



# From rebound to reinforcement effects—The role of analyzing underlying mechanisms for accounting

Stefan Schaltegger<sup>\*</sup>, Clara Amend, Sebastian Wüst

Centre for Sustainability Management (CSM), Leuphana University Lüneburg, Universitätsallee 1, D-21335 Lüneburg, Germany

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## ABSTRACT

Rebound effects can reduce planned environmental savings considerably if they are not known, accounted for and managed. Environmental activities only contribute effectively to reducing environmental impacts if rebound effects that diminish the intended improvements remain small. Research has so far focused on macroeconomic analyses and shows that rebound effects can be highly relevant on the level of industries and economies. While widespread agreement exists that rebound effects are an important phenomenon that needs to be better understood when managing environmental protection activities, little is however known about mechanisms that explicate the emergence of rebounds in companies and what consequences can be drawn for accounting and management to prevent or reduce them at the corporate level. To address this gap, this paper problematizes the underlying assumption of an automatic and almost inevitable formation of rebounds by investigating how rebound effects emerge from mechanisms, including decisions and actions within companies. Our conceptual analysis contributes to accounting research and practice by asking how rebound effects could be considered, prevented, or even transformed into outcomes that increase the intended environmental improvement, i.e. reinforcement effects. The study shows that rebound and reinforcement effects are not inevitable but that their emergence is subject to accounting and management decisions.

## Introduction

High and increasing levels of energy and resource use for production and consumption are in conflict with the need to transform the economy to remain within the safe operating space of planetary boundaries (Richardson et al., 2023). Globally, substantial absolute reductions of emissions and other environmental impacts are needed (UN, 2015; Wiedmann et al., 2015). Approaches to pursue reductions include, among others, increasing environmental efficiency of production and product use (von Weizsacker et al., 2013) including eco-efficiency (Caiado et al., 2017), redesigning production systems and products (Dahmani et al., 2021) either to substitute toxic with less toxic materials, to create closed circular systems (Kanda et al., 2021; Konietzko et al., 2023), or to reduce production and consumption levels to achieve more sufficient life-styles (Freudenreich & Schaltegger, 2020). However, despite numerous improvements in resource efficiency in areas, such as production (Cainelli et al., 2020) or transport (Lin & Abudu, 2020) and household heating (McAndrew et al., 2021), macro-level accounts for countries and the world show absolute levels of energy use in most

industries (Sicard et al., 2023) as well as resource use and related environmental impacts have strongly increased globally (Schandl et al., 2018).

In this context, the emergence of rebound effects has been identified as a possible key reason for these diverging developments at the organizational and global level (Lin & Abudu, 2020).

Rebound effects can be defined as the difference between expected or immediate and actual final resource savings of an environmental (efficiency) improvement activity due to subsequent changes in behavior, which are caused by characteristics of the improvement itself (e.g. Hertwich, 2005). These effects impair the actual environmental improvement achieved (Greening et al., 2000). In the extreme case of backfire, the undesired environmental impacts are even higher after the measure has been implemented than before (Santarius & Soland, 2018; Zink & Geyer, 2017).

So far, research has focused on the identification, measurement and relevance of different types of rebound effects at industry and geographical levels (Font Vivanco et al., 2022; Jenkins et al., 2011; Saunders, 2013), at the macro-level of economies (Druckman et al.,

<sup>\*</sup> Corresponding author.

E-mail address: [stefan.schaltegger@leuphana.de](mailto:stefan.schaltegger@leuphana.de) (S. Schaltegger).

2011; Yang et al., 2023) and with regard to household consumption (Motavasseli, 2024; Santarius, 2016). Fang et al. (2020), for example, identified water rebounds of 60–70 % related to irrigation improvements in China, and Freire-González (2019) even found a water rebound effect of about 100 % for the whole Spanish economy, which means that water consumption has not been reduced at all.

More recently, rebounds have been mentioned in the corporate environmental management literature, too (Lin & Abudu, 2020; Niero et al., 2021). If companies only conduct benefit assessments of environmental efficiency improvements, they neglect rebound effects. As a result, the environmental benefits of environmental protection measures can be expected to be often overrated. We, however, only know whether this is the case or not, if we understand the underlying mechanisms of rebound effects and if we account for them.

Whether rebound effects are inevitable, or how they could be accounted for, prevented or managed at the level of companies, has, however, not gained much attention so far. Yet, this is of high relevance because companies influence much of the global resource use through the design of production processes, products, and services. Key decisions that cause, prevent or reduce rebounds are taken at the corporate level. To manage them therefore requires to understand their emergence and to account for them.

The next section reviews prevalent typologies of rebound effects to identify key mechanisms leading to their emergence. The analysis of these mechanisms shows that management decisions – and therefore also accounting information to support such decisions – are a crucial starting point for the emergence and possible prevention of rebound effects as well as for the management of reinforcement effects (Egan & Schaltegger, 2023). To develop management recommendations on how to counter rebound effects to safeguard or even reinforce intended environmental improvements, we develop a typology of reinforcement effects. Finally, conclusions are drawn with implications for both research and management.

### Literature review: necessity to account for rebounds at the corporate level

To understand what needs to be measured to manage rebounds, we review the literature on the emergence and types of rebound effects from a lens whether and how rebound effects can be counteracted and potential reinforcement effects created. The *notion* ‘rebound effect’ refers to counterintuitive consequences that reduce and/or overcompensate intended environmental improvements (Greening et al., 2000; Lange et al., 2021; Sorrell et al., 2020). Despite some disagreement about the precise definition of what effects are considered rebound effects (e.g. is embodied energy or resource use to operate an efficiency measure part of the measure or a rebound? See Font Vivanco et al., 2016; Gillingham et al., 2013; Santarius, 2016), most views focus on the difference between theoretical and actual savings resulting from behavioral changes or cost savings and related larger available budgets *after* an initial efficiency measure has been implemented (Lange et al., 2021; Santarius & Soland, 2018). Agreement exists that the improvement measure itself is the cause for this lower than anticipated efficiency increase (Hertwich, 2005).

