DOI: 10.1111/jiec.13295

RESEARCH AND ANALYSIS

JOURNAL OF INDUSTRIAL ECOLOGY WILEY

Rebound effect and sustainability science

A review

David Font Vivanco[1] | Jaume Freire-González[2,3] | Ray Galvin[4,5] | Tilman Santarius[6] | Hans Jakob Walnum[7] | Tamar Makov[8] | Serenella Sala[9]

[1]2.-0 LCA consultants, Aalborg, Denmark

[2]Institute for Economic Analysis (CSIC) and Barcelona School of Economics, Bellaterra, Barcelona, Spain

[3]ENT Foundation, Barcelona, Spain

[4]Institute for Future Energy Consumer Needs and Behavior, Aachen, Germany

[5]Cambridge Institute for Sustainability Leadership, University of Cambridge, Cambridge, UK

[6]Department of Social Transformation and Sustainable Digitalization and Einstein Centre Digital Future, Technical University of Berlin, Berlin, Germany

[7]Western Norway Research Institute, Sogndal, Norway

[8]Department of Management, Guilford Glazer Faculty of Business and Management, Ben-Gurion University of the Negev Be'er Sheva, Israel

[9]European Commission, Joint Research Centre, Ispra, Italy

Correspondence
David Font Vivanco, Rendsburggade 14, Room 4.315B, 9000 Aalborg, Denmark.
Email: david.font@lca-net.com

Editor Managing Review: Junming Zhu

Funding information
Jaume Freire-González received the support of the Beatriu de Pinós postdoctoral program of the Generalitat de Catalunya - Agència de Gestió d'Ajuts Universitaris i de Recerca.

Abstract

Rebound effects have been historically studied through narrow framings which may overlook the complexity of sustainability challenges, sometimes leading to badly informed conclusions and policy recommendations. Here we present a critical literature review of rebound effects in the context of sustainability science in order to (1) map existing rebound research which goes beyond mainstream approaches, (2) unveil and classify current knowledge gaps in relation to sustainability science, (3) outline a research agenda, and (4) provide a knowledge base to support the design of effective policies toward sustainable development. We analyzed the literature in accordance with seven criteria for sustainable assessment: boundary orientedness, comprehensiveness, integratedness, stakeholder involvement, scalability, strategicness, and transparency. Our review identified three main issues: (1) the failure to address the multidimensionality of rebound effects, whereby both negative and positive outcomes may arise simultaneously, (2) the shift toward absolute rebound metrics which enables the contextualization of its effect with respect to science and policy goals, and (3) a general lack of attention to behavioral effects. We conclude that addressing these issues will help rebound research gain explanatory power and relevance for key decision-makers. We envision that with better alignment with sustainability science, future rebound research could help elucidate trade-offs in policies, including why certain strategies such as those based on the circular economy might fall short of expectations, and why achieving key goals and targets such as the sustainable development goals is so challenging. This knowledge is crucial for promoting a prioritization of actions and a concrete transition toward sustainability.

KEYWORDS
circular economy, industrial ecology, literature review, rebound effect, sustainability science, sustainable development goals

1 INTRODUCTION

The rebound effect has long been the object of interest and debate in academia. The resulting rich body of evidence has even sparked concern among policymakers, who fear that such an effect may render laboriously designed environmental and broader sustainability-oriented policy largely ineffective (Vivanco et al., 2016a). While definitions of the rebound effect are diverse in their breadth and depth, their essence is the contrast between the potential and the actual energy benefits and broader environmental benefits delivered by a given efficiency improvement (Greening et al., 2000; Jenkins et al., 2011; Sorrell, 2007). The rebound effect (RE) is thus generally defined as the absolute or relative difference between the "ceteris paribus" potential environmental benefits (PEB) (e.g., the expected energy savings from replacing incandescent light bulbs with more energy-efficient LED lights, all else being equal) and the "actual" environmental benefits (AEB) (e.g., the energy savings given the effects of cheaper lighting costs, moral licensing, and so on) (Vivanco et al., 2016b). Using absolute metrics, $\mathrm{RE} = \mathrm{PEB} - \mathrm{AEB}$, while, in relative terms, $\%\mathrm{RE} = (\frac{\mathrm{PEB}-\mathrm{AEB}}{|\mathrm{PEB}|}) \times 100$ (Vivanco et al., 2014). Building on this basic idea, definitions and related research on rebound effects have focused on a panoply of specific issues, such as energy savings from energy efficiency policies (Gillingham et al., 2016), water savings from crop irrigation practices (Berbel et al., 2015), and induced transport demand from fuel efficiency improvements (Galvin, 2020; Hymel et al., 2010). Moreover, rebound research tends to focus on specific economic effects, generally direct, indirect, and macroeconomic effects (Greening et al., 2000) as well as behavioral effects, namely increased/diffusion of responsibility, moral licensing, attenuated consequences, and frugality (Santarius & Soland, 2018). In the context of multi-faceted and inherently complex sustainability issues (TWI2050 2018), however, such overly specific framings can lead to overlooking key aspects, such as (1) the trade-offs between life cycle stages and environmental impacts, (2) macroeconomic effects, (3) social impacts, and (4) behavioral insights, in turn leading to badly informed conclusions and policy recommendations (Vivanco et al. 2018). For example, additional energy demand by low-income groups may contribute to eradicating energy poverty (Ürge-Vorsatz & Tirado Herrero, 2012) or indicate that poverty is being overcome (Galvin, 2015a). The usefulness of rebound effect analyses to tackle complex sustainability challenges across "areas of protection," for instance, human health, prosperity, and natural resources, and within the domains of society, the environment, and the economy (Finnveden et al., 2009), thus relies on framings that integrate as many aspects of sustainability as possible.

From its inception within energy economics, rebound effect research has progressively absorbed, albeit generally but not explicitly, aspects from industrial ecology and the broader field of sustainability science. Broadly speaking, sustainability science deals with the interactions between bio-physical and sociotechnical systems and how such interactions relate to the challenge of sustainable development (Kates et al., 2001). Sustainability science can be operationalized through sustainability assessment to support policy and decision-making in a broad environmental, economic, and social context (Sala et al., 2015). Sustainability science has been defined as a metadiscipline where key disciplines such as industrial ecology, environmental assessment modeling, risk assessment, and others are integrated (Mihelcic et al., 2003). In relation to industrial ecology, this field has been regarded as the science of sustainability (Ehrenfeld, 2004), and research further points to a growing unification between both fields based on their shared principles (Brent et al., 2008). Various works have analyzed the rebound literature according to broader framings related to industrial ecology (Hertwich, 2005), life cycle assessment (LCA) (Vivanco & van der Voet, 2014), psychology and sociology (Santarius & Soland, 2018; Santarius et al., 2018), non-energy rebound (Vivanco et al., 2018), power relations in industry and politics (Galvin, 2020), and thermodynamic-evolutionary theory (Ruzzenenti & Basosi, 2008). The explicit links between rebound effect research and sustainability science have not, however, been drawn, and current state-of-the-art approaches are scattered across different disciplinary niches.

