

Explaining the rebound effects of sustainable design: a behavioural perspective

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Abstract

Despite its importance, the understanding of the behavioural mechanisms underlying rebound effects triggered by sustainable design is still limited. Through a systematic literature review, this study analyses and discusses 18 behavioural mechanisms. The key gaps of behavioural research on rebound effects are (1) limited in-depth analysis of different mechanisms (2); lack of clearly defined concepts; and (3) neglect of various research topics. To bring the behavioural understanding of rebound effects and sustainable design to a higher level, four key steps for future research are suggested.

Keywords: sustainable design, rebound effects, human behaviour

1. Introduction

Due to the urgent environmental challenges, governmental and non-governmental organisations are increasingly investing on design of sustainability-oriented initiatives through a number of best practices (European Parliament, 2020; Pigosso et al., 2014), nevertheless, the full environmental potential of design for sustainability remains unrealised due to the occurrence of rebound effects. Rebound effects are the result of systemic responses that offset the expected environmental gains of sustainability-oriented actions (Hertwich, 2005; Lange et al., 2021). Previous studies indicate that rebound effects can undermine up to 40% of the intended environmental gains and, in some cases, even lead to a negative net impact (i.e. backfire) (Antal & Van Den Bergh, 2013; Chang et al., 2018; Chitnis et al., 2014; Santarius & Soland, 2018).

To successfully prevent the potential rebound effects of sustainable design, a comprehensive understanding of the underlying mechanisms, which are structures of causal processes that explain the occurrence of rebound effects, is essential (Hedström & Ylikoski, 2010). Most existing research on rebound mechanisms comes from the field of economics (Metic & Pigosso, 2022; Sorrell et al., 2020), often explaining rebound effects as outcomes of changes in relative prices (i.e., substitution effect) or income (i.e., income effect) (Chitnis & Sorrell, 2015; Gillingham et al., 2016). These explanations are built upon the assumption that agents involve in rational decision processes, act independently based on full and relevant information, and aim to maximise utility (Scott, 2000). However, a growing body of behavioural research questions these traditional economic assumptions and demonstrates that decision-making is influenced by a variety of psychological and social factors (Santarius & Soland, 2018; Tversky & Kahneman, 1974). Therefore, in addition to the economic perspective, a behavioural perspective is needed to develop a comprehensive understanding of rebound effects (Exadaktylos & van den Bergh, 2021; Jolls et al., 1998). Nevertheless, studies examining the behavioural mechanisms underlying rebound effects are relatively scarce and face several limitations (Exadaktylos & van den Bergh, 2021; Sorrell et al., 2020). This paper aims to address this research gap by firstly elaborating on the current behavioural understanding of rebound effects (Section

3.1), and secondly, by mapping the related strengths and limitations (Section 3.2). Finally, three steps for future studies are proposed to bring the behavioural understanding of rebound effects triggered by sustainable design to a higher level (Section 4).

2. Research methodology

A systematic literature review, following the guidelines of [Biolchini et al. \(2005\)](#), is employed to obtain a comprehensive overview of the existing behavioural mechanisms explaining the rebound effects triggered by sustainable design. Three blocks of keywords (i.e., behaviour, rebound effect, sustainability) and their synonyms are used for the search string. The keywords related to “behaviour” and “rebound effect” are required to be in the title of the articles, while words related to “sustainability” are required to be in the title, abstract, or keywords. Scopus is used as the scientific database due to its relevance to the topic and extensive journal coverage ([Falagas et al., 2008](#)). The search results in 259 unique studies. Relevant studies are selected from the search output with the aid of four filters: the article title and keywords, the abstract, the introduction, and conclusion, and finally the full text. After filtering the results based on the inclusion criteria (Figure 1), 42 articles are selected for the final analyses.