As a forerunner investigating the rebound phenomenon in the 19th century, Jevons explained the counterintuitive consequences of increased efficiency of coal combustion on the absolute level of coal consumption (Jevons, 1865; Sorrell, 2009). He observed that higher efficiency of coal combustion did not reduce but rather went along with higher coal consumption. Since then, the focus on increasing energy efficiency of consumer products and services has remained prominent in the rebound literature (Lange et al., 2021; Santarius & Soland, 2018). Rebound effects reduce intended efficiency improvements and lead to resource saving deficits of cars (Santarius & Soland, 2018) or household energy use (Sorrell et al., 2009). More recently, this initial focus has been broadened, including rebound effects of measures to reduce the use

of water (Berbel et al., 2018; Wu et al., 2018) or materials (Skelton et al., 2020) – the latter especially gaining attention in light of the circular economy approach (Zink & Geyer, 2017).

Rebound effects may arise from economic or psychological causes with underlying technological enablers. So far, the *emergence* of rebounds from economic or financial effects of efficiency measures has dominated the discussion (e.g. Borenstein, 2015). A reduction of energy or material use that results in cost reductions subsequently leads to a higher remaining available budget (Borenstein, 2015; Hertwich, 2005). For example, costs are reduced through more energy-efficient heating, which allows to re-spend the monetary savings. Also, product refurbishment reduces the relative material volume required and consequently reduces procurement costs. Dang et al. (2024) find in their empirical study on the influence of climate regulations on manufacturing firms’ real investment decisions that manufacturers show a notable resilience, which in turn, means that companies find economic ways to adapt to climate regulations. This means that even when enforced, companies can and do often create savings from environmental measures that lead to higher future budgets.

Besides economic causes, psychological and sociological causes have been discussed mainly in a conceptual manner for consumer decisions (Rabaa et al., 2024; Seebauer, 2018). Consumers of fuel-efficient cars can be triggered by the idea of driving a “clean” car to drive more than before (Binswanger, 2001) or the substitution of LED lighting may entice to not switch off lights with the effect of increasing total lighting time (Hicks et al., 2020). Recent examples at the industry level show relevant carbon rebound effects in tourism transportation (Yang et al., 2023) and energy conservation (Lin & Abudu, 2020). Similarly, recent studies for the circular economy approach analyze, among others, the increase in product adoption due to refurbishment activities making products cheaper (Konietzko et al., 2023; Zink & Geyer, 2017). At the consumer level, a study for modular smartphones, which aim to extend product lifetime, shows that users are prone to replace modules more frequently because replacing single modules is relatively cheaper than replacing the entire smartphone (Schischke et al., 2019). Some authors consider embodied energy, i.e. the energy necessary to produce the technologies enabling higher efficiencies in the first place, as a technological cause of rebounds (Santarius, 2016). This rebound aspect highlights an increase of energy and material input in manufacturing of products that are intended to be more sustainable. For example, to manufacture modular smartphones, a larger quantity of metals (especially gold) is needed for producing stable connectors (Schischke et al., 2019).

A considerable number of studies has accounted for and *empirically analyzed rebound effects at industry, consumer, and large geographical levels*. Depending on the considered area and the definition of rebound, the magnitude can vary considerably (Font Vivanco et al., 2022). In consumption, direct rebound effects mostly seem to be rather small (approx. 10–30 %) for household heating, electricity, and fuel use (Dahmus, 2014). Empirical studies investigating production-related rebounds reveal more diverse results. Overall, the existing studies find in average larger rebounds than for consumption (e.g. in transport services with approx. 4–84 %, the use of energy and fuels in light and heavy industry with approx. 24–334 %, and water use in agriculture with over 100 %, i.e., backfire; Berbel et al., 2018; Fang et al., 2020).

In summary, the existing literature has identified a remarkable number and high relevance of rebound effects for energy, water, and other resource efficiency activities mainly at the scale of product groups, industries, and economies (Font Vivanco et al., 2022). They have been assessed to considerably lower the efficiency improvement potential of reducing resource consumption (Sorrell et al., 2020). Increasing resource efficiency can only contribute effectively to reducing environmental problems if it is not (significantly) counteracted by subsequent rebound effects.

While the literature is scattered about the underlying mechanisms that link causes and rebound effects, little management guidance is offered how to analyze and account for rebound effects at the corporate

level. On the corporate level, however, key decisions are taken (e.g. on product design) that can cause, prevent or reduce rebound effects. To counteract rebound effects requires an analytical and decision-oriented framework to better understand the mechanisms leading to rebound effects, to account for them, and options how to manage them. Such mechanisms should, firstly, explain different causes (potentially) leading to rebounds, secondly, link these causes to different types of effects, and thirdly, offer management orientation, i.e. inform about potential measures to deal with rebounds at the organizational level. To fill this research gap, this paper conceptualizes existing research and proposes a management framework.

## Method of conceptualization

Conceptual papers follow “a process of abstract thinking involving the mental representation of an idea” (MacInnis, 2011, p. 140). Thereby, argumentation is not grounded in data but assimilates and advances previously developed concepts and theories, and thus indirectly builds on empirical insights (Hirschheim, 2008; Jaakkola, 2020). Whereas Vargo and Koskela-Huotari (2020) outline a rather general process for conceptualization, Jaakkola (2020) proposes four different methods, i.e. theory synthesis, theory adaptation, typology, and model. This conceptual paper follows a mixed approach of theory synthesis and theory adaptation (Fig. 1) as proposed by Jaakkola (2020).

Through theory synthesis, current concepts or theories are summarized and integrated (Jaakkola, 2020). This paper first distinguishes different causes of rebounds and links them to types of effects that have been proposed in the existing literature. Subsequently, mechanisms are deduced that aim to explicate underlying decisions, actions, and activities leading to rebound effects. The goal is to create a better understanding of the emergence of rebound effects and their causes, to provide a framework to analyze mechanisms leading to rebounds, and to identify key aspects for decision-making. The discussion of these mechanisms aims to guide management in how it can address and reduce rebound effects, safeguard effective impact reductions, or even reinforce, i.e. further improve, environmental improvements.

