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The rebound effect of circular economy: Definitions, mechanisms and a research agenda

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\textbf{A R T I C L E I N F O}

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Rebound effect mechanisms
Circular economy rebound
Unintended consequences

\textbf{A B S T R A C T}

Circular economy (CE) is an umbrella concept for closing material loops towards enhanced environmental performance. Despite the recognized benefits of CE, the intended outcomes are not always achieved due to the occurrence of rebound effects. The lack of consideration of potential rebound effects triggered by CE is delaying the achievement of CE’s full potential. This paper aims to further evolve the concept and mechanisms of circular rebound effects by means of a systematic literature review. In this context, this paper proposes a conceptual framework which brings together the main characteristics and mechanisms (incl. the initiating, developer, and mitigating mechanisms) of a rebound effect in the CE context. The four major lessons learned from research on the circular rebound effect were discussed, including its contextual dependencies, the need for new forms of governance, and how direct effects can overshadow the indirect effects of circularity, indicating a need for early-detection instruments. In addition to proposing six avenues of future research, the research provides clarification and a basis for integrating rebound effect concepts into the CE practice, with important implications for a successful CE transition.

\section{Introduction}

Currently, there is a growing need for solutions that are capable of reducing the impact of human activity on the planet. A circular economy (CE) seeks to decouple economic growth from the exploitation of natural resources, minimizing the negative environmental impact caused by human activities (Bressanelli et al., 2019; Lieder and Rashid, 2016). Ultimately, a common CE objective is to “maximize the value of the resources in use” (Kalmykova et al., 2018), to reduce emissions, energy consumption, and waste disposal, going beyond reverse logistics. The literature presents a great debate around the circular economy and the different ways that resources can be managed (Blomsma and Brennan, 2017). The CE represents an optimistic possibility to save material flows, preserve nature, and minimize the extensive use of energy for the transformation of primary materials (Calisto Friant et al., 2020). The benefits of adopting a CE are expressible, and different circular business models that support the transition are currently available (Pieroni et al., 2019, 2020; Rosa et al., 2019b). According to Rosa et al. (2019a), when companies pursue circularity principles, they can improve economic, environmental, and social aspects. For instance, some potential benefits are reducing costs and risks, increasing competitive advantage, minimizing environmental impacts, improving resource efficiency and workplace, developing workers’ skills and knowledge, among others (Rosa et al., 2019a).

Despite the benefits linked with the implementation of CE strategies to achieve sustainability and minimize the environmental impact of economic growth, there are still barriers for the implementation (Schröder et al., 2019). de Jesus and Mendonça (2018) state that CE has been implemented guided by soft drivers, like legislative policies, but at the same time, it has hard barriers, such as lack of technical solutions and low financial investment. Korhonen, Honkasalo and Seppälä (2018) list six limits and challenges for a CE that relate to (1) system boundaries, (2) physical scale of economy, (3) governance, (4)
## Abbreviations

| Abbreviation | Description |
|--------------|-------------|
| CE           | Circular Economy |
| CER          | Circular Economy Rebound |
| EoL          | End of Life |
| ERE          | Environmental Rebound Effect |
| LCA          | Life Cycle Assessment |
| RE           | Rebound Effect |

thermodynamic, and (5) social and (6) cultural context. In particular, the thermodynamic limit listed is about the change in the system to close the loop. However, new flows of resources are created with CE, leading to more waste and emissions. 

Khobron, Honkasalo and Seppälä (2018) state that a holistic (and global) analysis must be performed to assess the environmental benefit of implementing CE strategies. In addition, CE solutions will generate multiple adverse effects (Font Vivanco, Medowall, et al., 2016), since it requires additional resources and infrastructure to be implemented, such the availability of spare parts and different logistics infrastructure (Morseletto, 2020). Figge and Thorpe (2019) and Zink and Geyer (2017) demonstrate that the efficiency of the CE could be affected by how strategies are designed, which represents a theoretical limitation to achieve circularity.

While most of the CE research focuses on implementation and on barriers behind strategies, Corvellec et al. (2021) point out challenges in different levels of CE implementation (policy level, organizational level, and consumer level) emphasizing the complexity of implementing a CE. Multiple stakeholders are needed to be involved in the transition. Private companies, consumers, and policymakers act in the transition to CE in different spheres of applications, which can have different levels of complexity (Guzzo et al., 2019). CE transition goes beyond market changes and definitely impacts sustainability, so it is important to recognize the high complexity arising from the relationships between actors, strategies, energy, material flows and the circular ecosystem (Trevisan et al., 2021; Calisto Friant et al., 2020). Calisto Friant et al. (2020) states that the complexity of CE is given by the following: the implementation extent, on a temporal and spatial scale; the sustainability pillars (highlighting the importance of the social aspect), and the complexity of the interrelationships of the resource nexus.

Different CE strategies can bring different outcomes, and undoubtedly, there is a need to assess the impact of increasing implemented CE strategies. A different result can be a rebound effect (RE) or an unintended consequence. RE theory started with Khazzoom (1980) in energy economics and can be defined as “RE refers to a less than one-for-one correspondence between fuel and efficiency gains and reduced fuel use” (Saunders, 2000, p. 439). The term circular economy rebound (CER) is used when the eco-efficiency of a productive system is offset by an increase in production or consumption (Zink and Geyer, 2017). The adoption and recognition of the importance of CER is justified due CE is primarily interested in material flows, not energy efficiency, so it is fundamental to evaluate the suitability of borrowing RE definitions, classifications, and mechanisms from energy economics. To illustrate the difference between perspectives, a common example of CER is the increase in material usage per product when recycled material is used so, at end-of-life, it generates a greater amount of waste per unit of product. Zink and Geyer (2017) highlight the importance to recognize two mechanisms (1) the product substitution effect and (2) the price effect of CE strategies, corresponding to what Greening et al. (2000), in their seminal work on energy economics, point out as direct and secondary effects. Nevertheless, as shown in the example, these mechanisms are far from fully addressing the complexity of CE implementation and do not explain the adverse result obtained.