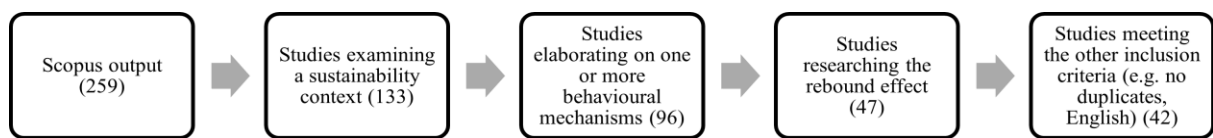


Figure 1. The filtering process, applied criteria, and output in chronologic order

Next, the mechanisms are extracted from the selected studies. The included mechanisms are labelled as behavioural because they are either caused by or lead to a shift in pro-environmental behaviour. In this study, pro-environmental behaviour refers to individual or group actions that minimise the negative environmental impact ([Kollmuss & Agyeman, 2002](#)). The behavioural mechanisms are grouped into three clusters: psychological (i.e., focus on cognitive processes), economic (i.e., focus on rational utility maximisation), and social mechanisms (i.e., focus on interacting actors). For each mechanism a general and a specific definition applied to rebound effects is extracted from the literature and/or derived from general behavioural science knowledge. The definitions are exemplified through the hypothetical case of electric cars. Unless otherwise stated, the quotes are formulated by the authors. Additionally, to enable the analysis of the strengths and limitations of the current state-of-the-art, the identified mechanisms are categorised based on five research criteria (Table 1). The full reference list of included papers can be retrieved at <https://orcid.org/0009-0005-1664-7022>.

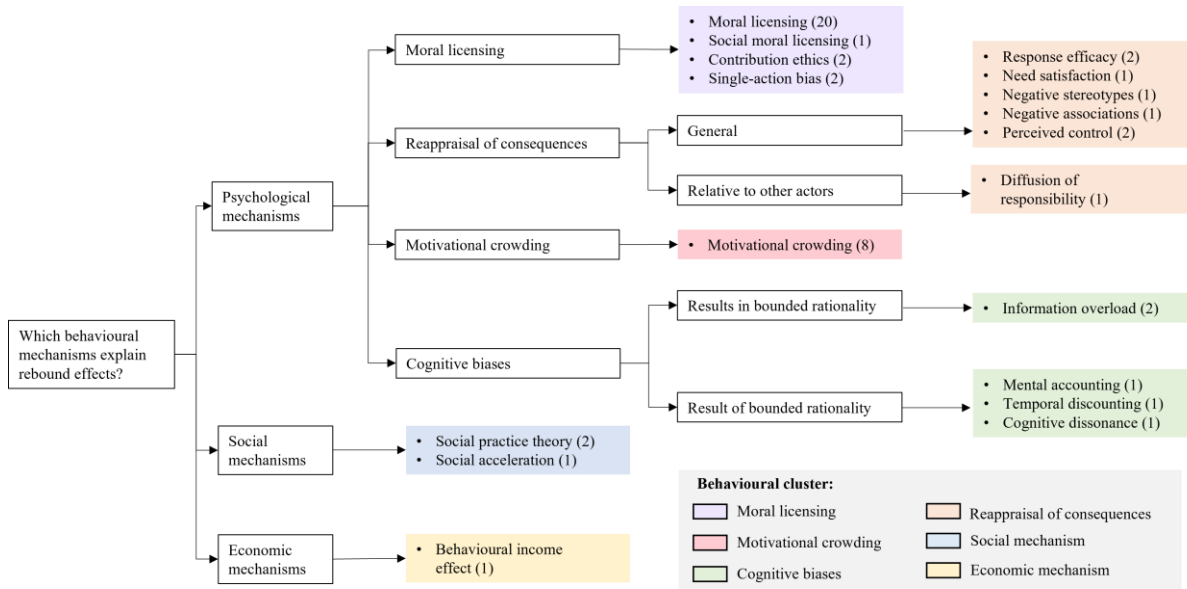
Table 1. The analysed criteria and the related definitions and options

Research criteria	Definitions and options
Rebound effect type	A rebound effect can be either direct (i.e., increased demand for the same product, product/service system, or socio-technical system), indirect (i.e., increased demand for another product, product/service system, or socio-technical system), or economy-wide (i.e., a rebalance in the economic system because of combined direct and indirect rebound effects) (Sorrel, 2007).
Rebound effect context	The context in which the rebound effect and the underlying mechanisms are analysed. This can be either sustainability in general, energy, recycling, or other specific contexts such as beach cleaning, eating vegetarian, and eco-labelling.
Behavioural level	The behavioural mechanisms explain rebound effects on a cognitive (i.e., individual) or social (i.e., group) level.
Rebound effect actor	The rebound effect can be demonstrated by either a consumer or a producer of a sustainable product, product/service system, or socio-technical system.
Research methodology	Research can be either quantitative (i.e., measurable analysis based on numerical data) or qualitative (i.e., descriptive analyses based on non-numerical data).