In a second step, this paper adopts a theory adaptation approach for the key analysis. Theory adaptation describes the revision of current concepts or theories (Jaakkola, 2020) with the purpose to create new perspectives (MacInnis, 2011). To develop management recommendations on how to counter rebound effects to safeguard or even reinforce intended environmental improvements, this paper categorizes reinforcement effects. By proposing the existence of reinforcement mechanisms and effects and by conceptualizing approaches to create them we advance and complement the literature on rebound effects.

## Rebound mechanisms – from origins to consequential decisions and behavior

To only account for environmental efficiency gains (e.g. of energy savings or other sustainability improvements; see e.g. Schaltegger & Burritt, 2006; Schaltegger et al., 2008) overestimates the positive environmental impacts if rebounds exist. Accounting for environmental efficiency improvements should therefore consider the mechanisms of

rebounds. Rebound effects result only if subsequent decisions are taken as shown in Fig. 2, which is the underlying assumption in the mainstream literature.

Rebound *mechanisms* describe behavioral changes resulting from decisions and activities that link causes with rebound effects (e.g. Lange et al., 2021). We propose that rebound mechanisms connect the initial decision on an environmental improvement measure with subsequent decisions and behavior leading to a rebound effect (Fig. 2). More generally, rebound mechanisms link decisions and actions with consequences, and therefore need to be considered when accounting for rebounds. They explain *how* a rebound effect develops, i.e. how the difference between intended environmental improvements and actual environmental effects, happen. Although this paper considers fundamental concepts, these mechanisms involving decisions and actions may differ between management and consumption levels. For example, management may re-invest cost savings from efficiency measures to increase the overall output. Consumers, however, who install LED lights as an efficiency technology to reduce electricity consumption tend to leave the lights switched to save cost (Hicks et al., 2020).

The *left side* of Fig. 2 shows *efficiency measures* as the *origins and precondition of rebounds*, i.e. the goals, decisions, and direct efficiency improvement effects and benefits. The *right side* of the figure depicts *subsequent decisions and behavior leading to rebound effects*.

With regard to the left side of Fig. 2 – the origin of efficiency measures as precondition for the emergence of rebound mechanisms – efficiency improvements are not implemented for their own sake, but as a means to achieve various *environmental goals*, such as reducing energy, material, and resource consumption (Zink & Geyer, 2017), and/or to achieve conventional *economic goals*, such as profit, revenues, market share, etc. Overall, a measure can be classified ‘efficiency increasing’ if one or several of these intended benefits are achieved at least in the short term as a direct consequence of implementing the measure. Depending on the underlying goals, different decisions and actions will be considered efficiency increasing (Santarius, 2016; Sorrell et al., 2020). The decisions and actions to increase efficiency can lead to immediate effects, e.g. electricity consumption is reduced after installation of LED light bulbs. Implementation deficits can result in smaller immediate effects (third box to the left in Fig. 2) than originally intended. Such implementation problems (top box to the left in Fig. 2), however, are not rebound effects as they are integrated in the implementation of the measure and not a result of the implemented measure (i.e. not subsequent to the immediate efficiency increase). Such efficiency gains and implementation deficits can be calculated with energy calculations and conventional investment appraisals.

Subsequent to the immediate effects (towards the right side in Fig. 2), the rebound mechanism becomes effective if inefficiency decisions are taken to use more energy. Subsequent decisions following an effectively implemented efficiency measure are undertaken to reallocate efficiency gains (second box to the right in Fig. 2). For example, lights may not be switched off when leaving a room (i.e. psychological rebound). Consequently, resource use is increased which finally leads to a reduced environmental improvement or back-fire effect in the extreme case. The difference between the immediate effect of the implemented efficiency measure and the actual effect after subsequent

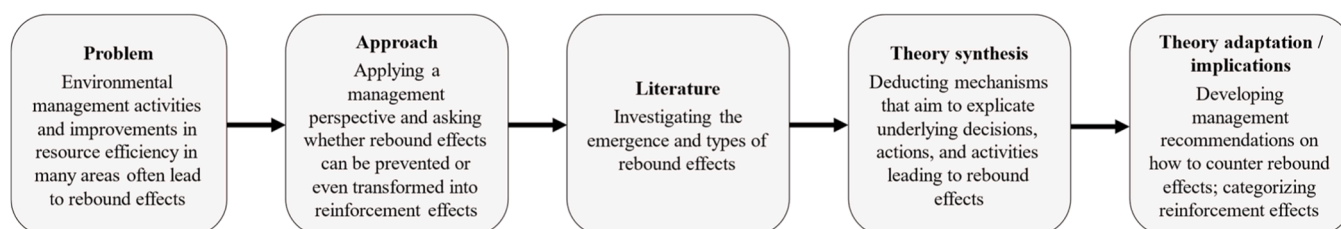


Fig. 1. Theory synthesis and adaptation process (adapted from Jaakkola, 2020, and Vargo & Koskela-Huotari, 2020).