Although the existence of the RE is indisputable, the concept is overlooked due to the difficulty of identification and evaluation of the effects, in part because of the lack of clarity and the chosen indicators (Sorrell, 2007). The concept of RE is being timidly transposed to CE, even though it is essential to understand the aforementioned complexity. Zink and Geyer (2017) advanced the theory by proposing a definition and demonstrating how its application differs from the classical application, the next step, therefore, is to explain the occurrence of the phenomenon and the need to investigate the validity of the energy economics mechanisms in the complex system of CE. The first research gap addressed in this paper is explaining that RE may result from several strategic changes at different levels of CE implementation and complexity. The second research gap addressed in this work is the necessity to understand the differences between the mechanisms of the RE in the CE context and those studied in the context of energy economics.

In order to address the above-mentioned theoretical gaps, the research question addressed in this paper is “How does the rebound effect occur in a circular economy?”. The aim of this paper is to investigate the mechanisms that lead to a rebound effect in a circular economy, creating an analytical pattern based on the literature. The CER brings a critical discussion to the CE theory and an overview of new challenges encompassing broad mechanisms of rebound effect to practice. Understanding the RE mechanisms and their relations will assist in developing better future policies, in which strategies are cause-oriented rather than effect-oriented.

The paper is structured as follows. Section two presents the theoretical foundations of CE and RE that guided this research; section three describes the systematic literature review method adopted. The research question is discussed in section four, presenting the CER mechanisms. In section five, discussion, the lessons from results are discussed. One of the main contributions of this research is presented in section six, along with the indication of prominent avenues for research. In section seven, the conclusion points to the main contribution and limitations of this paper.

## 2. Theoretical foundation: definitions and boundaries

### 2.1. Circular economy

Despite the many fields of research, the current understanding of CE is based on three fundamental principles: “(1) Designing waste and pollution, (2) keeping products and materials in use, and (3) regenerating natural systems” (EMF, n.d.). CE is defined here, following Geissdoerfer et al. (2017), as “a regenerative system in which resource input and waste, emission, 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.” A CE requires practical actions that we understand as strategies, following the practical perspective of Guzzo et al. (2019) on how to achieve circularity. This implies that a CE goes beyond material recirculation and expands to other domains like innovation, human behavior, and consumption. Indeed, the social and cultural facets should be central to the CE debate (Hobson and Lynch, 2016).

Viewing the CE as a complex system that connects different markets, stakeholders, material, information, and energy flows, its result is still not well understood. Assessing and evaluating the sustainability impacts of circular systems is another significant challenge. Even though the circularity performance can be measured by different methodologies, such as Life Cycle Assessment, Data Envelopment Analysis, Simulation, Material Flow Analysis, and others, a reliable and practical measuring process is not a simple task (Sossanelli et al., 2019). Calisto Friant et al. (2020) classified the circularity complexity in five levels; the first one is short-time and micro-scale, including single products or services. The complexity rises as time gets longer and the unit of analysis expands to industries, industrial parks, regions, countries, and the whole planet. These levels of complexity lead to different levels of implementation in a CE.

System boundaries are relevant when taking into account the levels of implementation of and Corvellec et al. (2021) divide them into three
levels: (1) policy level, (2) organizational level, and (3) individual level. The concern is about system boundary limits at the policy level, with policies to stimulate material flow and innovations. However, there is a lack of interest in social aspects, focusing on allowing economic growth. At the organizational levels, there is a variety of circular business models implemented only partially or working just in a specific context. Circular business models fail to address the roots of sustainability problems, leading to the third level: the consumer. At this individual level, the cultural change should be addressed, revealing a circular structural problem (Korhonen et al., 2018).

The impact of industrial activities can also be grouped in different levels of system boundaries, and “the transition to circular economy is a multilevel governance challenge” (Antikainen et al., 2018, p. 125). These authors state that research is needed to support decision systems, and the necessary transformation involves issues of innovation, business models, fiscal adjustments, and technologic. Innovations are needed for improvements in material processes, new business model proposals, and public policies support. Technology supports the sharing of information and responsibility among stakeholders. Manninen et al. (2018) point out the challenge in estimating the real benefits of the CE at different assessment scales, especially when many actors are involved in the value chain.

2.2. Rebound effect

The classical RE theory from energy economics initially approaches the effects of energy efficiency on the power system itself (Khazzoom, 1980) with the estimation of changes in energy demand in the function of price elasticity and improvement on efficiency. In a second moment, the RE theory also estimates changes in carbon emissions (Brookes, 1990; Saunders, 1992) in the function of energy improvement and demand. The need to achieve lower environmental impact increased interest in the RE theme. While Khazzoom sees only price elasticity without ramifications, Brookes incorporates a macroeconomic view, observes GHG and CO2 emissions, and comments that the RE theme is answering a green fever. Researchers have already seen the complexity of the RE phenomenon, with the direct or first-order effect, which reverberates through the system and creates second-order or indirect effects (Berkhout et al., 2000; Greening et al., 2000).

The literature mostly identifies three types of RE: direct, indirect, and economy-wide rebound effect (Greening et al., 2000; Saunders, 2000; Sorrell and Dimitropoulos, 2008). A fourth type commonly found is the transformational effect. There is a relationship between the effects’ response time; the direct ones have a fast response, the indirect ones are slower, and, in the long run, the changes reach economy-wide effects (Ruzzenenti and Basosi, 2008). In contrast with the previous attempt of classifying and creating a typology of RE, Turner (2013) lists fourteen mechanisms that generate a RE and four causes, without classification and with a greater possibility of generalization to different areas.

A more focused perspective on actions against climate change is taken by Sorrell (2007), but entirely within the theoretical framework of energy economics. Authors highlight the importance of defining inputs and outputs and the appropriate definition of limits for the studies; in his case, definitions of efficiency and energy consumption. Ruzzenenti and Basosi (2008) found that the increase in the complexity of the production system increased the circulation of materials and consequently the energy density. The authors suggest that increasing the system’s complexity corresponds to increased efficiency, showing that the difference in productivity is used not to save resources but to increase production.

The classical theory evolved from energy efficiency to sufficiency (Alessi, 2008), and Giampietro and Mayumi (2018) stated that RE was valid not only in relation to energy efficiency but also to resources in general. It is essential to evolve the theory, but the main body of literature focuses on energy efficiency and disregards other resources, such as water, materials extractions, and land use (Font Vivanco et al., 2018). Under the theoretical lens of industrial ecology, the RE concept was expanded to include life cycle consequences (Santarius and Soland, 2018). Expanded views of the possibilities for understanding the RE through other disciplines to address environmental impact were provided later. Walnum et al. (2014) analyze the RE under five perspectives: energy economics, urban planning, evolutionary, socio-psychological, and socio-technological. The authors conclude that a multidisciplinary approach is the best to understand the complex phenomenon of RE.