In this article, we carry out a critical literature review of rebound effect research under the framing of sustainability science. It merits noting that we do not aim to carry out an exhaustive literature review to inventory all rebound effect research. Rather, we aim to identify key literature to discuss how a better alignment of current goals and scopes of rebound research with sustainability science may enable a range of stakeholders, from academics to policymakers, to draw attention to a fuller array of sustainability impacts and trade-offs mediated by rebound effects. We therefore do not negate the value of studies with narrow goals and/or scopes focusing on particular issues but we imply that assessing these studies against a sustainability assessment framework may help in unveiling hidden barriers toward the ultimate goal of sustainable development. Illustratively, typical energy or water rebound studies at local scales may ignore broader macro-scale effects (e.g., global market prices), the social implications of additional demand (e.g., energy poverty and malnutrition), the trade-offs between life cycle stages and/or environmental impacts (e.g., mining-related emissions into water stocks), and the positive impact of stakeholder involvement (e.g., to enhance communication of results). While such broadening of the goal and scope may not be relevant and/or feasible in all cases, the proposed exercise is critical to reconcile the study of specific issues with broader global goals.

This review is structured using, as criteria for evaluation of rebound effect studies, the criteria proposed in Sala et al. (2015) to compare different approaches to sustainability assessment. Despite the fact that several other frameworks for sustainability have been published, none had been translated into operational dimensions to be assessed. To overcome this limitation, Sala et al. (2015) proposed a pragmatic approach to evaluation addressing seven aspects: boundary orientedness, comprehensiveness, integratedness, stakeholder involvement, scalability, strategicness, and transparency (see Section 2 for definitions).

The objectives of this review are to (1) produce a comprehensive map of existing rebound research beyond mainstream energy economics, including existing ontologies and methods, (2) unveil and classify current knowledge gaps in relation to sustainability science, (3) outline a research agenda for future rebound research, and (4) aid the design of effective policies help transition toward sustainability. This review is structured as follows: Section 1.1 introduces the rebound effect concept from the perspective of energy economics, Section 2 reviews relevant literature through the lenses of sustainability science, Section 3 outlines a research agenda from current knowledge gaps, and Section 4 concludes.

1.1 | The origins: Jevons' paradox and energy rebound effect

The origin of the awareness of rebound effects can be traced to the seminal works of William Stanley Jevons (1865), who suggested that efficiency gains in the use of coal would lead to a net increase in coal demand. Such an argument would be later branded the "Jevons' paradox" (Giampietro & Mayumi, 1998; Wirl, 1997). Jevons' ideas were however largely dismissed due to the lack of empirical evidence by contemporaneous colleagues such as Mundella (1878). It was not until a century later that Brookes (1979) and Khazzoom (1980, 1987, 1989) first proposed and formalized, from a macroeconomic and microeconomic perspective, respectively, that energy efficiency could increase energy demand rather than decrease it. The term "rebound effect" was coined for the first time by Khazzoom (1980) in reference to the increase in demand for energy services due to the decrease in the unit price of energy from an energy efficiency improvement in household appliances (Khazzoom, 1980). More generally, the rebound effect was defined as the additional consumption of energy services from overall changes in demand as a result of behavioral and other systemic responses to energy efficiency improvements (Binswanger, 2001; Brookes, 1990; Saunders, 1992). The newly named rebound effect became a central topic in an intense debate among energy economists in the aftermath of the 1970s energy crisis and the subsequent needs of policy to reduce energy use and dependence (Herring, 2008). Later, Saunders (1992) labeled the "Khazzoom–Brookes Postulate," the case where energy use ends up increasing after an energy efficiency improvement, which is also called "backfire," and he suggested it occurs in accordance with a particular implementation of a neoclassical growth model. The first empirical studies on the rebound effect took shape after these early contributions, framed mostly in terms of neoclassical economic theory, and focused on energy uses.

During the 1980s and 1990s, further contributions to the ongoing debate were proposed, fuelled by climate change concerns and a new social and policy awareness on energy scarcity, consolidated during the energy crisis (Herring, 2008). These studies directed the debate not toward the existence of the rebound effect, but rather toward its impact on the viability of energy efficiency policies. Some scholars argued that energy efficiency leads to an increase in energy use (following Brookes (1979) and Saunders (1992), among others), while others argued that, while rebound effects offset some of the potential energy savings, energy efficiency nonetheless reduces energy use (Schipper & Grubb, 2000, among others). Notable contributions to the debate in this second wave were made by Lovins (1988), Schipper and Meyers (1992), Howarth (1997), Wirl (1997), Greene et al. (1999), Saunders (2000), and Binswanger (2001).

Greening et al. (2000) made the first comprehensive review covering 75 estimates of the rebound in the energy rebound literature of the 1980s and 1990s. They found that estimates of rebound effect size ranged between very low and moderate. Later, Sorrell (2007) provided another extensive literature review of over 500 studies and reports. These documents include both empirical estimates of rebound effects and qualitative discussions. The review showed the impressive growth in rebound literature over these three decades, even though the larger growth in rebound effects literature occurred after 2007. Sorrell concluded that while backfire effects (i.e., rebound effects higher than 100%) were unlikely to follow most energy efficiency improvements, they could emerge during early diffusion stages of improved "general purpose technologies," such as electricity and mechanization. Additional reviews, including reports from "grey" and policy-oriented literature, have arrived at similar results (Jenkins et al., 2011; Madlener & Turner, 2016; Maxwell et al., 2011).

2 | REVIEW RESULTS: THE REBOUND EFFECT IN THE CONTEXT OF SUSTAINABILITY SCIENCE

This section reviews the rebound effect literature through the lenses of sustainability science by organizing the relevant literature according to the seven key aspects, noted above, which Sala et al. (2015) proposed as criteria to be considered when comparing sustainability assessment approaches:

- Comprehensiveness: the inclusion of sustainability dimensions (environmental, social, and economic), and the principles related to these, in the scope of analysis.[1]
- Strategicness: the level to which an approach to assess sustainability is solution oriented, and so is focusing on transitions and changes toward sustainability.
- Integratedness: the level of integration between different sustainability dimensions. This includes the ability to consider the interplay among multiple sustainability dimensions as well as the use of transdisciplinary, inter-sectoral, and participatory approaches.
- Boundary orientedness: the adoption of science and/or policy-based thresholds, such as specific emission limits or broader planetary boundaries.
- Scalability: the inclusion of spatial (local, regional, and multi-regional) and temporal (short-, medium-, and long-term) scales of analysis.