Lastly, the key steps that should be taken by future research to improve the behavioural understanding of rebound effects caused by sustainable design are defined.

3. Results: current behavioural understanding of rebound effects

In total, 18 distinct behavioural mechanisms are identified: 2 social, 15 psychological and 1 economic (Figure 2). The psychological mechanisms are clustered further into moral licensing (i.e., deciding based on prior or subsequent behaviours), motivational crowding (i.e., deciding based on motivations), reappraisal of consequences (i.e., deciding based on consequences), and cognitive biases (i.e., deciding based on systematic deviations in thinking).



Note: The number of papers that explain each mechanism is presented in between brackets.

Figure 2. Overview of the clustered mechanisms

The identified behavioural mechanisms underlying rebound effects are described in Sections 3.1.1-3.1.6, in six clusters: moral licensing, reappraisal of consequences, motivational crowding, cognitive biases, social mechanisms, and economic mechanisms.

3.1.1. Cluster 1: Moral licensing

The mechanisms in this cluster are psychological mechanisms that include prior moral behaviour (e.g., recycling) and subsequent immoral behaviour (e.g., taking a flight) or inaction (Table 2).

Table 2. Overview of the moral licensing mechanisms underlying rebound effects (RE)

Mechanism	General definition	Definition to RE	Explanatory quote
Moral licensing (Barkemeyer et al., 2023; Brügger & Höchli, 2019; Clot et al., 2022; Dorner, 2019; Dreijerink et al., 2021; Dütschke et al., 2018; Ek, 2018; Exadaktylos & van den Bergh, 2021; Isbanner et al., 2021; Kerner & Brudermann, 2021; Lacroix et al., 2022; Meijers et al., 2019; Nash et al., 2017; Nilsson et al., 2017; Reimers et al., 2021, 2022; Santarius & Soland, 2018; Sorrell et al., 2020; Spaccatini et al., 2023; Truelove et al., 2014)	Performing an initial moral behaviour can create the perception of moral entitlement to perform subsequent morally questionable behaviour (Nash et al., 2017).	Sustainable solutions contributing to pro-environmental behaviour can create perceived room for subsequent environmentally harmful behaviour.	“I drive an electric car, so it feels justified to go by plane to my holiday destination”

Contribution ethics (Nash et al., 2017; Werfel, 2017)	An individual's belief of having appropriately contributed to a moral good, leads to limited further actions (Guagnano et al., 1994).	Using sustainable solutions can result in the belief of contributing enough to the environment, leading to limited further pro-environmental behaviours.	"I already drive an electric car at work, so I don't have to get an electric car at home too"
Single-action bias (Nash et al., 2017; Truelove et al., 2014)	The belief that a single action can resolve a complex issue, leading to limited further actions (Nash et al., 2017).	The belief that a single pro-environmental behaviour is enough to tackle environmental crises, leading to limited further pro-environmental behaviours.	"Driving an electric car is enough to reduce my CO2 emissions, therefore I don't have to eat vegetarian."
Social moral licensing (Lasarov et al., 2022)	People may interpret the moral behaviour of others as a liberating excuse to engage in immoral behaviour (Lasarov et al., 2022).	People may interpret the pro-environmental behaviour of others as a moral license or a liberating excuse to diverge from this behaviour.	"Many other people drive electric cars, so it is fine that I don't"

3.1.2. Reappraisal of consequences

The psychological mechanisms in the reappraisal of consequences cluster reflect how actors re-evaluate the (relative) personal or environmental consequences of their pro-environmental behaviour (Table 3).

Table 3. Reappraisal of consequences mechanisms underlying rebound effects (RE)