In line with Lange et al. (2021) and Sorrel (2014, p. 2850), who writes: “The ‘rebound effect’ is an umbrella term for a variety of economic mechanisms that reduce the ‘energy savings’ from improved energy efficiency,” the term rebound phenomenon is used in this paper to refer to the entire RE problem. The variety of mechanisms, effects, and outcomes is a rebound phenomenon. Therefore, a distinction must be made between RE and the phenomenon definition. The RE definition adopted in this paper is: RE is a divergent outcome or effect from the intended benefits caused by a systemic response to efficiency or technological change (Berkhout et al., 2000). This means that although introducing more efficient equipment or processes may generate energy savings or increase productivity, the rest of the system (producers and consumers) react to this change, increasing consumption and production.

As stated by Chen (2021, p. 5), “the development of CE should not solely focus on how much energy can be saved or how many job opportunities will be created” as part of the expected benefit could be lost because of behavioral changes (Walnum et al., 2014).

The CE is causing a complex systemic change with different results from energy economics. The focus of this paper is on the environmental outcomes of CE, which generally involve a secondary production and a market for secondary goods, replacing the primary production (with the extraction of virgin materials). In this paper, secondary production refers to activities such as reuse of components, remanufacturing, and recycling. Therefore, the rebound effect of circular economy occurs when the impact of secondary production does not replace primary production in the same proportion, and its environmental impacts are increased, not reduced (Zink and Geyer, 2017). In other words, the perceived benefit from the CE strategy is less than the potential benefits because of systemic changes, such as increased productivity and consumption. This concept is aligned with the classical RE concept, as in Weidema et al. (2009, p. 23): “Rebound effects are the derived changes in production and consumption when the implementation of an improvement liberates or binds a scarce production or consumption factor.” It is emphasized that this improvement in production leads to a change in consumption behavior.

3. Research methodology

This paper employed a systematic literature review approach (Briner and Denyer, 2012; Tranfield et al., 2003) to investigate the rebound effect phenomenon within a CE context. A systematic review makes it possible to achieve new theoretical results based on evidence, synthesizing the state of knowledge and providing new insights into the area. A good review opens up possibilities for further discussions and the advancement of future research (Cronin and George, 2020). The research design was constructed based on the five steps proposed by Briner and Denyer (2012): (1) planning the review; (2) locating studies; (3) appraising contributions; (4) analyzing and synthesizing information; and (5) reporting “best evidence”. Following an already established methodology, it is possible that the result represents the perspective of different theoretical communities and integrates different concepts.

Planning the review. Two main questions guided the literature review: (1) what is the rebound effect phenomenon in the field of CE? and (2) how do rebound effects occur in CE implementation? The concepts and constructs of CE and rebound effect were analyzed separately. As a result, a list of concepts, typologies, and mechanisms specific to each area were obtained. This made it possible to capture the nuances of the
relationship between the concepts, understand the perspectives and design the search strings for articles.

**Locating the studies.** Three preliminary tests for searching papers were done using different keyword strings, including the addition of new keywords after the snowballing strategy. The search results were rigorously evaluated by the researchers, and search strings for which results would be mostly discarded due to incompatibility with the research objectives were not used in the final search protocol. The final formulation of the search string included the keywords “rebound effect,” “circular economy,” and their synonyms. The complete search protocol is presented in Table 1. The search was conducted in the Scopus and Web of Science databases, resulting in 73 articles after duplicates and editorials were removed and after reading the abstract (Fig. 1), in the basis of the inclusion and exclusion criteria detailed in Table 1.

**Appraising contributions.** The list of 73 papers was selected to be fully read, 20 were excluded, and 6 new papers were added due to the snowballing strategy. A backward snowballing (Wohlin, 2014) was conducted, which means that the references from the 53 pre-selected papers were scrutinized to search for other relevant papers. The final sample included 59 articles. The search was an iterative process until June 2021. This iteration allowed newly published papers to be inserted and ensured that the analysis proceeded without the risk of overlooking relevant articles. The newly added articles provided a set of new examples but did not interfere in the results and framework proposed here. Thus, we consider that the selected papers are sufficient to answer the proposed research questions.

**Analyzing and synthesizing information.** The analyses were conducted with the Maxqda professional software, used for qualitative analyses. A robust code system was created to analyze the selected papers, following the code cycle rationale proposed by Miles et al. (2014). During the first coding cycle (descriptive code), the researchers assigned code to chunks of text to detect reoccurring patterns. This first cycle aimed to detect the prominent existing concepts around RE and CE. The second coding cycle (attribute code) aimed to analyze the major concepts of RE. The fundamental elements were coded and categorized, revealing the existence of RE mechanisms and contextual factors that influenced the magnitude of the RE. Finally, the third coding cycle (hypothesis code) aimed to understand the particularities of the mechanisms of the circular rebound effect and generate new knowledge about it. The final code structure of the three cycles is presented in Table 2.

The synthesis of the information focuses on (1st) uncovering the theoretical perspective of the literature of RE (presented in section 4) and (2nd) developing a framework to explain the RE mechanisms and the intervening factors.

### 4. Circular rebound effect mechanisms

A mechanism is a commonly used term that refers to a set of interdependent elements that cause an activity or process to occur, such as mechanical and physiological mechanisms. This work investigates the existence of specific mechanisms of RE, thus responding the research question, “How does the rebound effect occur in a circular economy?” In this research, the phenomenon identified has in the structure two explicit mechanisms: the initiator and the developer mechanisms. They are linked to the reasons for the occurrence of RE. Our analysis also reveals the possible existence of a third mechanism: the mitigating mechanism. As implied by the name, this mechanism mitigates or minimizes a RE. The proposed framework (Fig. 2) shows the phenomenon structure, in other word, shows how rebound effects can arise under the theoretical lens of CE and unifies the CER phenomenon. It shows the mechanisms within the CE lens responsible for the CER phenomenon, with the initiating mechanisms triggering changes that lead to developer mechanisms that cause RE. Mechanisms that can mitigate RE and some of the relationships between these mechanisms are presented. One of the important relationships is the cyclical behavior of the mitigating mechanism, which, through its interaction with the socioeconomic context, can also act as an initiating mechanism to another RE. These mechanisms and their elements are intricately detailed in this section. The presence of some raised RE is noteworthy, presented together with the mechanisms. These REs are not limited to this list, and it is understood that, although classical studies only quantify RE linked to the environmental sphere, social and economic effects are equally relevant for the CE to lead to sustainability.

