) explain that using other indicators (such as water use, land use or biodiversity) could yield other or more extreme rebound magnitudes that also need to be tackled in the quest for climate change solutions and the environmental crisis. Furthermore, Font Vivanco et al. (2015) mention that further academic research could study innovation diffusion, diversion factors, technology change data and expenditure patterns. While rebound effects are heavily linked to the sales of products and customer behavior, studying factors related to new technologies could lead to more detailed conclusions. Underwood and Fremstad (2018) believe that future research should explore the differences between densely and sparsely populated areas and the resulting income effects that rebound effects. Then there are some research gaps related specifically to the most represented research topic of transport. Ottelin et al. (2018) highlight that emissions from flying are not included in most studies while the EU has implemented legislation to reduce emissions from personal vehicles. At the same time, air travel is the main reason why policies that aim to reduce transportation emissions have significant rebound effects. Amatuni et al. (2020) highlight that upswing of new modes of travel such as bike or e-scooter sharing gains popularity and this may affect how other modes of transport like car sharing are used. How these different ‘circular business models interact also provides an interesting area for future research.

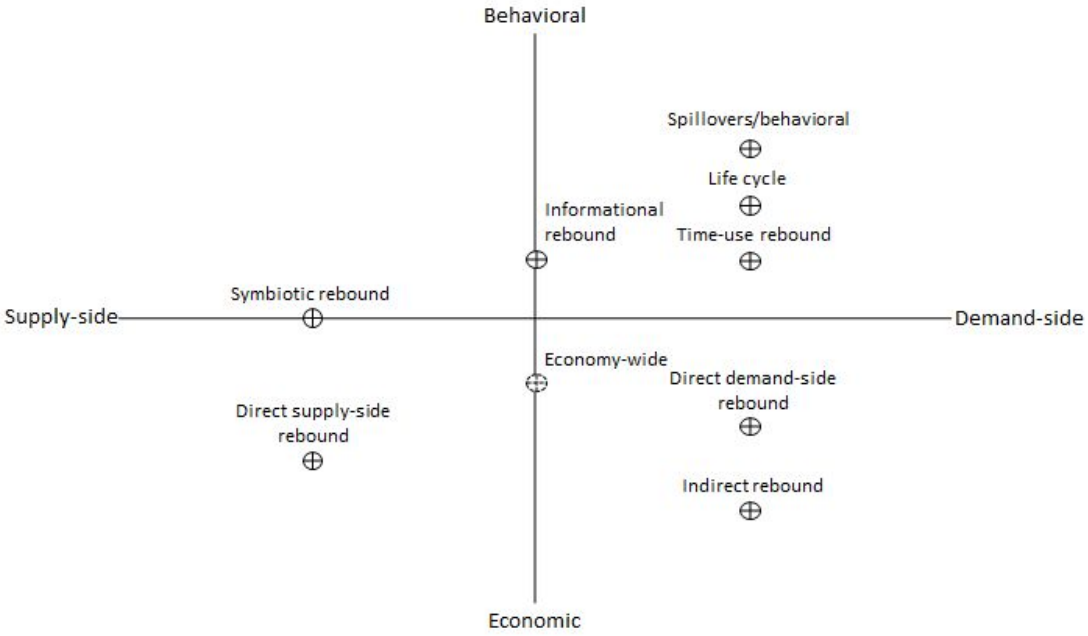
4.5 Typology framework

Most of the rebound effect literature reviewed in this research focused on empirical evidence which generally discusses the size of a particular type of rebound effect by using a variation of methods and assumptions. This does not allow for an overall generalization or conclusion that contributes to theory building since findings are greatly diverse. Considerably less research has attempted to interpret the underlying mechanisms that cause different rebound effects to happen. So, to open up a discussion about the actual environmental potential of the circular economy, considering rebound effects, and create common understanding of the complex nature of the rebound concept, a framework that identifies these different types and places them in order according to important variables that are involved, would be helpful. As far as the

author's knowledge goes, no further research has been conducted that merges all existing rebound types that occur in a circular economy, in one framework to create a clear overview. Such a typology framework can also be used as a decision support technique by policymakers to see what causes different rebounds and who to address to overcome these effects.