Mechanism	General definition	Definition applied to RE	Explanatory quote
Need satisfaction (Hofstetter et al., 2006)	The better an activity, product, or service satisfies basic needs and maximises ultimate utility, the lower the propensity for more (material) consumption (Hofstetter et al., 2006)	A sustainable solution might alter the degree to which needs are satisfied, leading to more (unsustainable) consumption.	"Driving my new electric car is less fun because it is automatic. Therefore, I ride my manual motorcycle more often in my free time."
Response efficacy (Dorner, 2019; Peters & Düttschke, 2016)	The awareness of a specific behaviour as being an effective action to mitigate a perceived problem (Peters & Düttschke, 2016)	Sustainable design can alter the awareness of a specific behaviour as being an effective action to mitigate environmental crises (Peters & Düttschke, 2016).	"Now I have an electric car, driving has less environmental impact, so I started driving more often" (Peters & Düttschke, 2016)
Negative associations (Acuti et al., 2022)	Negative associations related to a product, product/service, or socio-technological system influence the related consumption rate (Acuti et al., 2022).	Negative associations related to sustainable design, such as perceptions of reduced quality or higher prices, can lead to reduced pro-environmental behaviour.	"I don't trust the quality of the battery of my electric car, so for longer trips I will borrow a friend's car that runs on fossil fuels"
Negative stereotypes (Acuti et al., 2022)	Stereotypes associated with consuming a product, product/service, or socio-technological system influence the related consumption rate (Acuti et al., 2022).	Stereotypes associated with sustainable design, such as being labelled as "hippy" or "feminine" can lead to reduced sustainable behaviour.	"I won't start eating vegetarian because I already drive an electric car, and I don't want my friends to think that I am becoming a softy"

Perceived behavioural control (Santarius & Soland, 2018; Simon & Schweitzer, 2023)	A person's perceived ability to perform a behaviour due to non-motivational reasons such as the actual and perceived availability of opportunities and resources (Ajzen, 1991).	Sustainable design can be related to a decrease in a person's actual or perceived ability to perform pro-environmental behaviour.	"I don't know how to find the charging points for my electric car outside my neighbourhood, so whenever I have to drive far, I will rent a car that runs on fossil fuels."
Diffusion of responsibility (Santarius & Soland, 2018)	By shifting the responsibility of tackling a problem to other actors, you feel less responsibility to tackle the problem yourself (Santarius & Soland, 2018).	Sustainable design might shift the perceived responsibility for protecting the environment to other agents, which can result in decreased pro-environmental behaviours (Santarius & Soland, 2018).	"Seeing how well engineers can design sustainable alternatives, such as electric cars, makes me believe that they can achieve way more environmental impact reductions than me".

3.1.3. Motivational crowding

Motivational crowding includes the psychological mechanisms that reflect how influencing intrinsic (i.e., related to internal rewards) and extrinsic (i.e., related to external rewards) motivations can alter the pro-environmental behaviour (Allison et al., 2015)(Table 4).

Table 4. Overview of the motivational crowding mechanism underlying rebound effects (RE)

Mechanism	General definition	Definition applied to RE	Explanatory quote
Motivational crowding (Graafland & de Bakker, 2021; Grepperud, 2007; Isbanner et al., 2021; Ling et al., 2023; Otto et al., 2014; Van Der Werff & Steg, 2018; Vorlauffer et al., 2023; Wollbrant et al., 2022)	Increasing extrinsic motivations can overrule intrinsic motivations, leading to a decrease in the targeted behaviour (e.g., Wollbrant et al., 2022).	When sustainable solutions increase the extrinsic motivations for pro-environmental behaviour (such as monetary rewards), people might feel less intrinsic motivation to engage in pro-environmental behaviours.	"Since the government implemented mandatory sustainability targets, the car manufacturer I work for reduced their sustainability investments because their performance was already higher than the target."

3.1.4. Cognitive biases

Cognitive biases include the psychological mechanisms that reflect systematic errors in thinking that may lead people to deviate from rationality, make inaccurate judgements, or interpret information illogically (Haselton et al., 2015)(Table 5). Mechanisms in this cluster are either examples of cognitive biases or heighten the probability that a cognitive bias occurs.

Table 5. Overview of the cognitive biases mechanisms underlying rebound effects (RE)

Mechanism	General definition	Definition applied to RE	Explanatory quote
Information overload (Acuti et al., 2022; Exadaktylos & van den Bergh, 2021)	Limited cognitive capacity and time hinder the proper analysis of information, leading to inattention and misconception (Exadaktylos & van den Bergh, 2021).	When a sustainable solution contains new or complicated information, it might lead to people misunderstanding or complete ignorance of the sustainable solution.	"My energy company informs me when I should charge my electric car to benefit from renewable energy. I bet they only tell me this to increase their profits"
Time discounting (Exadaktylos & van den Bergh, 2021)	The tendency of people to over-value immediate costs and benefits compared with future ones leads to time-inconsistent choices (Laibson, 1997).	People might overvalue the immediate benefits of using a sustainable solution in an unsustainable way over the future benefits of using a sustainable solution in a sustainable way.	"Because the driving costs of my electric car are low, I can afford driving more kilometres. This is bad for the environment, but that is a problem for later."