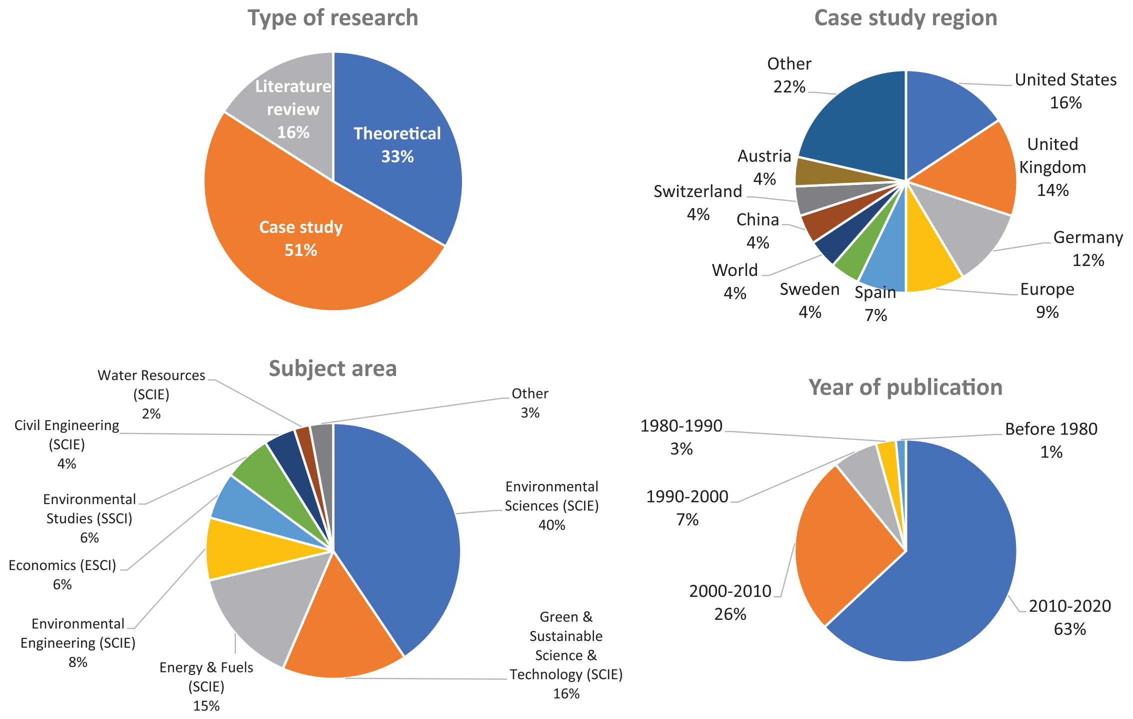

FIGURE 1 Summary statistics of the reviewed literature by type of article, year, journal subject area, and case study region. ESCI, Emerging Sources Citation Index; SCIE, Science Citation Index Expanded; SSCI, Social Sciences Citation Index, . Journal subject areas' description can be found in the Supporting Information

- Stakeholders' involvement: the involvement of relevant stakeholders in the assessment process, namely their interaction, promoting consensus building, access to information, and clear communication.
- Transparency: the openness regarding the data, data sources, models, indicators, results, and public accessibility thereof.

The literature review method used is based on the six generic steps described in Paré and Kitsiou (2016)—formulating the research question(s) and objective(s), searching the extant literature, screening for inclusion, assessing the quality of primary studies, extracting data, and analyzing data. The review can be categorized as a "critical review" as our goal is to offer an interpretative analysis of existing literature on a particular topic—the rebound effect—to reveal relevant issues, such as strengths and weaknesses, with respect to a particular theory—sustainability assessment and broader sustainability science—(Paré & Kitsiou, 2016). Given the significant volume of extant literature on the topic of the rebound effect, assessing the representativeness and quality of primary studies deserves special attention in order to ensure the validity of this exercise. First, we ensure that the selected literature is representative of this topic by applying an exhaustive coverage, thereby ensuring that all relevant studies are included in the review. The exhaustive coverage is validated through the literature review method and the comprehensive knowledge of the review team on this topic. Even so, some relevant studies may still have been unintentionally omitted, and this constitutes a limitation of this approach (see Section 3.7). Second, we have assessed the scientific quality of a selection of studies purely based on the rigor of their research design and methods. Such an assessment will be explicit whenever relevant to the main discussion. This approach can generate a bias toward recent literature due to the iterative nature of the scientific process (see Figure 1). We have prevented the overrepresentation of studies on the same topic by generally avoiding duplication of goals and scopes, namely a single study will be selected from a selection with similar goal and scope. The reviewed literature contains both peer-reviewed academic articles and grey literature. It was conducted using a variety of approaches, such as keyword search (e.g., "rebound effect" and "water efficiency" for the case of water rebound literature) and cross-reference analysis. A total of 138 documents have been included in this critical review. From all documents, 65% are academic papers published in peer-reviewed journals, 28% are books or book chapters, while the remaining 7% are reports, conference papers, or white papers. A summary of the reviewed literature (by type of article, year, journal subject area, and case study region) is presented in Figure 1. Full statistics and individual scores for each reviewed document using the systemic framework for sustainability assessment from Sala et al. (2015) are shown in the Supporting Information. Also note that scores do not relate to the scientific quality of the research but to the extent to which the research fulfils the framework's dimensions. Studies were classified as "case study," "theoretical," or "literature review" according to their primary goal, and only documents containing case studies will have a case study region and a score for scalability. Documents containing literature reviews were not scored as these do not contain original research.

2.1 | Comprehensiveness: Economic, environmental, and social dimensions

2.1.1 | Economic dimension

While rebound effects are generally expressed through indicators of interest such as resource use (e.g., coal and primary energy) or broader environmental issues (e.g., climate change and waste generation), it merits noting that rebound is mediated by changes in consumption and/or production. Following Vivanco et al. (2016b), rebound expressed using "pressure" indicators such as resource use can also be characterized using economic indicators such as relative/absolute changes in income, GDP, and factor productivity, which then lead to environmental consequences. While not inherently related to a given issue under scrutiny (e.g., whether a given policy led to a net reduction in energy use), such indicators are useful to make explicit the relationship between the driving forces behind changes in resource use. These indicators link resource efficiency with the so-called "core rebound mechanisms," such as re-spending and price effects, which are later represented as indicators of interest (Freire-González, 2017; Vivanco et al., 2016b). Expressing rebound through economic indicators (e.g., changes in income and GDP) was not common in early rebound studies, as these were focused on estimations of direct rebound effects and largely relied on price elasticities as a proxy to estimate direct energy rebound in relative terms (percentage of energy savings that are taken back). There was therefore no need to estimate "intermediate results" such as the economic savings associated with fuel improvements, more efficient appliances, etc. The emergence of studies focusing on indirect effects (relating to other products and services, which were not the object of resource improvements), and broader macroeconomic effects made such intermediate results a necessity sometimes worth reporting.