Before this framework is presented, a simple representation of important steps is considered that show the triggers, drivers and actors involved in a rebound effect in the circular economy. First, the effect is triggered by an emerging technological innovation, in this case a particular CBM that offers a product, service or encourages sufficiency measures. Second, this changes demand and supply of these particular offers. Third, these changes are driven by either behavioral or economic factors that lead to a specific type of rebound effect.

To visualize this, a framework (1) is constructed that plots all identified types of the rebound effect in a 2-by-2 matrix with dimensions that include the actors of the last two steps. The horizontal axis refers to the supply chain, and on which side of this chain a rebound effect can occur. This is either on the supply-side of a CBM, which includes producers, businesses or policymakers, or the demand-side of a CBM, which includes individual consumers, customers or households. The vertical axis refers to the drives of a rebound effect, with on top the behavioral and on the bottom the economic dimension. The authors identified a total of 10 different rebound effect types. These are listed and explained in the text beneath the matrix. Also, these explanations list which CBM is used most to study a particular rebound effect, and which methodologies are used predominantly. These insights can help future researchers to choose which approach is suitable for comparable research.



Framework 1. Matrix constructed by the author to show for different types of rebound effects, what drives them and which actors are involved.

Direct supply-side rebound effect:

For producers or business owners, saving material resources by designing products or services that last longer and/or can be shared and used by several consumers (dematerialization) results in lower production costs and increased usages, which are likely to increase revenue that can be reinvested to increase production. In other words, firms receiving new revenue may respond by increasing their energy services to expand output. Besides that, circular business models which make use of refurbished or reused products can fail to compete with primary production and thereby just 'grow the pie', which is explained by the imperfect substitution principle.

This type of the direct rebound effect predominantly occurs within 'access and performance' business models and is mostly researched by LCAs, according to the literature.

Direct demand-side rebound effect:

For consumers, making use of services that are less expensive than buying and owning new products saves money which is later available to spend on more of the same goods and services. As long as people do not start saving money to spend on services with low energy intensity, the benefits of CBMs are diminished and in some cases even backfired.

According to the literature, this rebound effect occurs especially in sharing platform services, which invites people for redundant use of the product or service. This rebound effect is also studied predominantly by the use of LCAs.

Indirect rebound effect:
This type is placed in the economic/demand-side corner, beneath the direct demand-side rebound for several reasons. The indirect effect is more difficult to measure and that is why the size is often underestimated and expected to be larger than the direct demand-side effect. When people save initial money by purchasing circular services or goods which are less expensive, they buy additional goods from that saved money. Additional bought products are often energy intensive products (this differs per income group), which are more energy intensive than the initial circular good and therefore the expected rebound is larger. Furthermore, producers or business owners have no influence on the consumption patterns of individual consumers after they saved money and therefore the dot is placed at the economic/demand-side corner.

According to the literature, this effect also predominantly occurs within sharing platform services and is mostly studied by the use of LCAs and input-output.

Economy-wide rebound effect:
This is the only macroeconomic rebound identified by the authors. The transformational effect, as explained by Greening et al. (2000) in section 2.3, has not been identified in the reviewed literature at all. For the economy-wide rebound effect, the literature has proven that it is extremely difficult to measure and therefore it has been insufficiently studied. However, theory provides insights on the potential mechanisms in a CBM that cause this effect. Either the use of CBMs drives down the overall price of other linear business products forced by competition, or CBMs stimulate GDP growth which increases the purchasing power of households and indirectly stimulates production and consumption growth. Both imply economy-wide rebound effects that involve neither solely suppliers or demanders, whereas it seems that these effects are driven by economic mechanisms. Since not many researchers have considered this rebound type in empirical studies, the exact location where to place the dot in the matrix is still open for debate.

Studies that have made effort to study these effects make use of integrated modelling techniques (CGE) within the product-service system domain.

Symbiotic rebound effect:
This effect implies that one inferior circular strategy is preferred above a superior strategy due to the implementation of policies which offer subsidies for the inferior one, on a systemwide level as described by Horvath et al. (2019), or due to supplier preferences which are mostly based on opportunity costs (Figge and Thorpe, 2019). This implies that for example the choice for recycling comes at the cost of having to discard the option of reusing. In both cases, the supplier has the opportunity to choose for the better option, so this choice is based on either morals or economic reasons. That is why the dot is placed in the middle of the economic/behavioral axis.