#### 4.1. Rebound initiating mechanisms

The initiating mechanism can be understood as a trigger that alters the function or structure’s system leading to a rebound effect. The actions of the mechanisms are the first ones perceived when observing the CE phenomenon, and are related to the three levels of CE implementation. Five groups of potential triggers were found: (1) CE strategies, (2) CE transition, (3) innovation, (4) new business models, and (5) environmental policies. In Table 3 the mechanisms are briefly described and pointed out some examples of each cause.

In the first level of CE implementation related to consumers, individual level, the circular economy strategies are implemented to improve the system’s environmental efficiency, reduce resource use, improve the middle-of-life and the end-of-life, and better integrate the network actors. But, as one change is implemented, it can cause RE. A high number of papers in our sample (24) presents some evidence of CE strategies triggering RE and making it difficult for the CE to reach its potential. Horvath et al. (2019) directly emphasize this contradiction, as the developments to improve waste treatment efficiency will encourage business as usual and generate more waste than before. Dace et al. (2014) also conclude that a recycling strategy for plastic packaging will cause landfills to grow quickly, as we need a large amount of secondary materials to substitute virgin materials and obtain the same properties. Another effect of recycling is a social one, raised by Sinha et al. (2016), where the valorization of electronics waste can induce informal recycling and material losses. According to the authors, the recovery rate of informal recycling is lower than the regular recycling of the CE system. The easy access to CE strategies needs to be considered for the success of CE. Dace et al. (2014) discovered that there has to be a container nearby to sort the waste for people to start considering recycling. The same logic is applied to reuse or repair, Niero et al. (2021) exemplify this with the consumers’ adoption of reuse of shampoo bottles dependence on the proximity of a store to refill it. van Looon et al. (2021) argue that if the product does not require energy use during use, the reuse and remanufacturing strategy will have a positive impact. On the other hand, if the product consumes energy during use, replacing it with new ones can avoid the negative effects of old and polluting products, such as older refrigerator models containing GHG.

The CE transition has to be considered when implementing and evaluating the impacts of the CE. Makov and Font Vivanco (2018) affirm...
that operating costs must be contemplated, and Wallenborn (2018) complements by affirming that the intensification of material use and the construction of infrastructure are necessary but rarely measured how it will increase the embodied energy. Some of the CE strategies to be implemented may require more transportation, spare parts, additional industrial processes, and new sales or trade points. This process rarely occurs in the same geographical location (Ottelin et al., 2020). Siderius and Poldner (2021) are emphatic that some rebound effects’ causes come directly from the transition. “This includes the need for infrastructure and transportation between organizations that can now benefit from each other’s waste streams and the increased necessity for (dis-)assembly practices due to modular design. This type of rebound is inherent to the transition, as it embodies the energy required to move from one system to the next” (Siderius and Poldner, 2021, p. 6). The authors argue that a separation between transitional CER and the design, economic and behavioral CER is useful to propose better mitigation strategies.

Innovation is another perceived activity related to a CE transition. The incremental innovation can contribute to reducing emissions, saving energy consumption, and improving efficiency. While a positive impact is clear, the innovation can generate many new products, partially substituting old products and changing the way we

Table 2

| Cycle                  | Code structure (1 level) | Code structure (2 level) |
|------------------------|--------------------------|--------------------------|
| 1st Cycle (Descriptive Code) | Article information       | - Objective              |
|                        |                          | - Theoretical approach   |
|                        |                          | - Methodology            |
| Rebound effect         |                          | - Definitions and theoretical perspective |
|                        |                          | - Causes and consequences|
|                        |                          | - Levels of occurrence   |
|                        |                          | - Sector of analyses     |
| Circular economy       |                          | - Mitigation strategies  |
|                        |                          | - CE strategies          |
|                        |                          | - CE goals (intended impacts) |
| 2nd Cycle (Attribute code) | Rebound effect           | - Types                  |
|                        |                          | - Actors                 |
|                        |                          | - Consequences           |
|                        |                          | - Mechanisms             |
|                        |                          | - Contextual factors     |
| 3rd Cycle (Hypothesis code) | Rebound effect           | - Initiating             |
| Mechanism              |                          | - Developers             |
|                        | Socioeconomic context   | - N/A                    |

Fig. 1. The results of data retrieved.

Fig. 2. Circular economy rebound phenomenon: The framework shows how the CER phenomenon occurs, illustrating the relation between the initiating, developers and mitigating mechanisms, with the RE and the socioeconomic context.
challenging to anticipate. It is possible to see that the new business create a new market system for the end of life of final goods. However, it
Furthermore, new technology brings a problem of obsolescence. Incre
also creates more interactions, and the results for society are more
between firms, and these new connections can initiate a RE within the
ecodesign choices also create other needs of new connections within and
consumption.
products are replaced by newer ones (LED lamps) before the end of life,
the CE
CE strategies Strategies like recycling, reusing, or extending product longevity will alter the system function, adding new actors, new connections, and, consequently, new flows among them. This represents systemic responses to the implementation of circular strategies.

- Business models
- Actor’s interaction
- Generate more waste
- Increase in informal jobs
- Generate more emissions

CE transition The implementation of circular strategies requires investment in new infrastructure or adaptations and new actors in the ecosystem. Transition impacts and RE can be transitory.

- Ecosystem design
- Actor’s interaction
- Consumer behavior
- More embodied energy
- Waste generation
- Waste generation

Innovation A needed action in CE to develop more sustainable products (circular products) or facilitate the end of life, but one that could generate too many options or use dangerous materials (such as present in electronics).

- Product design
- Consumer behavior
- Ecosystem design
- Actor’s interaction
- Increase in energy consumption
- Generate more emissions

New business models New business models create varying demands for new (secondary) markets and materials. These new systems create new impacts. The efficiency of CE and the interaction between systems can create new industries and new rebound effects.

- Travel
- Increase in transportation
- Waste generation
- Energy generation
- Energy generation

Environmental policies Environmental policies are the means for governments to encourage the transition to CE; however, without adaptation to specific local contexts and without collaboration between governments for joint measures, they can lead to RE locally, or in places outside their borders.