Relating to individual spending, Vivanco et al. (2015), Makov and Vivanco (2018), and Thiesen et al. (2008), among others, reported rebound effects both in terms of individual economic savings and their associated environmental consequences. Briceno et al. (2004) reported rebound in terms of increases in passenger and vehicle kilometers, where economic savings lead to a rebound in terms of climate change. As for factor productivity, Sorrel (2007) reviewed various examples from the energy efficiency literature, which investigate the link between improved energy efficiency and improved total factor productivity. Regarding macroeconomic effects, a rich body of literature can be found where indicators relating to productivity, GDP, employment, etc. are associated with rebounds (Dimitropoulos, 2007; Duarte et al., 2018). For example, Allan et al. (2006) estimated the effects of energy efficiency improvements in terms of changes in long-run GDP, employment, and wages. Barker et al. (2007) also estimated the contribution of GDP changes to the total macroeconomic rebound expressed in terms of greenhouse gas (GHG) emissions.

2.1.2 | Environmental dimension

Environmental issues have traditionally been the object of interest in rebound studies, from resources use and depletion (e.g., coal and energy use) to more complex pressures and impacts, such as climate change. Environmental indicators used to represent rebound can be classified according to the DPSIR (driving forces, pressures, states, impacts, and responses) modeling framework, as pressures (e.g., CO_2 emissions and water use), states (e.g., global warming and nature occupation), and impacts (e.g., impacts on ecosystems and human well-being) (Smeets & Weterings, 1999). Using LCA terminology, pressures, states, and impacts can be defined as elementary flows, midpoint impacts, and endpoint impacts (Weidema et al., 2008). Other than energy rebound, a wide array of environmental issues have been addressed in rebound studies through the so-called "environmental rebound effect" framework (Vivanco et al., 2016b), and some studies have further addressed the so-called cross-rebound effects by analyzing the effects on other resources different from the resource initially targeted by the efficiency improvement (Freire-González & Vivanco, 2017). Aside from energy and related GHG emissions (see Section 1.1), water rebound has received special attention.

Water rebound effect

Berbel et al. (2015) performed a literature review on water rebound. They found that, much like traditional energy rebound literature, research into water rebound produces a wide range of sometimes contradictory results. Sears et al. (2018) also performed a brief literature review focused on the Jevons' paradox and efficient irrigation technologies, and suggested that existing empirical literature on the effects of incentive-based groundwater conservation policies on groundwater extraction lent support to the possibility of Jevons' paradox or backfire.

Recent studies show potentially high rebounds for water use, among which we highlight the most relevant ones. Gutierrez-Martin and Gomez (2011) found that the potential water savings from improved irrigation techniques were compromised by increased water demand due to higher water productivity. In another case study, Pfeiffer and Lin (2014) evaluated the effect of a conversion to higher efficiency irrigation systems and found that the intended reduction in groundwater use did not occur, partly because of shifting crop patterns toward more water-intensive crops. Berbel and Mateos (2014) found high additional water consumption due to the expansion of irrigated land, leading to backfire. Song et al. (2018) and Fang et al. (2020) found water rebound in the order of 60–70% for China following improvements in irrigation technology. Freire-González (2019) found a water economy-wide rebound effect of just over 100% for Spain, meaning that efficiency improvements in water use did not lead to reduced water consumption at the national level.

Other environmental rebound effects

Air emissions have been the focus of many rebound studies, mostly focusing on carbon dioxide and broader GHG emissions. Rebound has been expressed as GHG emissions in a number of such works using LCA, input–output analysis (IOA), or a combination of both, among which we highlight the works of Takahashi et al. (2004), Briceno et al. (2004), Alfredsson (2004), Takase et al (2005), Sandén and Karlstrom (2007), Girod (2008), Ornetzeder et al. (2008), Spielmann et al. (2008), Murray (2009), Rajagopal et al. (2011), Whitefoot et al. (2011), Girod et al. (2011), Tukker et al. (2011), Druckman et al. (2011), Cellura et al. (2013), Grabs (2015), Galvin (2020), Makov and Vivanco (2018), and Skelton et al. (2020). Among these, we highlight the pioneering work of Takahashi et al. (2004) where LCA was first used to translate demand metrics into life cycle emissions. Also, Briceno et al. (2004) first described rebound in terms of an impact category (global warming) as well as combining LCA with IOA to address the impacts from re-spending. Sandén and Karlstrom (2007) first applied consequential LCA in the context of rebound research, while Murray (2009) first calculated direct and indirect GHG rebound effects using IOA. Multiple air emissions, including nitrogen oxides and sulfur oxides, have been addressed by Thomas and Azevedo (2013) and Vivanco et al. (2014, 2015). For additional discussion on environmental metrics used in rebound studies and statistics, we refer to Vivanco et al. (2014).

Other environmental issues examined in the rebound literature include metals and minerals (Freire-González & Vivanco, 2017), abiotic resource depletion (Vivanco et al., 2014), land use (Bahn-Walkowiak et al., 2012; Larson et al., 2012; Vivanco et al., 2015), and household waste generation (Chitnis et al., 2012; Salemdeeb et al., 2017; Takase et al., 2005). Further, biodiversity rebound has been explored by Andrés et al. (2012). Rebound for multiple environmental issues has been addressed by Briceno et al. (2004) and Thiesen et al. (2008), while Weidema et al. (2008) further addressed both midpoint and endpoint indicators. The study from Weidema et al. (2008) is of particular relevance as it shows the differences in the relative score across impact categories by adopting different impact assessment metrics. Beyond simply expressing rebound through multiple indicators, the trade-offs across environmental indicators have been assessed by Freire-González and Vivanco (2017) in terms of the economic structure, the consumption patterns, and the own price elasticity of the demand for energy.