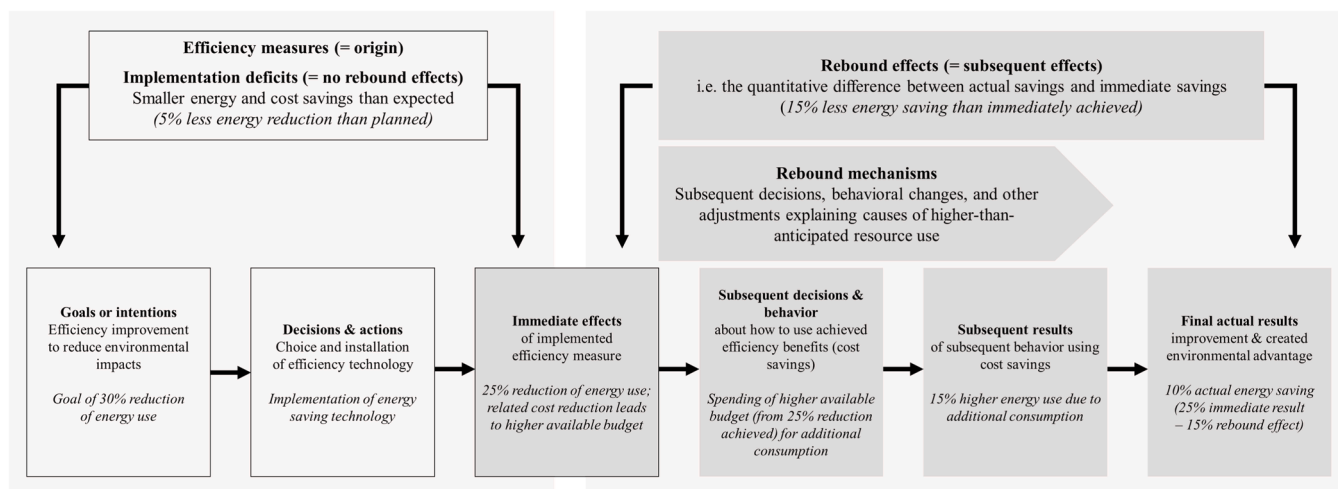


Fig. 2. Rebound mechanisms, with illustrative accounting example, connecting goals, decisions, and activities causing rebound effects.

decisions and actions are undertaken is what is called a rebound effect (right box in Fig. 2). The accounting literature has, so far, largely neglected to investigate the question how to measure rebound effects as subsequent effects (an exception is Schaltegger & Egan, 2023).

As the subsequent consequential decisions and actions, following an implemented efficiency measure, are decisive whether a rebound occurs or not, we need to analyze them in more detail to understand what needs to be accounted for. From a management perspective, to understand the rebound mechanisms well is a precondition to measure whether they occur, how large they are, and what can or needs to be done by a company to prevent or reduce them.

#### Types of rebound mechanisms

##### Differentiating rebound mechanisms

Adopting the general classification of economic and psychological rebound effects (see rows in Table 1) as well as technological enablers distinguished above, this section discusses rebound mechanisms for these groups in detail. It should be noted that economic and psychological effects are interrelated and may occur simultaneously or may reinforce each other (Otto et al., 2014; Santarius & Soland, 2018). This phenomenon is sometimes also called ‘hybrid effects’ (Santarius & Soland, 2018). In addition, both effects are influenced or enforced by technological enablers. Table 1 provides an overview of the immediate results of an environmental (efficiency) measure, subsequent decisions and actions, and subsequent results for each type. The immediate economic effects are usually considered well in management accounting (mainly cost accounting, budgeting) and with benefits accounts (for the energy savings in kwh, etc.) whereas the psychological aspects may be taken into considerations in ‘mental accounts’ leading to reevaluations of environmental impacts.

While the initial effect of an efficiency measure forms the basis for a rebound effect, the actual rebound starts afterwards and can be described by its underlying rebound mechanism of subsequent decisions and effects (two columns to the right in Table 1).

##### Economically induced subsequent decisions and actions

To account for economically induced rebounds requires to measure what the savings achieved with environmental measures are used for (Egan & Schaltegger, 2023). Such rebounds (right side in Table 1) are usually not accounted for at the company level. Savings resulting from reduced costs achieved with efficiency gains can be used in different ways (see second column “subsequent decisions” in Table 1). The decision on how the savings are spent has implications about the subsequent use of resources and the subsequent environmental effects (Zerbino,

2022). Reduced costs can trigger decisions for price reduction, productivity increase, to serve additional demand, or to promote sales, which in turn, increases the production output. To account for these rebounds requires to identify the subsequent activities and to measure them:

- First, *price-reduction-oriented decisions* represent the widely shared implicit assumption of much of the existing rebound research: cost savings from efficiency gains are used to lower prices. This, in turn, generates ceteris paribus an income effect (Santarius, 2016). Therefore, demand of the product, and consequently quantities of supply, are increased (as known from conventional economics). For example, reduced energy prices for renewable energy increase costs savings which can be spend on increasing total energy use or elsewhere.
- Second, *productivity-oriented decisions* are related to using cost savings to increase the productivity of production or to overcome resource bottlenecks in production. For example, savings can be re-invested into more productive manufacturing technology or increased automatization to overcome labor shortages.
- Third, *demand-oriented decisions* aim to increase production output. This option is not necessarily coupled with a price reduction, but the efficiency-based cost savings are used to serve additional, so far unmet demand for the product. Related to productivity-oriented decisions, more efficient manufacturing technology can increase production output, and thus serve greater demand.
- Fourth, *sales-promotion-oriented decisions* aim to use cost savings for sales promotion, leading to higher demand and product sales.

All economic rebounds can in principle be accounted for with conventional management accounting approaches considering changes of costs, revenues, and sales. However, the different decision categories can reinforce each other (Santarius, 2016). For example, refurbishment (Zink & Geyer, 2017; i.e. technological enabler) can help overcoming material shortages (i.e. productivity-oriented decisions) but subsequently reduces product prices (i.e. price-reduction-oriented decisions) which can result in increasing overall supply and demand (i.e. demand-oriented decisions).

##### Psychologically induced subsequent decisions and actions

To account for psychological rebounds requires to measure behavioral changes resulting from environmental improvement measures. Psychological rebound mechanisms originate from a re-evaluation of activities based on (expected or) immediately achieved environmental benefits after an efficiency measure has been implemented (see e.g., Ma et al., 2019 for recycling). Santarius and Soland (2018) propose three

**Table 1**  
Rebound effects – types and mechanisms (Font Vivanco et al., 2016; Santarius, 2016; Santarius & Soland, 2018; Truelove et al., 2014).