- Increase in energy consumption
- Generate more emissions

Table 3 Description of the initiating mechanisms.

| Group          | Description                                                                 | Impacted Structure | CER                                      | Source                                                                 |
|----------------|------------------------------------------------------------------------------|--------------------|------------------------------------------|------------------------------------------------------------------------|
| CE strategies  | Strategies like recycling, reusing, or extending product longevity will alter the system function, adding new actors, new connections, and, consequently, new flows among them. This represents systemic responses to the implementation of circular strategies. | + Business models + Actor’s interaction | Generate more waste + Increase in informal jobs + Generate more emissions | Dace et al. (2014); Horvath and Magda (2017); Kjaer et al. (2018); Laurenti et al., 2016; Niero et al. (2021); Otteil et al. (2020); Sinha et al. (2016); Widmer et al. (2018) |
| CE transition  | The implementation of circular strategies requires investment in new infrastructure or adaptations and new actors in the ecosystem. Transition impacts and RE can be transitory. | + Ecosystem design + Actor’s interaction + Consumer behavior | More embodied energy + Waste generation + Waste generation | Barrie et al. (2017); Bridgens et al. (2019); Flachenecker (2018); Otteil et al. (2020); Siderius and Poldner (2021); Wallenborn (2018) |
| Innovation     | A needed action in CE to develop more sustainable products (circular products) or facilitate the end of life, but one that could generate too many options or use dangerous materials (such as present in electronics). | + Product design + Consumer behavior + Ecosystem design + Actor’s interaction | Waste generation + Increase in energy consumption + Generate more emissions | Barrie et al. (2017); Beckma et al. (2021); Dzomabak et al. (2019); Freeman (2018); Jia et al. (2019); Laurenti et al., 2016; Wallenborn (2018); Zink and Geyer (2017) |
| New business models | New business models create varying demands for new (secondary) markets and materials. These new systems create new impacts. The efficiency of CE and the interaction between systems can create new industries and new rebound effects. | + Travel | Increase in transportation + Waste generation + Energy generation + Energy generation | Bridgens et al. (2019); Kjaer et al. (2018, 2019); Makov and Font Vivanco (2018); Otteil et al. (2020); Siderius and Poldner (2021); Skelton et al. (2020); Wallenborn-Lundström and Laurenti (2020); Widmer et al. (2018) |
| Environmental policies | Environmental policies are the means for governments to encourage the transition to CE; however, without adaptation to specific local contexts and without collaboration between governments for joint measures, they can lead to RE locally, or in places outside their borders. | + Increase in energy consumption | Generate more emissions | Barrie et al. (2017); Dace et al. (2014); Giljum et al. (2008); Giraudet et al. (2021); Muposhi et al. (2021); Niero et al. (2017); Qi and Roe (2017); Santarius (2016); Solaymani et al. (2015); Zhang et al. (2017) |

communicate and produce (Wallenborn, 2018). For example, we have more efficient communication devices – i.e., smartphones and tablets – as they become more accessible, but we have more devices than before. Furthermore, new technology brings a problem of obsolescence. Incremental innovation leads to a short product lifecycle and more consumption (Laurenti et al., 2016a), and new technologies do not always completely replace the old ones. Dzomabak et al. (2019) state that some products are replaced by newer ones (LED lamps) before the end of life, with the justification of being more efficient, which increases the waste generated. Another effect of technology is the time saved; the consumer can spend time on other activities with negative impacts. Freeman (2018) also argues that these efficiency improvements can interact and generate a rebound effect in the meso and macro levels. As seen in the transportation sector, the increase in vehicle productivity and new business models (sharing economy) has caused more CO2 emissions (Ottelin et al., 2020). Zink and Geyer (2017) exemplify the problem of new technologies related to virtualization as a circular strategy brought about by video-on-demand. Although the solution has less impact than the very least – to the creation of entirely new industries and new rebound effects.

The CE encourages strategies that remove the sense of ownership and consumers are stimulated to rent products, fulfilling the need to use the function, without the need to have the product, shifting the focus from product to function, like sharing economy and Product-service-system - PSS (Laurenti et al., 2016a,b). PSS refers to a business model where the company sells a service associated with a product or sells its function. Thus, the consumer does not own the product but uses all the benefits associated with it (Martin et al., 2021). Sharing economy is based on PSS, and differentiated from it as it allows the consumer to share their resources or those of the orchestrating company (Li et al., 2022). The sharing economy can enhance product utilization, avoiding over production. However, these new business models can save consumers money, which they will spend on other activities and products that require additional resources. Another source of RE is the adaptation of the market to this new offer, with changes resulting from the demand and the availability of the service and materials that move to other activities (Kjaer et al., 2019). A common requirement for product robustness needed in the sharing economy can also lead to product designs with more material to guarantee mechanical endurance, or a change in a fleet can lead to more waste generation at the time of transition. The equilibrium point between transitional CER and the latter benefits of CE needs to be further investigated.

On the one hand, PSS can help disseminate circular ideas by proposing new user behavior patterns, encouraging other attitudes such as maintenance, recycling, or reuse. PSS is, therefore, an enabler to operational efficiency, product longevity, and intensified product usage (Kjaer et al., 2019). However, efficiency must be guaranteed and ensure a net resource reduction (Kjaer et al., 2019). PSS can consume more energy and have more emissions than product offerings. Studying peer-to-peer sharing boat users, Wallenborn-Lundström and Laurenti (2020) found that 49.6% of users saved money due to leasing a boat.
They increased spending in other areas, living costs, and 18% declared taking additional travels. If the sharing economy is analyzed in isolation, it is an advantage, but other factors will influence it in the system.

At a policy level of implementation, new environmental policies are created to accelerate the transition to CE (e.g. policies that ban the use of some products/materials, carbon emission taxes or energy consumption regulations). Such policies aim to change the actions and interactions between producers, users, and the market. Nevertheless, the potential policy-induced intended effects can be compromised by not modifying linear user behavior, leading to more production, or shifting the production to other locations, and leading to a RE. The RE coming from policies can be perceived as material loss, social impact and carbon leaking. There is a long-term loss of the benefits brought by the imposition in using recycled materials, such as the increase of material per product, increasing its weight. That would lead to more material in sanitary landfills (Nhamo, 2008). Another possibility is the product that replaces the banned from consuming more material than the first. An example is reusable bags, with despite having a long-life cycle and not going to dumps soon they could pollute more in their production. The effects can also be indirect, such as a decrease in jobs in the production of the material, or health, as reported by Muposhi et al. (2021), in which 12 people died from contamination with bacteria from unwashed reusable bags.