2.1.3 | Social dimension

The rebound effect has social implications and impacts on several fronts. First, rebound is a social phenomenon because *people* are always involved in causing rebounds. Most micro-level rebound research focuses on types of consumer behavior which lead to rebound effects. The classic econometric definition of the direct rebound effect as the price elasticity of energy services (Berkhout et al., 2000; Saunders, 1992; Sorrell & Dimitropoulos, 2008) assumes individuals cause rebounds by increasing their take of energy services. This assumption focuses on individual consumers' response to cost-effective efficiency improvements which reduce the "effective price" of energy services (Gillingham et al., 2016).

The focus on individual consumers is also evident in research examining how consumers' attitudes and adoption of social norms cause these economically motivated rebound effects (Peters & Dütschke, 2016; Santarius & Soland, 2018). Some research goes beyond the economic framework to investigate broader psychological concepts such as "moral licensing"—where consumers feel free to consume more energy services because they have done their bit for the environment by increasing the energy efficiency of their appliances or home—again putting the focus squarely on the individual consumer. Moral licensing has also been documented in field experiments investigating consumers' behavior in response to circular economy strategies such as recycling (Ma et al., 2019; Sun & Trudel, 2017) or sharing (Briceno et al., 2004; Cheng et al., 2020; Warmington-Lundström & Laurenti, 2020).

The sole focus on the individual consumer has been critiqued by authors such as Labanca and Bertoldi (2018) and Ruzzenenti and Wagner (2018), who point out that it ignores the social structural constraints which tend to lock people into rebound behaviors. People who heat more rooms in their house after a thermal retrofit often do so because society has changed: for example, their children have to do their individual homework on their own computers in the privacy and quiet of their own space. Women tend to buy high fuel-consumption sports utility vehicles because these vehicles merge the traditional role of women as shoppers and transporters of children, with the feminist image of a powerful woman enhanced by symbols of prestige and competence (Jain, 2002; Sheller, 2004).

The theme of social and political power in driving rebound effects has begun to be explored in relation to the social structural constraints on individual consumers that lead them and sometimes lock them into rebound behavior. An example is Galvin's (2020) study of rebound effects in the US automotive industry. These rebounds statistically correlate with increases in average engine power, which are driven by specific, politically powerful actors and groups of actors in the industry. Taking this into account would require rebound scholars to consider theories of (social–political–economic) power (e.g., Geels, 2014; Giddens, 1984; Winters, 2011). By incorporating well-developed theories of power such as that of Sovacool and Brisbois (2019) into rebound studies, researchers would be better equipped to trace the lines of causation from energy efficiency upgrades to increases in energy services consumption.

Another important social aspect of micro-level rebound effects is that they are often welfare enhancing for people who would otherwise be deprived of life's basic necessities. Roy (2000) and Chakravarty et al. (2013) explored this in the context of emerging economies. Where there is unmet demand, energy efficiency increases can bring the price of essential energy services within the reach of low-income people. Similarly in the UK context, Chitnis et al. (2014) found a tendency toward higher rebounds among lower socioeconomic groups. The welfare-enhancing aspect of rebound effects began to be evidenced in a striking way in the early 21st century in a stream of studies of heating behavior in homes in European countries including England (e.g., Kelly, 2011), Germany (e.g., Sunikka-Blank & Galvin, 2012); Belgium (e.g., Hens et al. 2010), Austria (e.g., Haas & Biermayer, 2000), France (e.g., Cayre et al., 2011), the Netherlands (e.g., Tigchelaar et al., 2011), and Switzerland (e.g., Jakob, 2007). In all of these countries, households in thermally poor dwellings used far less heating energy, on average, than was required to achieve a healthy indoor environment, whereas in dwellings of high thermal quality or after a dwelling was retrofitted to high thermal quality, occupants used about the same as or slightly more than the required amount. After homes were thermally retrofitted, rebound effects often averaged around 40%, but much of this was welfare enhancing: people were now living in warmer, healthier indoor climates. More generally regarding thermal retrofits, some households need large rebounds to escape from fuel poverty because of structural deficiencies such as inadequate housing policies (Bouzarovski et al., 2016), regressive tax systems, and inadequate welfare systems (Galvin, 2019).

To some extent, then, rebound effects may be necessary to mitigate energy poverty. But there are caveats. As Bouzarovski et al. (2016) point out, for many low-income households the problem is not (only) thermally poor dwellings but (also) high fuel prices, often due to regressive fuel price policies (cf., Haar, 2019). Also, there are clear cases where poorer households still have cold homes after retrofitting because they see this as an opportunity to save money by keeping the thermostat set on low (Chen et al., 2018).

Rebounds can also bring welfare-enhancing effects in relation to gender. We draw attention to this because scholarship overwhelmingly supports the notion that women on average frequently have less access than men to energy services in certain domains. Galvin's (2015b) study of commuting to work in the German state of North Rhine-Westphalia revealed that in the 14 years from 1999 to 2013, females' commuting distances increased proportionately more than males' and therefore, using the standard rebound formula based on elasticities, females' rebound effects were 16.5% points higher than those of males. When the increase in the number of female workers was factored in alongside the decrease in male workers, females' rebound effects were more than twice as high as males'. Looking at absolute values, however, females' commuting distances had been far shorter than males' in 1999 and were still shorter in 2013, so the rebound effect could be seen as welfare enhancing in that through it, females were beginning to catch up. The discussion above on social structural factors is also relevant here. Women commuters have high rebounds in part because social structural factors long kept them from having the same range of jobs and commute choices as men (Blanke et al., 1996; and see reviews in Crane, 2007; Hanson, 2010).

Finally, welfare-enhancing effects from rebounds can also be accounted for at the macroeconomic level. Although welfare is correlated with GDP, we find evidence that it also correlates with the level of energy services consumed (and not necessarily the level of energy consumed). In the so-called "least developed" countries significant shares of the population still do not have access to electricity and so do not enjoy the energy services that electricity brings. As such, efficiency improvements are welcome avenues to make electricity more available and affordable so that more people can enjoy their benefits. In these cases, rebound effects may not be considered as "unintended side effects of intended energy efficiency improvements" (Santarius, 2012), but rather as a straight means to reduce (energy) poverty and improve economic wealth. But even from a bare (macro)economic point of view, in both poor and rich countries, some researchers point out that rebound effects always imply increased utility for users and nations, and hence conclude that "where there is rebound, it's a damn good thing!" (Grubb, 2014) since "It's economic value creation" (Borenstein, 2012).

2.2 | Strategicness and integratedness

On strategicness, sustainability principles are increasingly considered in rebound studies, albeit such considerations are still scarce. As shown in the previous section, the conflict between positive welfare-enhancing effects and negative environmental impacts from energy efficiency improvements has been addressed in a number of studies from a social science perspective. Similarly, macroeconomic studies such as that of Barker et al. (2007) describe a related conflict between increased energy demand and increased GDP and employment.