	Initial efficiency effect -> <i>How considered in accounting?</i>	Rebound mechanisms (= subsequent decisions & effects) -> <i>So far not explicitly considered as rebound in cost accounting, budgeting, financial planning, etc.</i>	
Rebound type	Immediate effects (1st tier results) of implemented efficiency measure	Subsequent decisions and actions about the use of benefits achieved with efficiency gains (leading to 2nd tier results)	Rebound effects resulting from subsequent decisions after achieved efficiency benefits
Economic	Reduced costs through energy or resource savings lead to a higher available budget -> <b>Benefit accounting, investment appraisal, cost accounting, budgeting</b>	Decisions on re-use of financial resources for: <ul style="list-style-type: none"> <li>– Price reduction</li> <li>– Productivity increase</li> <li>– Serving additional demand</li> <li>– Sales promotion</li> </ul>	1) <b>Output expansion</b> 2) <b>Intensified use</b> of the more efficient process, product, or service... (i.e. more frequent or intensive use) 3) <b>Substitution</b> of production factors with more environmentally damaging factors (e.g. substitution of labor with energy because energy becomes relatively cheaper)
Psychological	Perception of environmental benefits of efficiency improvement leads to (re) evaluation of relevance of environmental impact (-> <b>'Mental' benefit accounting</b> )	<ul style="list-style-type: none"> <li>– Reappraisal because of smaller perceived consequences (e.g. "As I drive an efficient car, my environmental impacts are negligible.")</li> <li>– Perceived shift of responsibility ("As I drive an efficient car, I do not cause relevant problems anymore. The engineers are responsible for further improvement.")</li> <li>– Moral licensing (e.g. "I can drive the car more often because it is an electric car."; Raaba et al., 2024)</li> </ul>	

different explanations leading to this re-evaluation of impacts and the subsequent change in behavior:

- First, the impression of reduced negative consequences due to the efficiency improvement can lead to a “*reappraisal of personal monetary, social, or emotional consequences*” (Santarius & Soland, 2018) and serve as a motivation and justification for changes in behavior, which in turn can cause increased consumption of the product. This is also termed ‘single action bias’ (Truelove et al., 2014), which may trigger people acting (either in a company or in a household) to assume that a substantial contribution has already been made with the implemented efficiency improvement. Consequently, further efforts are perceived to be less necessary or even unnecessary as other problems are negligible in comparison and therefore do not need further attention or action. For example, “an electric car reduces attitudes, intentions and perceived moral obligation to reduce car use” (Klöckner et al., 2013, p. 38; Rabaa et al., 2024). However, as

this example conveys, the efficiency improvement also causes monetary savings in the use phase generating an income effect, which means that the rebound mechanism is not only psychologically induced but also economically (Santarius & Soland, 2018). This is also an example for a hybrid rebound effect induced through technological innovation.

- Second, the impression that an environmental problem has already been reduced or (is) solved by someone else or is someone else’s duty (e.g. of the car manufacturer to make the car more efficient), the efficiency improvement can lead to a *perceived shift of responsibility*. The fact that oneself has (already) made a contribution (e.g. by purchasing a more efficient car) can create the impression that it is now the duty of others to contribute to solutions (e.g. Navum & Thøgersen, 2022). Such judgments that the environmental problem has been addressed by an efficiency improvement can be perceived as a justification to increasingly use the more efficient product, service, or process. For example, LED light bulbs (i.e. technological enabler) tend to be left switched on due to their lower energy use (Peters et al., 2012), although more intrinsically motivated consumers are more prone to offset this rebound mechanism (Clot et al., 2016).
- Third, *moral licensing* describes that using the efficient product is a good deed and justified in moral terms motivating further consumption of this product or consumption of other energy-consuming goods (Rabaa et al., 2024; Santarius & Soland, 2018). Contrary to the responsibility diffusion, less intrinsically motivated people are more prone to moral licensing (Clot et al., 2016). For example, an empirical study by Tiefenbeck et al. (2013) found that successful campaigning for water-use reduction was offset by increased electricity consumption. Another example is airlines offering customers carbon offsets (e.g. planting trees) to reduce the guilt of flying (Khan et al., 2010).

Behavioral changes are usually not considered directly and explicitly in management accounting. To account for their indirect economic effects therefore requires to first identify the psychological rebound mechanism and then its subsequent economic consequences.

#### *Rebound effects resulting from subsequent economic and psychological decisions*

Economically and psychologically induced decisions based on the immediate results of efficiency improvements can lead to subsequent effects, i.e. rebound effects (right column in Table 1), which need to be accounted for to capture the overall environmental benefit of environmental protection measures. Three types of rebound effects are distinguished and can materialize in the same domain (e.g. more efficient cars lead to more cars sold and driven) or another domain (other areas of production and consumption, such as more airplane flights): output expansion, intensified use of the more efficient processes and products, and substitution of production factors (Galvin, 2015, 2020; Jenkins et al., 2011; Santarius, 2016):

- 1) *Output expansion* explains increases in product or service output which compensates for efficiency increases through either respending of financial savings as short- to midterm expenditures (e.g. going by plane on vacation after using more energy-efficient technology) or re-investment of cumulated financial savings for long-term investments (e.g. installing new manufacturing technology).
- 2) *Intensified use of the more efficient processes, products, and services* – both in production and consumption – characterizes the compensation of efficiency increases. For example, more energy-efficient lighting tends to be switched on, or more fuel-efficient cars are driven more, which consequently increases energy use.
- 3) *Substitution of production factors with more environmentally damaging factors* (substitution of labor with energy because energy becomes

relatively cheaper) in production and consumption describes increases of energy services/machinery use that compensates for increases in efficiency of these energy services. A frequent example is the substitution of labor by automatized manufacturing technology, and digitalization.

In sum, rebound effects can be conceptualized as technologically enabled economic and psychological effects resulting from subsequent decisions of (expected or achieved) immediate effects of efficiency measures. Rebound mechanisms explain the link between subsequent decisions leading to rebound effects. To counteract rebound effects therefore requires to account for these (potential) subsequent effects with regard to decision and action options that succeed from (expected or achieved) immediate gains efficiency measures.