Another perceived RE is carbon leaking, as a common policy aiming sustainable development is carbon taxes. Giljum et al. (2008) point out in their study the introduction of a carbon tax and implementation of more circular strategies in Europe will enhance the manufacturing sector, and it will specialize the extractive industry in developing countries, leading to a RE outside the borders where the measures were implemented. The geographical boundary of an environmental policy is indicated as a barrier to policy effectiveness. Unilateral laws and incentives applied in small regions can overwhelm neighboring areas or other countries (Zhang et al., 2017). The author studied how the carbon tax in China will rebound in other countries around the world. They found that cross-border externalities can be a barrier to reducing GHG emissions and add that the country of origin of the policy may lose competitiveness through the energy channel. For example, if the industrial sector is taxed in China, there may be a decrease in price in other parts of the world, which would increase the competitiveness of these countries, harming Chinese trade.

### 4.2. Rebound developer mechanisms

The dynamics of the rebound phenomenon depend on the initiating factor, which triggers a response mechanism called developer mechanisms. These involve significant changes in the system and have a causal relationship with the initiating mechanisms. In this paper, the developer mechanisms are divided into three groups: (1) consumer behavior, (2) producer behavior, and (3) macroeconomics, and we recognize a circular pattern of causality between them. A summary of these groups is presented in Table 4.

Makov and Font Vivanco (2018) argue that the ERE is very sensitive to consumer behavior. Kjaer et al. (2018) mention three consumption factors involved in the rebound phenomenon concerning PSS: money, time, and access. These three factors can be understood as the income effect, the consumer savings by the CE strategy, with lower price, less time consuming, or more accessible choice opportunity, alters the demand. As a result, the user can consume others products and spend time doing non-efficient and higher environmental impact activities (Laurenti et al., 2016a). Thus, consumer behavior can be resumed by increasing consumption (even sustainable options) and changing habits. In the clothing market, for example, primary production is not replaced by the second-hand market, on the contrary, the consumer buys these reused clothes in addition to others. These clothes are cheaper, which increases the consumer’s purchasing power (van Loon et al., 2021).

The classic rebound effect theory examines consumer demand as an

### Table 4
Description of developer mechanism.

| Group | Description | Impacted Structure | Source |
|-------|-------------|-------------------|--------|
| **Consumer behavior** | The change in consumer behavior from linear to circular is desired, but in some situations promoted by CE, the linear behavior is amplified. | - Income increase<br>- Increase in consumption<br>- New activities | Beekma et al. (2021); Chan et al. (2020); Dace et al. (2014); Dzombak et al. (2019); Fernandez-Mena et al. (2020); Freeman (2018); Gava et al. (2020); Ghisellini et al. (2019); Giraudet et al. (2021); Hall (2013); Hardadi et al. (2021); Horvath and Magda (2017); Kjaer et al. (2018), 2019; Laurenti et al. (2015); Laurenti et al., 2014; MacCutcheon et al. (2020); Makov and Font Vivanco (2018); Niero et al. 2021; Otten et al. 2020; Qi and Roe (2017); Siderius and Poldner (2021); Singh et al. (2019); Skelton et al. (2020); Sprecher et al. (2017); Unni and Takeuchi (2014); van Loon et al. (2021); Wallenborn (2018); Warmington-Lundstrom and Laurenti (2020); Widmer et al. (2018); Zhang et al. (2017); Zink and Geyer (2017) Beekma et al. (2021); Chan et al. (2020); Figge and Thorpe (2019); Flachenecker (2018); Giraudet et al. (2021); Horvath and Magda (2017); Jia et al. (2019); Kjaer et al. (2018); Laurenti et al., 2016; Makov and Font Vivanco (2018); Niero et al. (2021); Otten et al. (2020); Santarius (2016); Sinha et al. (2016); Skelton et al. (2020); Solaymani et al. (2015); Wallenborn (2018); Zhang et al. (2017) Flachenecker (2018); Font Vivanco and van der Vooet (2014); Freeman (2018); Ghisellini et al. (2019); Giljum et al. (2008); Jia et al. (2019); Makov and Font Vivanco (2018); Muposhi et al. (2021); Skelton et al. (2020); Solaymani et al. (2015) | |
The strategies to mitigate CER should include a combination of some of these 5 mechanisms groups: (1) early detection, (2) environmental policy, (3) Sustainable R&D, (4) price control, and (5) motivating the population, a summary of them presented in Table 5. Some of the proposed mechanisms may harm low-income consumer groups, such as price controls, so there is no consumption growth. The mitigation should consider the asymmetrical distribution of wealth and inequality. Prioritization must be made between these elements, giving preference to mechanisms that lead to structural change instead of a more constrained world. Barrie et al. (2017) state that niche strategies should be encouraged in the socio-technical system for efficient circularity.

Environmental Policies are the most cited and studied instruments to mitigate RE. They can be divided into production taxation or incentives to environmental actions. The government must “seek a trade-off between economic development and emission reductions” (Jia et al., 2019, p. 2178). Lauretti et al. (2016a) point out that an instrument to reduce unintended consequences is by incorporating the environmental costs into price or production, or consumption, arguing that this revenue could be allocated to develop new infrastructure and markets. On the