On integratedness, rebound research has greatly evolved from its origins within energy economics to an increasingly transdisciplinary line of work (Santarius et al., 2016), allowing research to capture complex cause–effect interactions. Transdisciplinary research on rebound is gaining momentum and it has recently been the object of the book "Rethinking climate and energy policies: New perspectives on the rebound phenomenon" (Santarius et al., 2016) and the special issue "The Rebound Effect and the Jevons' paradox: Beyond the Conventional Wisdom" (Ruzzenenti et al., 2019). Among the various disciplinary understandings, those from industrial ecology and ecological economics deserve special attention in the context of sustainability science. These and other disciplines combine their own theories and metrics with those from energy and neoclassical economics, such as the use of price elasticities and household demand models, to address various dimensions of rebound.

2.2.1 | Industrial ecology

The early 2000s witnessed an emergence of rebound studies inspired by theories and methods from industrial ecology and specifically the application of LCA and/or IOA (Hertwich, 2005; Vivanco & van der Voet, 2014). Those studies have been framed within the so-called "environmental rebound effect" (Vivanco et al., 2016b), given their focus on environmental and broader sustainability issues. Yet rather than simply translating economic to environmental indicators via coefficients, the application of industrial ecology theory brought many valuable insights, from which we highlight the following:

- *Multidimensional indicators*. One of the main contributions of industrial ecology theory to rebound analysis is the ability to express rebound effects using multiple environmental indicators which go beyond energy and related emissions (see Section 3.1) at different levels of the society–environment interaction (mostly pressures and impacts). This extension allowed research to identify trade-offs between indicators or cross-rebound effects (Freire-González & Vivanco, 2017), with some analyses showing great disparity across indicators (Vivanco et al., 2014, 2015). Further, by expressing rebound at the impact level, the biophysical context could be considered, for example, where emissions are produced (e.g., in a city or close to a fragile ecosystem).
- *Environmental efficiency*. Classical rebound definitions from energy economics focused on "engineering" type definitions of efficiency, specifically the ratio between inputs (e.g., use of energy or other resources) and outputs (economic services). This "input/output efficiency" was expanded under the "environmental rebound effect" by the concept of "environmental efficiency," defined as the ratio between the fulfilment of a function (e.g., moving from A to B with a certain performance) and its associated environmental damage (e.g., kilogram of GHG emissions) (Vivanco et al., 2016b). Under such definition, studies could address the environmental consequences of changes in the characteristics of products, such as the content of recycled materials (Dace et al., 2014) and changes between functionally comparable products, such as shifts between vehicle powertrains (Vivanco et al., 2016c).
- *Technology detail*. The use of LCA to estimate rebound greatly increased the technology detail of rebound analysis, which allowed researchers to focus on specific products rather than technologies and sectors more broadly. Some examples include the analysis of cheese (Thiesen et al., 2008), electric cars (Vivanco et al., 2016c), and smartphones (Makov & Vivanco, 2018).
- *Life cycle perspective*. Aside from technology detail, LCA applications also innately integrate a life cycle perspective, with the power to unveil determining environmental consequences taking place along the entire supply chain (e.g., impacts from mineral extraction and land use; Vivanco et al., 2015). This perspective integrates embodied-type effects which some authors treat separately (Sorrell, 2009; van den Bergh, 2011). Other advantages of looking at the life cycle of products are the identification of actors along the supply chain, which can help assessing the process of knowledge generation and technological learning (Sandén & Karlstrom, 2007), and the tracing of external costs, which can lead to rebound estimates that are better aligned with sustainability principles (Hertwich, 2005; Roth & Ambs, 2004).

2.2.2 | Ecological economics

Some fundamental assumptions associated with ecological economics have a profound impact on the ecological economics view on rebound effects and on its view on achieving ecological sustainability. In his book "The Entropy Law and the Economic Process," Nicholas Georgescu-Roegen (2013) develops the basis for understanding society's economic system not as a closed circular system but as an entropic process closely integrated with natural sources of exergy (low entropy). This idea expanded the application of thermodynamic principles from traditional areas of engineering (energy systems, industrial processes, etc.) to include the overall economic system.

With its point of departure in the entropy law, ecological economics is fundamentally different from mainstream neoclassical economics, which does not include the physical dependence of the economy, especially with regard to the possibilities for decoupling energy use (which could come from energy efficiency improvements) from economic growth. According to neoclassical economics, energy productivity makes relatively small contributions to economic growth as energy inputs constitute a small share of total costs (Jones, 1975). Decoupling energy consumption from economic growth is thus considered both feasible and cheap. The ecological economics perspective states that capital, labor, and energy are interdependent inputs and have synergistic effects on economic output and that energy quality is a crucial but neglected causal variable in explaining economic growth (Ayres & Warr, 2005; Cleveland et al., 1986, 2000). A contribution from ecological economics has been to emphasize the dependency of modern societies on high-quality fossil fuels and that this is a driver for other input factors (for instance, on labor productivity) (Sorrell & Dimitropoulos, 2007). This dependency implies that rebound effects can be potentially larger, and improvements in energy productivity make an important contribution to economic growth (Røpke, 2009; Sorrell, 2010; Sorrell & Dimitropoulos, 2007; Jenkins et al., 2011).

Georgescu-Roegen's thinking also inspired research on degrowth, which focuses on the decrease in the amount of natural resources consumed by means of structural changes based on principles of sufficiency (Alcott, 2008; Princen, 2005). This perspective implies that the most effective measure for curbing rebound effects is absolute physical caps on natural resources such as keeping oil and gas in the ground (Alcott, 2010); if society first caps its resources, people will automatically live more efficiently and sufficiently (Alcott, 2014). The effectiveness of sufficiency measures is, however, not straightforward, as some degree of rebound can take place when the decrease in demand for some products lowers their price which subsequently induces extra demand (Alcott, 2008).

Other contributions under the umbrella of ecological economics include those from an evolutionary perspective, which are grounded in the idea that social and ecological systems are "metabolic systems which are organised in nested hierarchical levels and have the ability to evolve simultaneously across different scales to learn" (Giampietro & Mayumi, 2008, p. 91). Such an interpretation challenges neoclassical views on rebound in two important ways (Giampietro & Mayumi, 2008, pp. 79—80): (1) energy efficiency becomes harder to define and measure "when dealing with complex adaptive systems operating on multiple tasks across different hierarchical levels and scales," and (2) changes in energy efficiency can arise from either "a change in technological coefficients (when the system performs 'the same set of transformations' but 'better')" or "a change in the profile of tasks to be performed (when the system finds more convenient methods to perform 'something else' instead of the original set of transformations)." Some authors argue that the application of evolutionary principles could capture the dynamic adaptation of markets to new attributes, such as an improved carbon footprint, of existing products (Benedetto et al., 2014).