This effect is identified while studying the case of a product-service system in a theoretical case study.

Informational rebound effect:
This effect suggests that the promotion of policies to mitigate environmental damages may unintentionally undermine consumers intentions to reduce the waste of resources by themselves. Recycling policies implemented by policy makers can influence consumption behavior in a negative way because it can create the feeling that their own efforts are useless and unnecessary. The results showed that an ongoing recycling program significantly offsets the individual efforts of customers to reduce their waste. This rebound effect is caused by the implementation of policies by the 'supply-side', and at the same time the consequences of these policies are because of a behavioral response made by the 'demand-side'. That is why the dot is placed in between supply and demand, at the behavior upper half.

This is studied in an 'encouraging sufficiency' model by the use of an experimental case study

Spillovers and behavioral rebound effect:
Both these effects are triggered by the supplier-side and caused by a behavioral mechanism that implies that consumers have the feeling they have 'done their part'. This moral licensing phenomenon can either be caused by technological progress and the feeling that future technology will fix the environmental problems, or by consumers consciously participating in pro environmental behaviors, such as switching to a vegetarian diet, and then licensing themselves to use more energy intensive services or products like more international flights.

These effects are studied within the 'encourage sufficiency' business model domain by the use of a real effort experiment and a literature review.

Time-use rebound effect:
This effect can be explained by how people spend and plan their time. Making use of activities that involve using products as a service or sharing does not only have the capability to save money but can also save time. In the first place, this saved time can be used to earn extra money to later spend on extra consumption. Furthermore, this rebound effect appears when saved time is spent on other activities that also require the use of natural resources or energy. It is up to the consumer if this extra time is used to take part in other energy intensive activities, which implies a rebound of the potential saved resources.

This rebound type is identified in a literature review that studied efficiency encouragements by Sorrell et al. (2020).

Life cycle rebound effect:

This rebound mechanism is exclusively visible on the supply-side and is about the behavioral difference between owners and users or sharers. Owners tend to have a different psychological relationship with their belongings than users or sharers have with the products they use. This is even more the case with products that have a long life cycle. They are normally more expensive than products with a short life cycle, and owners of these products feel the responsibility to take care of the product and invest in repairing it when necessary. With a shift towards more sharing and renting models, this feeling of responsibility also shifts. At the first place, sharers are more prone to spend money on other goods and services instead of spending money on the performance of products they do not own. Junnila et al. (2018) found out that in the case of housing, sharers (or tenants) spend more money on air travel, which is known for its environmentally damaging character. Secondly, not owning a product yourself ensures careless behavior because the maintaining costs are for the supplier only. This is the case with for instance bike sharing initiatives, where the users know that the supplier takes care of the product when it breaks.

This rebound effect is identified by an input-output analysis when researching the potentials of reduced ownership.

5. Discussion

The findings of this literature review shed light on some noteworthy implications. First, as seen in section 4.3, 'the rebound effect and circular business models', the CBM framework by Bocken et al. (2016) is to a certain extent useful when attributing rebound effects to particular CBM strategies. The framework by Bocken et al. (2016) has proven its effectiveness in guiding businesses in the move from a linear to a circular economy in the past, but now it is time to assess whether these strategies are subject to rebound. The results showed that the existing literature only found rebound effects for four out of six strategies. This can be dedicated to the size of the use phases involved in the strategies. Strategies that have a relatively large use phase, like an 'access and performance model', are more prone to rebound. On the other hand, the research on rebound effects in the circular economy is still in its early stages, which implies that some strategies are just not empirically tested on the existence of a rebound effect. Furthermore, the 'encourage sufficiency' model might be not very suitable to specifically attribute rebound effects to, since it involves anything that implies a reduction of consumption. A more narrow definition or subdivision of the model could bring better targeted insights in which particular part of consumption reduction a rebound effect occurs. Second, the created typology framework contributed to the existing knowledge on the rebound effect in the circular economy by identifying types that involve consumer behavior. This adds to the four-part typology introduced by Greening et al. (2000) that is based on the classic rebound effect discussed in energy efficiency and energy economics and excludes these behavioral instances. The created framework could help to assess the environmental implications of circular products, services and policies in a more comprehensive manner, and shows future policymakers which actors and mechanisms are involved in specific rebound effect types.