Mental accounting (Exadaktylos & van den Bergh, 2021)	People organise money into mental accounts, which influences the way they spend money (Thaler, 2019).	When sustainable solutions increase the available money in one mental account, it is likely that it will be re-spent in the same category.	“I rather spend the money I save driving an electric car on using the car for short rides, than on buying bus tickets.
Cognitive dissonance (Kerner & Brudermann, 2021)	A mental conflict occurs when people hold different cognitions that contradict each other (Festinger, 1957). People often take irrational steps to avoid this conflict.	Sustainable solutions can be used as an excuse to keep engaging in environmentally harmful actions and to avoid a mental conflict.	“Recently, I bought an electric car. Now, I don’t feel bad about driving, so I am not taking the train to work anymore.”

3.1.5. Social mechanisms

Social mechanisms focus on the results of interactions between different actors (Table 6).

Table 6. Overview of the social mechanisms underlying rebound effects (RE)

Mechanism	General definition	Definition applied to RE	Explanatory quote
Social practice theory (Galvin & Gubernat, 2016; Nash et al., 2017)	Via carriers of practices, materiality, and through relationships between practices within wider systems of practice, one behaviour might spillover to other behaviours (Nash et al., 2017; Schatzki, 1990).	Sustainable solutions could affect wider society, organisations, and material-human relationships, leading to increased environmentally damaging consumption for reasons beyond economic utility (Galvin & Gubernat, 2016).	“Since I and many around me started driving electric cars, more charging stations and parking spaces became available. This enables me to run my errands by car rather than with public transportation”.
Social acceleration (Santarius, 2016)	Technological efficiency improvements increase the pace of production and consumption, accelerating the 'speed of life' and social change (Santarius, 2016).	Sustainable solutions leading to efficiency improvements increase the pace of production and consumption, accelerating the 'speed of life' and social change, which can have harmful consequences for the environment.	“Because of the increased demand, sustainable technologies have improved which makes driving electric cars cheaper and more popular. Which in turn increases demand for sustainable technologies”.

3.1.6. Economic mechanisms

Economic mechanisms are identified as behavioural mechanisms when they are triggered by a change in pro-environmental behaviours (Table 7).

Table 7. Overview of the economic mechanism underlying rebound effects (RE)

Mechanism	General definition	Definition applied to RE	Explanatory quote
Behavioural income effect (Dorner, 2019; Grabs, 2015)	Re-spending the expenditure saved due to a behavioural shift (Grabs, 2015).	Re-spending the savings gained by a shift in pro-environmental behaviour.	“Because I chose to eat vegetarian, I save some money. I spend this money on using the chair heating in my electric car.”