## Discussion and implications for management and accounting

### *Rebounds – neither ‘automatic’ nor inevitable consequences*

While the identification of different rebound mechanisms allows to better understand their emergence, the analysis shows that rebounds are no automatic, fixed, or inevitable consequence of efficiency or other environmental improvement activities. The emergence of rebound effects is a consequence of subsequent decisions and actions (i.e. behavior) to expected or initially achieved improvements, and how benefits of resource efficiency improvements or emission reductions are used. None of the mechanisms which have been identified so far as drivers of rebound effects are inevitable as the subsequent decisions that lead to rebound effects can in principle be changed. To know whether they occur or not requires identifying them based on the underlying mechanisms as shown in Fig. 2 and to account for them.

This raises the question for environmental management of how rebound effects can be prevented or even reinforcement effects created. The analysis in the previous section shows that, in essence, (i) the identification of the underlying mechanism is needed in each case, (ii) the effects caused at each stage of the mechanism need to be accounted for, and (iii) that based on this information, there is scope for a ‘positive’ shaping of follow-up decisions and activities that succeed environmental improvement activities and projects. The choice of subsequent decisions and activities is therefore key to counteract or prevent rebound effects or to even strengthen and reinforce environmental improvements. The next section therefore discusses how positive reinforcement effects could, in principle, be developed.

### *Reinforcement mechanisms*

Few authors have so far considered the potential to counteract rebound effects or to even increase initial environmental improvements further with subsequent decisions and actions. “Negative rebound effects” or “beneficial environmental effects” can result from motivating individuals to reduce even more energy or to re-invest cost savings of initial efficiency measures in environmentally beneficial technologies leading to additional environmental improvements (Otto et al., 2014; Santarius, 2014). Such mechanisms (i.e. decision-effect linkages), based on purposeful decisions that result in combatting rebound effects and creating positive reinforcement effects are in the following called ‘reinforcement mechanisms’.

Whether rebound effects emerge, whether they are small or large (or in the case of backfire, even larger than the initial benefit) or whether positive effects are created reinforcing environmentally beneficial effects requires that the rebound effects are accounted for along the steps of a rebound mechanism and then, it depends on decisions and actions subsequent to the initial environmental efficiency measure and effect. A key challenge for effective environmental management is therefore to identify, and then reduce or prevent rebound effects, or to even create reinforcement effects.

To guide savings of environmental efficiency improvements into a positive, reinforcing direction requires to first know how large they are, and thus to account for these savings, and second to use them beneficially for further environmental improvements, which requires to ‘tag’ the spending of these savings in the company’s accounts.

Reinforcement effects can either lead to further reduction of negative environmental effects (e.g. planting trees can help binding carbon in biomass) or positive overall effects (e.g. cost savings through increased energy efficiency are used to offer organic meals in canteens to positively reinforce the initial intention of contributing to sustainable development). Just like rebound effects are a type of negative externality (Borenstein, 2015), reinforcement effects can be viewed as a type of positive externality.

Based on the underlying mechanisms, different approaches exist to develop economic and psychological reinforcement mechanisms. Both effects can be influenced by technological innovation. Table 2 provides an overview of potential reinforcement mechanisms and effects. The basic steps of reinforcement mechanisms are the same as depicted in Table 1.

### *Approaches to create reinforcement effects*

Based on the underlying mechanisms, different approaches are discussed in the following to develop economic and psychological types of reinforcement mechanisms to create reinforcement effects. Both effects can sometimes be influenced by technological innovation.

### *Economically induced subsequent decisions and actions*

To counteract economic rebound effects, or even to turn them into economic reinforcement effects, requires, first, to identify the mechanism and to account for the effect caused at each stage. Second, based on the accounting information, it requires a purposeful and effective use of the freed-up money through cost reductions emanating from environmental improvements. Management has various decision options to reuse the financial savings of initial efficiency gains in a reinforcing way:

- First, through investment in further environmental improvements of the superior product and its production, *efficiency can be further increased*: A self-imposed, earmarked (re-)investment of efficiency gains in further environmental improvements of the product or environmental improvements of production can be driven by the aim of continuously reducing energy and resource consumption (Schaltegger et al., 2008) or the goal to further increase the environmental quality of the superior product (Roy, 2000). For example, higher-quality inputs with lower environmental impact can be procured and renewable raw materials can be used for the product, such as fair trade or organic ingredients. In production, renewable energies, or the use of waste heat from cooling processes can help to further lower the energy use and environmental impact of production. Other examples how the additional budget through initial efficiency gains can be invested positively is the realization of energy-extensive production, such as biotechnical production at room temperature instead of production with high pressure and fossil energy input. With such an approach, fossil fuels do not longer have to be explored, produced, stored, and transported, and the environmental impact of the fossil fuel supply chain is eliminated.
- Second, less environmentally friendly production factors can be substituted with more environmentally friendly production factors. For example, recycled materials can be used in production instead of virgin materials.
- Third, *services can be added or expanded* by supporting the environmentally superior products with services using the minimum of materials and energy (Herring & Roy, 2007). Instead of expanding production and thus the sales volume of products, additional services can be offered that help to prolong the product lifetime and increase customer satisfaction. Repair or maintenance services can help