| Table 5 Description of mitigating mechanisms. |
|---------------------------------------------|
| **Group** | **Description** | **Source** |
| Early detection | Orchestrators and governments must invest in systems thinking so that possible RE be identified before they occur in the project phase, and thus be diminished or avoided | Beekma et al. (2021); Fernandez-Mená et al. (2020); Gava et al. (2020); Jia et al. (2019); Niero et al. (2021); van Loon et al. (2021); Warmington-Lundstrom and Laurenti (2020) |
| Environmental policy | A popular instrument for circular and sustainable development, which has its effectiveness increased by analyzing a larger scenario and acting in favor of behavioral and structural changes. | Dace et al. (2014); Doombak et al. (2019); Giljum et al. (2008); Giraudet et al. (2021); Hall (2013); Hardadi et al. (2021); Jia et al. (2019); Laurenti et al. (2016); Makov and Font Vivanco (2018); Muposhi et al. (2021); Ottelin et al. (2020); Qi and Roe (2017); Siderius and Poldner (2021) |
| Sustainable R&D | Circular innovations that have long-term motivation and encourage fundamental changes in behavior acting in conjunction with other strategies can effectively reduce potential RE. | Beekma et al. (2021); Dace et al. (2014); Gava et al. (2020); Ghisellini et al. (2019); Horvath and Magda (2017); Jia et al. (2019); Siderius and Poldner (2021); Santarius et al. (2016); Singh et al. (2019); Shilton et al. (2020); Usui and Takeuchi (2014) |
| Price control | One way of mitigating RE from the increase in consumption, but social conditions must be observed before implementation. Avoids an increase in consumption and productivity caused by a decrease in the price of commodities, raw materials, and products. | Laurenti et al. (2016); Siderius and Poldner (2021); Zink and Geyer (2017) |
| Motivating the population | The combination of circular and rebound mitigation strategies should aim to motivate the population to engage in the process and maintain the proposed changes for a long time for the effectiveness of the positive long-term impact. | Dace et al. (2014); Muposhi et al. (2021); Siderius and Poldner (2021); Usui and Takeuchi (2014); Warmington-Lundstrom and Laurenti (2020) |
other hand, Hall (2013) affirms that policymakers should act as a “choice architect”. The intervention must not put more constraints on individual choices but rather work in changing behavior. When there is a combination of policy (tax) and eco-design strategies, this can decrease the use of natural resources and less waste flow (Dace et al., 2014). Santarius (2016) concludes that a policy should not be equal between different groups and contexts. According to the author, a policy must be designed to address consumer groups and producers separately to maximize effectiveness. As previously shown, policies are also a group of initiator mechanisms if this policy is developed in isolation without considering other instruments.

Sustainable R&D is another group of mechanisms that can mitigate RE. As mentioned earlier, innovations make up the group of initiator mechanisms, but it is important to emphasize that they can also act as a mitigating mechanism. Jia et al. (2019) emphasize that to serve as a mitigating factor, the development of technologies must have a long-term motivation and be associated with other factors such as environmental policies. The authors exemplify this point by discussing how an energy efficiency and carbon emission reduction strategy can mitigate RE in conjunction with other actions. Makov and Font Vivanco (2018) point out that it is possible to develop technologies that can change consumer behavior by avoiding the need for complementary products, for example, creating smartphones that accept more than one SIM card. Effective CE and R&D strategies to replace primary production (extraction of virgin materials) with secondary production are necessary to avoid RE. Nevertheless, Zink and Geyer (2017) argue that some common marketing strategies, lowering prices and finding new market niches, must be avoided. This statement brings an excluding character of CE policies that disregard the economic distribution. Makov and Font Vivanco (2018) stated that sometimes the RE could benefit low-income groups. Thus, the social aspect should be considered when developing CE strategies associated with environmental policy instruments (Lau renti et al., 2016a,b; Siderius and Poldner, 2021).

Mitigation strategies must start with the early detection of RE and end with the combination of actions to modify the structural behavior and motivate the population for such change. CE strategies should shift from products to efficient solutions to slow down the flow of materials or not create one (Horvath et al., 2019). van Loon et al. (2021) highlight that we do not know the impact of these strategies in the long term or if product longevity or ecodesign strategies are sufficient. As a result, Dace et al. (2014) point to the need for additional instruments to motivate the population to engage in CE strategies. The authors found in the combination of taxes and eco-design policies a possibility to reduce waste generation and increase the life of landfills. In that sense, Dzombak et al. (2019) conclude that the involvement of consumers, manufacturers, retailers, policymakers in the actions and the adoption of a systemic vision are necessary to achieve sustainability. Local cooperation and solidarity strategies are essential to avoid environmental burdens (Walleborn, 2018), as well as the development of cooperation (cooperation and competition) in the network or circular ecosystem (Trevisan et al., 2021). Without motivation, the consumers could quickly return to their old behavior (Usui and Takeuchi, 2014).

5. Discussion

Section 4 summarized how CER is caused by the implementation of circular strategies at different levels. The initial discussion of CER is timely and relevant, as CE research lacks research in relation to the potential negative impacts triggered by circular solutions. The proposed framework enables the visualization of the areas involved in implementing the CE, as well as their interactions. Some important lessons can be taken from the results:

Lesson 1: The CER is heavily dependent on the system’s complexity, i.e., the CER may not be the same across different geographical and cultural contexts, boundaries, and levels of implementation.

The adoption of circular activities at different levels of implementation increases the complexity of the system which according to Ruzzenteni and Basosi (2008) is due to the growth of actors and hierarchy in a network. CE implementation requires several traditional actors, increasing the nodes in the network, and the density of material and information flows in different directions. In agreement with Turner (2013), the occurrence of CER depend on the timing and boundary of the system, which is constantly changing with economic growth.

Lesson 2: CER involves the mechanisms described in the RE theory of energy economics, but these are not sufficient for explaining the whole system, particularly when multiple levels are analyzed.

The CER phenomenon originates from initial changes in the production system, clustered within the so-called initiating mechanisms driven by technical and efficiency improvement. RE can still happen, for example, when consumers have different choices of CE strategy they can back to previous non-green behavior of linear consumption. The CE rebound developer mechanisms are divided between the clusters demand and production side, and the interaction between these two sides can develop new effects. As a rebound effect developer, the investigation of the production side is still limited, being associated only with increased productivity. An income effect can also be questioned in relation to the producer or the market, and other mechanisms were found besides the classic ones, such as operational changes and investment decrease. The developer mechanisms urges to be dissociated from energy economics mechanisms and take a more multidisciplinary approach to be analyzed, to approach the system complexities.

Lesson 3: The complexity of CER requires a new systemic way of governance and management for organizations.

The transition to CE also influences the systems of governance, as the actors must deal with an overload of new information and new values to deliver. Part of the increase in information within the ecosystem comes from globalization, but circular objectives increase the load received. If self-governance guarantees an integration of government, industry, and academics, the different perspectives of these stakeholders may prevent harmful CER. Therefore, the CE transition implies new managerial learning, new attribution to companies, and a new vision of values associated with CE, which still need to be understood from the point of view of CE implementation.

Lesson 4: Early detection of direct effects can be beneficial, but it can overshadow important mechanisms that lead to indirect effects in social and economic areas.

The previous lessons led to the conclusion that a CE is not enough to reduce environmental pressure and that a RE can be an obstacle to achieving it. It is observed that markets that rely only on one strategy may need reinforcement by other actions and incentives to change the system. Strategies and mechanisms that generate changes can interact and lead to indirect effects, such as greater valuation of material for recycling, which in developing countries can increase the rate of informal activities and increase health risks. That is, if CER mitigation practices only envision reducing raw material extraction, social effects may go unnoticed.