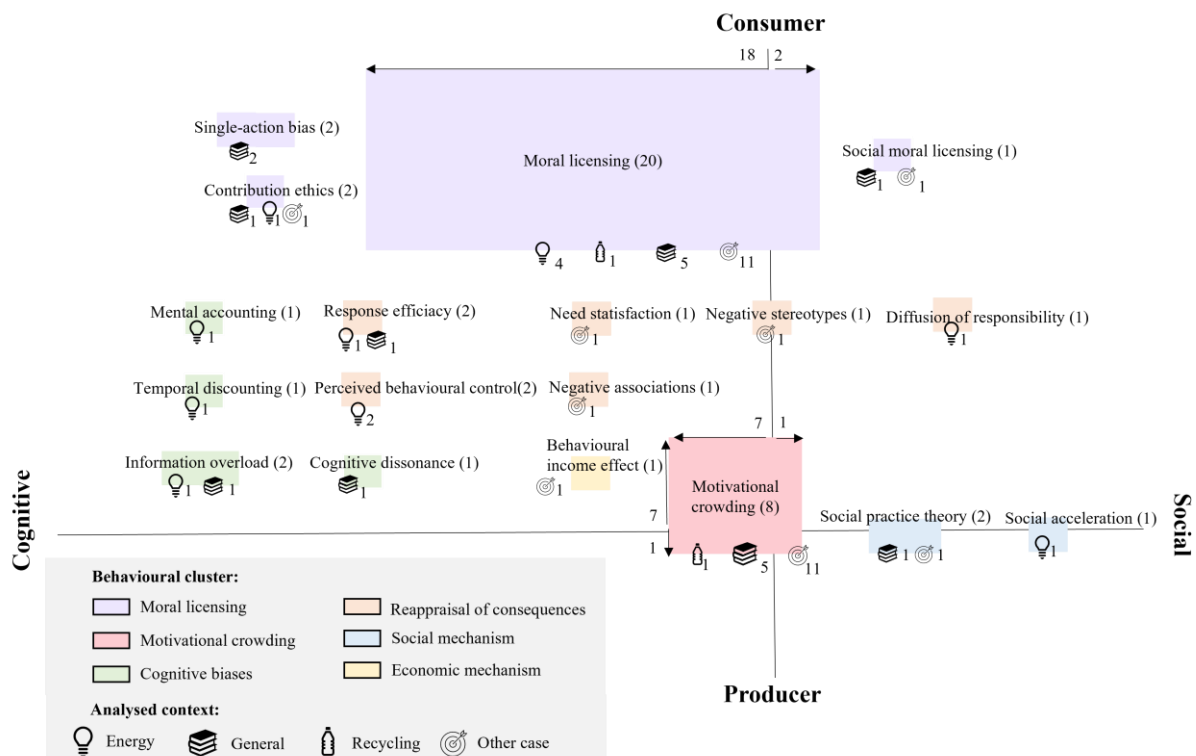
4. Discussion: strengths and limitations of the psychological understanding of rebound effects

The main strengths and limitations of existing research underlying behavioural mechanisms of rebound effects are discussed in this section.

The first limitation concerns the lack of in-depth analyses of most of the behavioural mechanisms underlying rebound effects, as only two out of the 18 mechanisms, moral licensing and moral crowding, are examined by more than two papers (i.e., 20 and 8 papers, respectively).

Secondly, limitations regarding the use of definitions are observed. Studies oftentimes use different terms for the same concepts, or the same term for different concepts. In the 42 examined studies, 8 different terms are used to define rebound effects (i.e., unintended negative side-effects, negative spillover, treadmill effect, backfire effect, paradoxical side-effects, boomerang effect, and the crowding-out effect). The use of similar terms for different concepts can be seen, for example, in the case of moral licensing. Whereas there are different types of moral licensing (e.g. contribution ethics, social moral licensing), studies often do not clearly differentiate them.

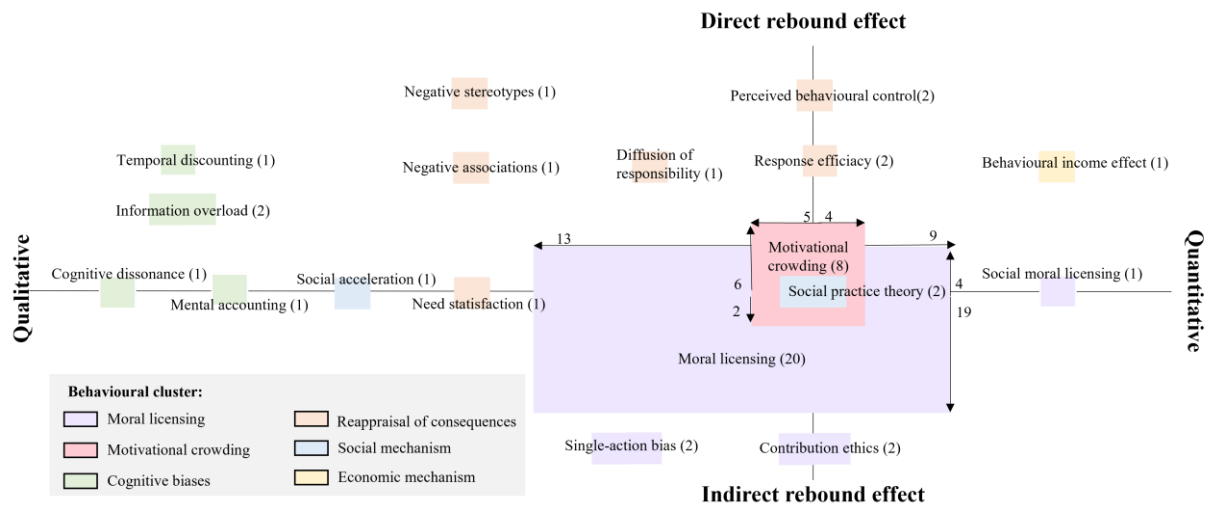
The third observed limitation reflects the constrained diversity in relation to the classification criteria described in Table 1, as illustrated in Figures 3 (i.e. mechanisms categorised based on examined actor, behavioural level, and context) and 4 (i.e. mechanisms categorised based on rebound effect type and research methodology).