Time as a consumption factor, rather than income, has been addressed within neoclassical and orthodox economics through the so-called time rebound effect (e.g., by Becker, 1965). The aspect of "time" was introduced to micro-economic rebound research by Binswanger (2001) and Jalas (2002). More recently, time rebound research has been more in line with ecological economics thinking, since research on time rebound has been concerned with the macro-level and how energy efficiency has led to time efficiency gains that have accelerated both production and consumption. Brenčič and Young (2009), Druckman et al. (2012), Buhl and Acosta (2016), and Buhl (2016) analyzed how time-saving technical innovations impact on energy service demand, while Santarius (2016a) discussed the implications of social acceleration and energy demand at the macro-level. Time rebound was largely applied to analyze transport systems (Girod et al., 2011; Hymel et al., 2010; Small & Van Dender, 2007; Spielmann et al., 2008). Building on Becker (1965) and Spreng (2013), time can be considered an input factor in (household) production functions that is interlinked, if not substitutable, with other inputs such as capital, energy, and information/knowledge. Hence, time efficiency improvements as well as changes in overall time use—for example, a faster pace of life that entails more activities performed per unit of time (day)—can have direct effects on the use of energy, environmental resources, as well as on social factors such as feelings of time stress or time wealth.

Historically, the relationship between technical energy efficiency, time efficiency and changing time use patterns, and energy demand can be studied from the history of transportation. There is plenty of evidence on how improvements in the technical efficiencies of locomotives, motors, automotive engineering, and transport infrastructures enabled faster and long-distance journeys, particularly during the 19th and 20th centuries (e.g., Fouquet, 2008; Schivelbusch, 2014). From the invention of the railway in the 19th century until about the 1980s, energy efficiency improvements effectively translated into higher travel speed at less costs (Obermayer & Maier, 1994). Vice versa, the extensive literature on social acceleration shows that, as people tend to travel faster and further and the pace of life increases, this may result in more energy demand as well as in more time stress and a reduction in the quality of life (Linder, 1970; Rosa, 2013; Schor, 1991; Wajcman, 2015).

2.2.3 | Other relevant disciplines

The use of models based on orthodox macroeconomics, such as computable general equilibrium and macroeconometric models (Dimitropoulos, 2007; Duarte et al., 2018), allowed researchers to quantify macroeconomic rebound effects that were previously only theorized, such as price, market, and growth effects (Jenkins et al., 2011). Theories from behavioral economics have also been used to study rebound, putting attention on the drivers behind consumer choices, such as product substitutability (Makov & Vivanco, 2018) and discount rates (Ceolotto, 2016). Consumer choices in rebound studies have also been explored with the use of agent-based modeling (ABM). For example, Hicks and Theis (2014) and Hicks et al. (2015) combined ABM with LCA to simulate emergent behavior related to the adoption of energy-efficient lighting technologies by households.

Several other studies were conducted with a psychological and behavioral science perspective (e.g., Girod & de Haan, 2009; Peters et al., 2012; Peters & Dütschke, 2016; Suffolk & Poortinga, 2016; Santarius, 2012; Santarius & Soland, 2018), while other approaches were built on sociological theories (e.g., Galvin, 2015b; Galvin & Gubernat, 2016; Santarius, 2016a; Sonnberger & Gross, 2018). In addition, several chapters in the volume by Santarius et al. (2016) addressed the issue from transdisciplinary and real-life-oriented perspectives (e.g., Aall et al., 2016, Næss, 2016; Walnum & Aall, 2016). Moreover, extensive literature in environmental psychology investigates mechanisms that are highly analogous to rebound effects, but do not necessarily use that term. For example, a wide range of studies show evidence for moral-licensing effects (e.g., Eskine, 2012; Kaklamanou, 2013; Khan & Dhar, 2006; Kivetz & Simonson, 2002; Mazar & Zhong, 2010; Merritt et al., 2010; Tiefenbeck et al., 2013). Similar to rebound research, such literature explains why individuals tend to consume more energy services after they have invested in energy efficient technologies. However, a meta-analysis suggests that moral-licensing effects may generally be rather small (Blanken et al., 2015), and several moral-licensing studies have been criticized for poor methodological grounds (Gneezy et al., 2011). A second strain of psychological research investigates spill-over effects (e.g., Dolan & Galizzi, 2015; Klöckner et al., 2013; Kuhn et al., 2021; Lauren et al., 2016; Thøgersen, 1999; Thøgersen & Ölander, 2003). Such literature can elucidate secondary effects of energy efficiency improvements in one domain to behaviors in other domains. At the same time, it shows evidence that runs against rebound argumentations, for example, by showing that efficiency improvements in one domain may incentivize individuals to achieve additional improvements in other domains, hence leading to beneficial environmental effects that countervail rebounds (Santarius & Soland, 2018).

2.3 | Boundary orientedness

Using the classic microeconomic definition of the rebound effect as an elasticity, namely the ratio between two proportions, rebound estimates become a weak tool because they give figures for proportions rather than amounts of resources saved. With the emergence of quantitative methods from industrial ecology, macroeconomics, etc., rebounds have been increasingly measured in absolute values, thus allowing these to be compared against any given reference.

2.3.1 | Rebounds compared to absolute levels of lost energy savings

In the context of energy rebound, a recurrent question is to what extent rebound estimates can indicate how much absolute reduction in energy consumption and CO_2 emissions is being achieved. Galvin (2014) touches on this issue as part of a wider discussion of how different definitions of rebound effects can mislead as to which energy retrofit gives the biggest absolute reductions in energy consumption. This issue is also mentioned in Section 2.1.3 in relation to increases in male and female commuting distances in North Rhine-Westphalia. The confusion it sows is evident in a European Commission report on the rebound effect (Maxwell et al., 2011), where it is often not clear whether the authors are speaking of absolute or merely proportionate reductions in energy use in specific spheres.

This point is concretely illustrated in examples given by Galvin (2014), who considers three identical apartment buildings each thermally retrofitted to different standards. The building with the least ambitious retrofit saved the least energy, as expected, but it also had the lowest rebound effect. This was because, after the retrofit, the occupants of this building consumed close to the level the engineers were aiming for, while the occupants of the buildings with the more ambitious retrofits found it difficult to bring their consumption down to the extremely low levels in the retrofit design. We can also see this in private car transport, as Frondel et al. (2012) found that households who do low mileage exhibited higher rebound effects, on average, than households who do higher mileage. The level of rebound effects was therefore not in proportion to the absolute amounts of lost energy savings.