Beyond these insights, the findings in this relatively new research area show that addressing rebound effects has the potential to mitigate unforeseen but significant environmental damages. While the circular economy is often seen by scholars and practitioners as a way to moderate or even overcome current problems regarding overconsumption and overproduction, it may fail to deliver on its potential when economic realities are considered. According to empirical evidence from the reviewed literature, an environmental rebound effect in the circular economy certainly exists. The magnitude however is still arguable and dependent on a lot of internal and external factors. It is important to mention that results are surrounded by high levels of uncertainty due to data quality and data shortcomings and assumptions. Presently, the direct rebound effect is the only effect that can be quantified with reasonable certainty, while indirect or economy-wide effects are less predictable and determinable due to their complexity.

Despite the fact that no new evidence emerged from this research, this systematic review is the first study to evaluate and examine all written research in this particular area. While a critical note towards the real environmental impact of the circular economy was missing, this research bundles all evidence of the rebound effect in the circular economy and shows the need for further research on this specific topic. Awareness on the existence of rebound effects needs to

be raised and acknowledged in order to rethink the value that the circular transition has to overcome current environmental problems.

Since this research area is becoming increasingly popular and research on this particular topic is conducted more often, another systematic review could be conducted in the future. Chapter 4.4 shows the research gaps that are identified by the authors which include; using different and better methodologies and research types, elaborate on the motivations of consumer behavior and different lifestyles, and complementing existing data on real life household spending patterns. Adding to this, future research could also focus on building an inclusive methodological framework that can be used to compare findings from different studies. Until now, the differences between results are large and incomparable. One type of centralized research method for every rebound type would increase the comparability of the studies in a couple of years.

This literature review has some limitations which have to do with the samples and its size. One would expect that there is abundant research that covers both the circular economy and the rebound effect, however, this is not the case. Because of a lack of previous research, only 36 papers were found relevant to include in this review and that has its limitations. This number is insufficient for any statistical analysis which reduces the validity of the research. Findings cannot be generalized and some specific rebound types are based on a single article. Besides that, the selection of the sample is subject to personal choices made by the author. Other researchers could have made a broader selection of articles and highlight different perspectives which could lead to different conclusions. Furthermore, if other or more search terms would have been included in search engine Scopus, perhaps other relevant articles could have been added to the review. Another limitation to this review is that only papers that include the term ‘rebound effect’ or related terms are included in this review. This can create a positive bias towards the existence and size of the rebound effect in the circular economy. Ideally, other studies that measure the potential (environmental) benefits of circular business models, which do not include anything related to the rebound effect, would have been considered as well. This would prevent the positive bias towards the size of the rebound effect and could make up for a comparison between the two literature strands.

6. Conclusion

The economic and environmental potential benefits of the circular economy and its corresponding business models are frequently proclaimed, however limited empirical evidence exists on the actual benefits and a critical note in the valuation of these models is still lacking. When rebound effects are not considered, it would be hard to say how these models differ from traditional linear business, since the environmental benefits are considered the main goal of the circular economy. That is why this research reviewed all relevant literature concerning rebound effects in the circular economy. The interest in studying the combination of these two subjects is growing and the outcomes could have a significant impact on future decisions made by policymakers that regard the circular economy and its further implementation.

The reviewed papers were collected with the help of search engine Scopus and by entering search terms related to both concepts. After discarding all non-relevant articles, a selection of 36 studies remained. These studies are examined on several indicators such as; identified rebound type, which CBM was studied, used methodologies, sectors and identified research gaps. This data helped to answer the following research question: ‘according to the existing rebound effect literature, to what extent does the circular economy lead to environmental rebound effects?’. Eventually, this has led to a framework that categorizes different types of environmental rebound effects that are present within the circular economy domain and places them according to the relevant actors (supply and demand) and causes (economic and behavioral) of these effects.

More than one third of the literature on the rebound effect in the circular economy is written about the transport sector and especially the automotive industry. Among other things, this can be explained by the large use phase that vehicles have in which most greenhouse gases are emitted and in which rebound effects are likely to occur. The other sectors are; general consumption, food, housing/construction, electronics/ICT and others, in which consumer behavior and lifestyle changes play a large role. Also, smart homes or buildings, food waste reductions and the role of electronics/ICT in the sustainability transition are considered subjects.