6. Research agenda

Although the increase in studies exploring the intersection between RE and CE has advanced in recent years, some research avenues still deserve further exploration. This section discusses the six main thematic areas that require more studies. Table 6 summarizes research topics with possible questions to be addressed by scholars.

The first avenue of research refers to models, methods, and tools to qualify and quantify rebound effects. According to Siderius and Poldner (2021, p. 9), “Although there is a need for more accessible metrics to assess the rebound effect, the neoclassical assumptions that underlie some of the conventionally used metrics might not hold anymore in the new paradigm.” In this regard, we suggest that scholars explore the best methods and metrics that help to represent the particularities of rebound effects of a closed-loop economy.
Second, many policymakers are aware of the possible existence of RE but ignore it because is hard to identify or measure. To increase the reliability of results, future research should adopt a lifecycle assessment to identify and analyze rebound effects (Laurenti et al., 2015). In particular, studies on how RE impacts the environmental performance of circular products (van Loon et al., 2021) and empirical approaches using LCA to compare the performance of used and new products has been a great avenue of research. The results will facilitate the detection of RE and contribute to developing mitigation strategies.

Third, despite the number of studies in the area, there are still research opportunities on causes and types of RE. As this is an ever-evolving topic, we suggest focusing on root cause identification be more fruitful for both theory and practice. It is also interesting to understand the role of public institutions in generating RE at the micro, meso, and macro levels (Santarius, 2016). Future studies should explore different variables (Figge and Thorpe, 2019) and investigate where it is no longer helpful to understand rebound effects for measuring environmental performance (Font Vivanco et al., 2016a,b).

The fourth avenue of research is related to aspects of human behavior. For example, different population groups can react differently to certain activities, influencing the generated results (Dace et al., 2014). Thus, it is interesting to understand how different user profiles behave to prevent or mitigate any impacts. There are also opportunities for future studies on prioritizing efforts to reduce RE. For example, “would the promotion of in-home composting systems undermine efforts to persuade householders to reduce food waste in the first place?” (Qi and Roe, 2017, p. 1169). Thus, we strongly recommend research on the social and human dimensions.

Fifth, in addition to aforementioned research avenues, it would be relevant to explore the technology’s role in CE and how their link to the mechanisms of the CER phenomenon. Implementing new technologies in the production or in products is a hot topic of investigation by practitioners and researchers in pursuit of circularity. But when the entire system is analyzed, we cannot only assume the positive aspects of switching to cleaner technologies. Are the digital technologies a trigger to RE or a mechanism to mitigate the effects?

Finally, another suggestion is to investigate how stakeholders react to RE, how the effect might evolve within the ecosystem. Research indicates that different phenomena can propagate within an ecosystem. For example, Gomes et al. (2020) show that uncertainties in innovation management can expand beyond organizational borders. Could this type of propagation phenomenon also occur with rebound effects? Can the effect be maximized within an ecosystem given the existence of different stakeholders? Future studies should focus on identifying which parties may be most influential or key propagators that expand the negative effects from a systemic perspective.

7. Conclusion

The circular rebound effect phenomenon starts from modifications of the CE creates in the system. This article presented a detailed investigation on how the RE arising from CE practices occurs, expanding the theory of CE and rebound effect. Despite being mentioned in several CE papers, the RE was not incorporated in many studies and few articles directly addressed its incidence. While other SLRs (Henry et al., 2021; van Loon et al., 2021; Widmer et al., 2019) on CE point to the need to study the CER, few studies focused on properly appropriating the two constructs, as shown, by incorporating aspects of the CE in the definition of the RE, and without the concern to understand non-economic mechanisms for the CE.

The main contribution of this paper is the mapping of the different mechanisms of the CER. The framework presented in this paper provides...
a broad comprehension of how the rebound phenomenon occurs in the CE, with an initiating, developing, and mitigating mechanisms built based on a systematic literature review. A greater understanding of how a CE acts in a society is beneficial for theoretical and practical research. A major contribution is the detachment of the CER mechanisms from the known mechanisms of the energy economics. Moreover, the mechanisms were organized from the groups of factors involved in the phenomenon, between what can cause, how they cause it, and which can serve as mitigators. This ordering is an advance for the CE and RE theories, and open to the need to research the phenomenon deeply and to standardize the methods so that a profound meta-analyses could be performed.

This framework has the potential to support the design of circular strategies and to analyze their implementation, in the recognition of effects and mechanisms. It is a generic framework, not specific to any sector or geographic space. There is a unique opportunity to include the CER concept in CE theory, since is a theory currently under development. It is necessary to understand the complexity of CE and adopt an evolutionary stance, leaving behind the end-of-pipe vision. Understanding how RE happens increases this possibility if due importance is given to initiating and developer mechanisms, as it is more important not to generate the effects than to mitigate them. The initiating mechanisms should be extrapolated and expanded in the future with more empirical evidence. As CE consolidates, new practices may emerge, as well as RE. However, the lack of knowledge of the CER phenomenon and its mechanisms can increase the rebound effect. It is important to have a systemic view of its implementation and observe the changes resulting from CE in each level of implementation.

The second contribution is providing avenues for further research on the topic, with gaps in CE literature on which scholars could focus. The CER literature still needs understanding on several fronts, and it also needs empirical evidence to support the theory. The gaps are interconnected, and the main ones are the human behavior aspects and the validation of CE practices. The consumer behavior that leads to CER is yet to be understood, as are the influences of context to RE. Empirical data should validate circular strategies and demonstrate what the best mechanisms for mitigating rebound effects actually are. A rising theory is the study of circular ecosystems, and, for better management and governance, the CER should be included with a systemic view.

The limitations of this research are the lack of empirical data to fully support the framework that needs to be validated with case studies in future research. Literature provides evidence that circular actions can cause a RE, but it was quite limited in empirical data, lacking a systematication of how this process could occur in real systems. New research could demonstrate the existence of new groups of factors inside each mechanism presented. As the CER mechanisms are not studied beyond the economic RE mechanisms, this paper shows a limitation regarding the groups and components of the mechanisms presented, which in practice may have more items not identified by the papers in this SLR.

Declaration of competing interest

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

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Appendix A. Supplementary data

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