Note: The number of papers that explain each mechanism is presented in between brackets. One paper can examine multiple research criteria.

Figure 3. Mechanisms categorised based on examined actor, behavioural level, and context

While the studies examining the social mechanisms consider both, the producer and the consumer perspective, none of the economic or psychological mechanisms have been explored from a producer perspective. The exception is motivational crowding, which has been investigated from a producer's viewpoint by one study, in addition to seven studies that apply a consumer perspective. Furthermore, whereas the social mechanisms are described from the social level, the psychological and economic mechanisms mostly focus on the cognitive level. Overall, the general sustainability context is studied equally often as specific case contexts. The specific case context is predominantly the energy context.



Note: The number of papers that explain each mechanism is presented in between brackets. One paper can examine multiple research criteria.

Figure 4. Mechanisms categorised based on rebound effect type and research methodology

The minority of the mechanisms has been investigated by both qualitative and quantitative research methodologies. Overall, the direct rebound effect is explained by more mechanisms than the indirect one. When considering individual mechanisms, only three mechanisms (i.e., moral licensing, motivational crowding, and the social practice theory) have been examined in relation to both, direct and indirect rebound effects. Lastly, behavioural mechanisms underlying indirect rebound effects are predominantly studied with qualitative rather than quantitative research methodologies, whereas this is more balanced for the direct rebound effect. Nevertheless, it is worth mentioning that this study has several limitations. Due to clarification purposes, this paper has developed a simplified clustered overview of the existing behavioural mechanisms underlying rebound effects. Future studies could build further on this by for example, delving deeper into the interconnectedness of different mechanisms, by distinguishing the selected studies based on their statistical power, or by updating this overview and categorisation when additional behavioural rebound mechanisms are identified.

5. Final remarks

This study uncovered how rebound effects are currently understood from a behavioural perspective, highlighting the related strengths and limitations. The findings reveal several research gaps, including the lack of clearly defined concepts and the neglect of various behavioural mechanisms and research criteria, as described in Section 3.2.

To overcome the existing limitations, this paper suggests three key steps for enhancing the understanding of rebound effects triggered by sustainable design, and the underlying behavioural mechanisms:

- (1) Research on behavioural mechanisms underlying rebound effects should not only increase in number, but also aim at addressing a wider range of behavioural mechanisms. The identification of 18 behavioural mechanisms indicates that potentially a variety of behavioural mechanisms underlies rebound effects, but more research is needed to better understand their functioning and impact.
- (2) Research on behavioural mechanisms underlying rebound effects should aim at using generalisable and well-described definitions of key concepts (e.g., rebound effect, moral licensing) to enhance clarity and facilitate the comparison between studies. This is especially important due to the novelty and interdisciplinary of research on behavioural rebound effects.
- (3) Research efforts uncovering the behavioural mechanisms underlying rebound effects should not be limited to the research criteria or topics that have already been studied. While the existing trends, such as examining moral licensing as an indirect rebound effect and studying cognitive biases from the consumer perspective, might stem from the assumption that certain mechanisms only apply in specific contexts, this can only be scientifically determined by extending the research scope.

In addition to the suggestions for researchers, this paper highly recommends designers to extend their focus to comprehensively explore the role of sustainable design in giving rise to rebound effects and preventing their occurrence.

In summary, to improve the understanding of rebound effects triggered by sustainable design, future research should build further upon existing research by addressing a wide range of behavioural mechanisms, understanding the potential combinations and dependencies among them, applying clear and generalisable definitions, and by including more variation in the studied research topics. Implementing the recommended research steps can significantly improve the behavioural understanding of rebound effects, which in turn contributes to the general understanding of rebound effects and their prevention during design.

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