Bocken et al. (2016) came up with a framework to identify different circular business models that either slow down or close the material loop. From this framework, the ‘access and performance model’ is studied most in relation to the rebound effect. Similar to the explanation about why the transport sector is predominantly studied, this CBM is also mostly involved in changes in the use phase and change in ownership. While results differ from study to study it seems that making use of sharing, hiring or repair services does not naturally decrease the material footprint. From both production and consumption sides there are arguments that strengthen this claim. The 1:1 displacement of primary raw materials by circular activities, such as reusing and refurbishment, seems unlikely due to technological limitations and unsustainable consumer behavior which implies a ‘grow of the pie’ principle. Furthermore, participating in such circular activities is bound to monetary savings, which will be spent on other consumer goods later on. Unfortunately,

consumer patterns tend to move towards buying more and more energy intensive products which in return indicate large rebound effects. The ‘encourage sufficiency model’ is mostly based on the consumer side of the story and in particular on the reduction of consumption. Also, specifically for this CBM several rebound effects do occur, among which the usual direct and indirect effects but also effects related to time-use, behavioral responses and policies implemented from above. These may have the same negative impact on the environment but are triggered by different motives than financial ones. Furthermore, several methods are used to study these different types of rebound effects. In short, quantitative methods, like LCA’s and input-output analysis, are commonly used to give a range of the size of the rebound effect, while qualitative methods, like surveys and experiments, are used to describe or explore new types of the rebound effect in combination with the circular economy. The identified research gaps showed that future research should focus on using integrated modelling techniques, such as GCE and ABM, in order to get a full picture of the size of a rebound effect (also economy-wide) while data on consumer behavior and economic preferences is integrated.

The magnitude of all the considered types of rebound effects depend upon a wide variety of factors, which makes studying this subject difficult, and makes it even more difficult to compare the different studies. Generally speaking, the empirical studies that have attempted to detect the rebound effect on dematerialization/decoupling still remain inconclusive. The scope, region, time period of analysis, product studied and assumptions all differ widely from study to study which makes overall conclusions insufficient. Furthermore, sufficiency strategies seem really dependent on consumer choices and their motivations, circumstances, individual behavior. Pro-environmental behavior that significantly reduces the carbon footprint only works when there is a tendency to behave in a persistent manner in multiple domains at the same time. However, (behavioral) rebound effects often reduce this pro-environmental behavior because people feel like they have ‘done their part’ or that technological changes will find solutions for further problems.

This research also shows that the circular economy might be too focused on individual business models and therefore companies neglect the bigger picture and might actually fail to make environmental improvements. There seem to be trade-offs between certain circular strategies. The symbiotic rebound effect entails that one cannot focus on the reduction of consumption and at the same time focus on recycling. As Zink and Geyer conclude: “What is truly required to reduce environmental impact is less production and less consumption. The circular economy promises this outcome, but, once economic realities are considered, may fail to deliver on its potential” (p. 600). Whilst this is a logical conclusion considering for instance the EU standards to measure a member states circularity index, which relies completely on recycling rates and still allows for maximum production and consumption, however, the tendency to move towards a circular system will still be better than continuing in the current linear means. As the world population keeps growing, satisfying the increasing demand for resources in a growing circular

economy would be favorable over business-as-usual, especially when the current rebound mechanisms present are understood and minimized in the future.

As long as the economy keeps growing as a result of the current neoclassical economy rebound effects will be evident (Walnum et al., 2014). However, to decrease the size and impact of rebound effects there are some areas in which environmental policy makers can put their focus, apart from the fact that the nature of rebound effects should be understood better. Several studies suggest that policy makers can focus on increasing the energy price by eliminating subsidies (Sorrell et al., 2020 and Walzberg et al., 2020), target consumer behavior and lifestyle changes by nudging consumer preferences (in the absence of technological innovation) (Murray, 2013, Vita et al., 2019 and Sorrel et al., 2020) and focus on eco-efficient value creation (Scheepens et al., 2016). All help to mitigate rebound effects by preventing people from spending money on energy intensive goods either by increasing the energy prices or by increasing the consumers' 'willingness to pay' for green consumption choices. Another option would be to increase taxes (carbon pricing in particular) to lower redundant consumption of energy intensive goods, however rebound effects at government level should then also be considered because of their increased revenue.

7. Reference list

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