**Table 2**  
Classification and examples of reinforcement mechanisms.

	Initial efficiency effect -> <i>How considered in accounting?</i>	Reinforcement mechanisms (= subsequent decisions & effects) -> <i>So far not explicitly considered as reinforcement effects in cost accounting, budgeting, financial planning, etc.</i>	
<b>Reinforcementtype</b>	<b>Immediate effects (1st tier results) of efficiency measure</b>	<b>Subsequent decisions and actions about the use of benefits achieved with efficiency gains</b> (initiating the reinforcing 2nd tier effects in the next column)	<b>Reinforcement effects resulting from subsequent decisions after achieved efficiency benefits</b>
<b>Economic</b>	<b>Reduced costs through energy savings lead to a higher available budget -&gt; <i>Benefit accounting, investment appraisal, cost accounting, budgeting</i></b>	Decisions on re-use of financial resources for: <ul style="list-style-type: none"> <li>- <b>Increasing efficiency further</b> (e.g. combined heat and power generation) or for <b>energy-extensive production</b> (e.g. biotechnical production at room temperature instead of production with high pressure and energy input)</li> <li>- <b>Substituting</b> less with more environmentally friendly production factors (e.g. using recycled materials)</li> <li>- <b>Increasing service efficiency</b> through providing end services to consumers that use the minimum of materials and energy use (Herring &amp; Roy, 2007; Roy, 2000) (e.g. repair services or full service models)</li> <li>- <b>Price reduction or sales promotion</b> of improved, sustainable products leading to a substitution of more polluting products (of competitors or the own assortment)</li> <li>- <b>Savings (retention of efficiency gains)</b> for future environmental projects</li> </ul>	<ol style="list-style-type: none"> <li>1) <b>Further environmental improvement</b> of more sustainable processes, products, or services.</li> <li>2) <b>Substitution</b> of (1) production factors with inputs with lower environmental impact, or (2) of products with services (e.g. car sharing is offered instead of selling cars)</li> <li>3) <b>Change of consumption patterns towards more sustainable consumption</b> (e.g. consumers buy organic food with the higher available budget)</li> <li>4) <b>Later spending of efficiency gains</b> for sustainability-oriented use</li> </ol>
<b>Psychological</b>	<b>Perception of environmental benefits of efficiency improvement leads to increased awareness of environmental impact (-&gt; <i>'Mental' benefit accounting</i>)</b>	Decisions increasing awareness and motivation for more environmental action: <ul style="list-style-type: none"> <li>- Enhancement of positive action and responsibility in production and consumption (Santarius &amp; Soland, 2018) (e.g. recycling has been shown to positively correlate with avoidance of excess packaging, e.g. Thøgersen, 1999), as well as energy conservation, water, e.g. Truelove et al., 2014)</li> <li>- Increasing salience of environmental norms, values, and consequences (Santarius &amp; Soland, 2018) (e.g. the acquisition of an energy efficient technology may increase the salience of environmental values; e.g. Eagly &amp; Chaiken, 1993)</li> <li>- Developing and implementing consequent strategic guidelines for sustainability can help to channel all decisions toward further reduction of energy and resource consumption (BMU, 2002)</li> </ul>	

reducing the company's physical output while increasing the competitiveness of the environmentally superior products (Das et al., 2023). Products can also be complemented by circular services to enhance sustainable/long-term use. For example, modular product design (i.e. technological enabler) promotes more efficient repair and refurbishment, however, complementing services must be designed and implemented to unleash the product's potential.

- Fourth, *price reduction* of improved products (with replacement of more polluting alternatives in competition) passes on the cost savings to consumers and the company gains market share at the expense of more polluting competitors. By creating a price advantage for the environmentally superior products, less efficient and more polluting competitors whose products and production methods are associated with a higher environmental impact are replaced. This type of decision and consequential action leads to a restructuring of market supply and demand as the 'greener', environmentally superior products substitute the former dominating, environmentally damaging products. While market restructuring will lead to a decline of the 'polluting' part of the market, the price reduction of the improved product must be further accompanied to ensure that no undesired (rebound) effect occurs that the whole market demand increases (Schaltegger et al., 2016). In addition, management can decide to invest the cost savings for the *promotion of products or services* that have a lower environmental impact than comparable substitutes. For example, car manufacturers may promote electric

cars or mobility services instead of conventional combustion engine cars. Moreover, choice-architectures, such as nudges, present another opportunity to promote sustainable choice for products or services by "organizing the context in which people make decisions" (Thaler & Sunstein, 2008, 428). For example, repairability scores or icons (Bovea et al., 2018) could trigger repairability perception and, thus, influence repair behavior to promote sustainability.

- Fifth, cost *savings* through efficiency gains can be used to professionalize the environmental management systems and organization in the company (e.g. BMU, 2002). Similarly, cost savings can be used to improve the potential for further improvements in the future, e.g. by saving them as *retention* for future environmental projects (Schaltegger et al., 2008).
- Sixth, the transformation of the existing into a new, sustainable business model can be financed, which requires an assessment of different possible, new business model innovations (Lüdeke-Freund et al., 2017).

#### *Psychologically induced subsequent decisions and actions*

Psychological reinforcement effects are triggered by increasing awareness about potential psychological and other rebound effects and have been observed and analyzed for entrepreneurial activities (Gielenik et al., 2015) as well as for environmental management (Hörisch et al., 2014). Accounting for rebounds increases awareness about them. High awareness of potential rebound effects as potentially adverse subsequent

effects is a precondition to anticipate and realize further reinforcing, environmental improvements with adequate decisions after the initial efficiency improvement. Identification of potential negative impacts can be demotivating or even prevent environmental engagement if rebounds are considered inevitable (Porritt, 2005). Management research reveals that bad news can lose its psychological impact and lead to detachment (Hodgkinson et al., 2001; Liem & Martin, 2012). Awareness about potential rebound effects, however, can also unfold energy to find counteracting solutions or even foster engagement to create reinforcement effects.

The psychological mechanism of successful engagement fostering further engagement has been described by action regulation theory. When projects, activities, and improvements are perceived as success, and positive feedback is received, actors often develop further engagement or even passion for further improvements (Gielnik et al., 2015). In other words, successful engagement for environmental and energy efficiency improvements leading to (initial) environmental improvements can create passion to continue pursuing further improvements (e.g. Hörisch et al., 2014). Key for such a reinforcement process is positive feedback and self-perception that fosters pleasure for further engagement. Positive feedback combined with awareness about potential rebound effects as well as the willingness and confidence to create further environmental improvements can therefore be a fruitful basis to realizing reinforcement effects. Management has various decision options to create psychological reinforcement effects:

- First, *positive action and responsibility can be enhanced in production and consumption*. Related to ‘diffusion of responsibility’ as a type of rebound effect (Santarius & Soland, 2018), responsibility can also be enhanced with accounting to create reinforcement effects. Higher awareness can foster the engagement for further sustainability improvements of processes, products, or services as a greater sense of responsibility for environmental impacts associated with production. For example, achieved environmental impact reduction in production is purposefully communicated to employees to increase motivation and knowledge, to foster diffusion to other business functions, and to re-invest savings in further environmental improvements. In consumption, recycling as an activity was found to correlate with avoiding packaging (Thøgersen, 1999) as well as energy and water conservation (Truelove et al., 2014). This, in turn, can motivate actors to further improve products and production methods regarding their environmental impacts.
- Second, *increasing salience of environmental norms, values, and consequences* may spur positive environmental action (Santarius & Soland, 2018). Nudges based on monitoring and accounting can, for example, increase the awareness of environmental impacts of hybrid cars and reduce driving (Santarius & Soland, 2018). As another example, an app on the mobile phone that shows the electricity production of a photovoltaic installation in real time may motivate to adjust the energy use (e.g. using the washing machine) to times when most electricity is generated (e.g. at noon when the sun shines most strongly). The effectiveness of different types of nudges may differ depending on whether an actor is more intrinsically or extrinsically motivated to behave sustainably (Clot et al., 2016). Previous research finds extrinsic (i.e. financial) incentives to be rather ineffective to motivate intrinsically-motivated individuals to behave sustainably and reduce rebound effects (Otto et al., 2014) while reminders of successful previous sustainable behavior can in other cases be effective to promote further sustainable behavior (Van der Werff et al., 2013).
- Third, *developing and implementing consequent strategic guidelines for sustainability* can help to focus all decisions in an organization with regard to sustainability improvements (BMU, 2002). A consistent environmental policy applied to all business function and areas of the company can channel and guide further measures to focus on further environmental improvements. Striving for an authentic ‘green

corporate identity’ in which the company aims to become a ‘green employer’ in its self-perception and in the perception of others. This may attract, motivate, and retain employees with high sustainability preferences and ambitions, which consequently is likely to foster further sustainability improvements.

#### *Reinforcement effects resulting from subsequent economic and psychological decisions after efficiency benefits have been achieved*

If implemented effectively, reinforcement mechanisms lead to subsequent reinforcement effects induced by economic and psychological decisions and actions as discussed above. The types of reinforcement effects may appear similar to rebound effects, but they are positively shaped, thus counteracting rebounds or leading to reinforcement effects. While the initial decision for an energy or material efficiency improvement is the same, management makes a different choice after the initial effect in order to foster further environmental improvements. If actions are channeled towards less negative or even positive environmental contributions, positive effects can be created and may occur simultaneously.

- 1) *Further environmental improvement* of more sustainable processes, products, or services instead of using alternative ‘unsustainable’ substitutes. Through increasing awareness and responsibility of sustainability impacts, sustainable action and thus use may increase in the same domain or spills-over into another domain.
- 2) *Substitution* of (1) other (still environmentally unfriendly) production factors with higher quality inputs with lower environmental impacts, or (2) products with services (e.g. offering car sharing instead of selling cars).
- 3) *Application of a social discount rate for environmental investments*: Schoenmaker and Schramade (2024) propose for investments in climate mitigation projects to apply a social discount rate including macroeconomic risks of rare disasters. The social discount rate is the rate at which society is willing to trade present consumption versus future consumption. The social discount rate is considerably lower than the standard financial discount rate and allows for investments with smaller short-term savings (and therefore less budget to be redistributed shorthand) but larger long-term economic benefits.
- 4) *Change of consumption patterns towards more sustainable consumption*. For example, consumers buy organic food with the higher available budget.
- 5) *Later spending of efficiency gains* for later sustainability-oriented use. For example, cost savings are used later for investment in renewable energy installations on the own facilities.

While these lists may not be complete, they illustrate that decision options exist that allow management to counteract and reduce rebound effects or even create reinforcement effects by using the cost savings of efficiency improvements in an environmentally beneficial way and/or increasing awareness of environmental impact.

#### **Conclusion and outlook**

Rebound effects can reduce planned environmental improvement considerably if they are not known, accounted for and managed. This paper therefore analyses mechanisms how rebounds emerge and finds that rebounds are the result of subsequent decisions and activities after an immediate environmental improvement has been achieved. Rebound effects are not inevitable, but their emergence is subject to accounting and management decisions.

Management is therefore challenged to, first, create transparency about potential rebound effects by accounting for rebounds in order to increase awareness about the psychological, economic, and technical mechanisms that link environmental improvement activities with subsequent effects (either rebound or reinforcement). Second, management needs a clear intention and management approach to plan the design of

subsequent activities succeeding environmental activities in a beneficial way. Companies are designers and suppliers of products and related offerings for consumption and lifestyles. A precondition to prevent rebounds is, firstly, to be aware of possible rebound effects by accounting for them and, secondly, to develop knowledge about starting points to counter rebound effects or to create reinforcement effects.

Although rebound effects are problematic because they can reduce, neutralize, or overcompensate beneficial effects of an efficiency measure, they are not an inevitable consequence of efficiency increases or other environmental protection measures. In principle, positive reinforcement effects, which work in the contrary direction of rebound effects, are possible and can further increase environmental improvements. However, this is only possible if management is aware of potential rebounds and potential reinforcement options as well as willing to actively account for rebounds and to create reinforcement effects.

This first discussion of management options and the necessity to develop accounting for rebounds to counteract rebound effects and to create reinforcement effects aims to encourage further research and practice on environmental management approaches to design activities that lead to effective improvements, including the consideration of subsequent effects.

### CRedit authorship contribution statement

**Clara Amend:** Writing – review & editing, Writing – original draft, Investigation. **Sebastian Wüst:** Writing – original draft, Project administration, Investigation, Conceptualization. **Stefan Schaltegger:** Writing – review & editing, Writing – original draft, Supervision, Investigation, Funding acquisition, Conceptualization.

### 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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