Part of the reason for these findings is built into definitions of the rebound effect. For example, if the expected energy reduction which engineers calculate on the basis of the planned energy efficiency increase is very large but the actual energy reduction is only moderate, the rebound effect will be high—even though in absolute terms a large amount of energy has been saved. On the other hand, if the expected energy reduction is very small and the actual energy reduction almost matches this, the rebound effect will be small but so will the absolute amount of saved energy.

2.3.2 | Absolute rebound and policy goals

Estimating rebound effects in absolute terms can be a powerful way to assess progress toward policy goals. For example, Vivanco et al. (2021) calculated a macroeconomic rebound in absolute terms for climate change from the introduction of governmental subsidy on electric cars in the United Kingdom, which offered a clearer idea of its impact toward broader goals such as achieving carbon neutrality in the United Kingdom by 2050 (CCC, 2019). Similarly, Vivanco et al. (2015) calculated the absolute change in GHG emissions for various transport eco-innovations in Europe considering the environmental rebound effect. By comparing the results of various innovations against each other, this study highlights that high rebound in relative terms may be negligible when the diffusion of certain innovations is low. In other words, expressing rebound as a ratio as traditionally done may not be very informative for policy. Lastly, the rebound framework has been used by Vivanco and Makov (2020) to examine linkages between different SDG targets and strategies, which are sometimes formulated in absolute terms. While SDGs are generally conceptualized as separate, isolated elements within a broader framework, many of the goals are inherently linked, such that progress toward one goal could affect progress toward other goals (Miola et al., 2019). Vivanco and Makov demonstrated that, since technology and technological change are central components to many SDG strategies, the rebound effect framework can be utilized to identify hidden barriers for achieving SDGs as well as the underlying mechanisms driving environmental–economic–social trade-offs. Being able to calculate absolute rebounds offers a better understanding of such trade-offs, which is key for formulating informed management strategies to improve the overall cohesiveness of the SDG framework.

2.4 | Scalability, stakeholders’ involvement, and transparency

Regarding scalability, most studies focus on short-term rebound analysis by calibrating models using historical and/or average data, such as input–output relationships and survey data. Medium-term analyses can be found in those studies applying consequential LCA (e.g., Thiesen et al., 2008; Whitefoot et al., 2011) and macroeconomic forecasting (e.g., Barker et al., 2007; Vivanco et al., 2021). Long-term analyses deal with the so-called transformational effects (Greening et al., 2000; Polimeni et al., 2008), namely the consequences beyond cause–effect relationships between supply and demand, by describing changes in actors’ preferences and the availability and cost of technologies from the cumulative build-up of stocks and structures. Such effects were addressed by Sandén and Karlstrom (2007) by combining consequential LCA with theories of technical change, such as scenarios and learning curves. On spatial scales, rebound effects at the micro-, meso-, and macro-scales are well researched, while rebound studies focus largely on developed economies (Chakravarty et al., 2013; Sorrell, 2007).

Regarding stakeholders’ involvement, rebound research has been progressively involving stakeholders outside of academic circles. For example, the project “Addressing the rebound effect” (Maxwell et al., 2011), commissioned by the European Commission, gathered the viewpoints of policymakers, businesses, and NGOs. Similarly, the project “Capping Macro Rebounds - ReCap” (Lange et al., 2019), commissioned by the German

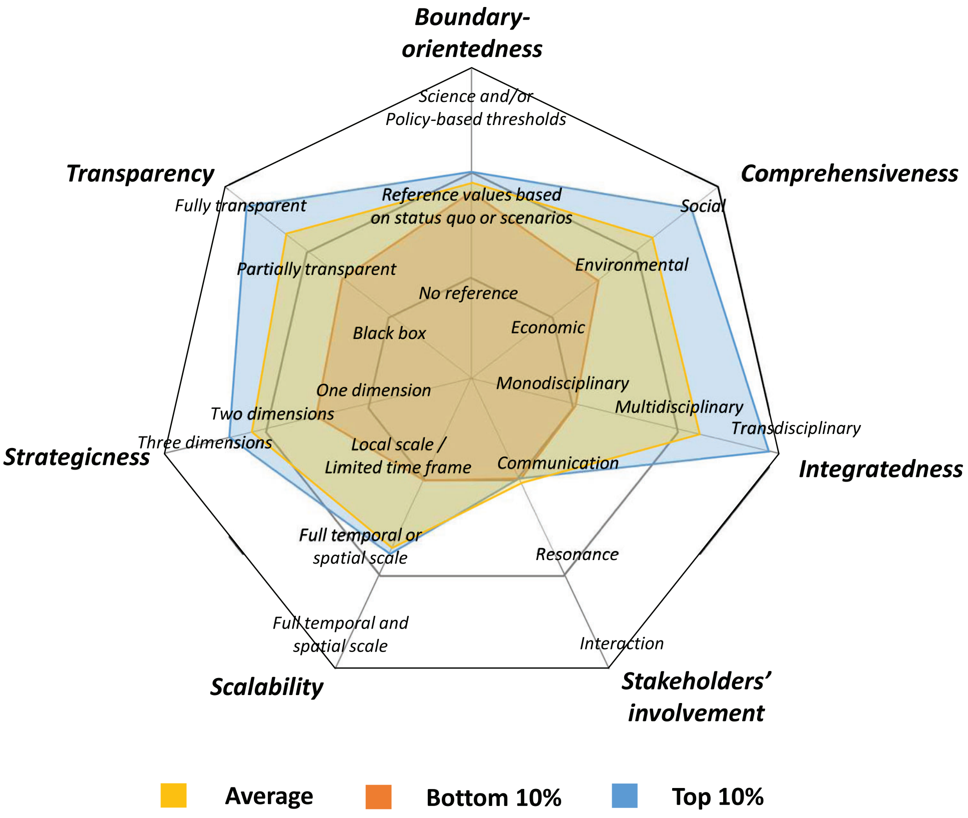

FIGURE 2 Current state of rebound research according to sustainability assessment scores. Based on Sala et al. (2015)

government, brought together different stakeholders to develop proposals to limit economy-wide rebound. Stakeholder consultations have even led to tangible policy action such as the UK government acceptance and inclusion of direct rebound in energy policies after consulting relevant stakeholders (Maxwell et al., 2011).

Regarding transparency, rebound models are generally transparent about data sources and assumptions, but with exceptions. For example, some studies using macroeconomic models have been labeled as not being fully transparent, and sensitivity and uncertainty analyses are rarely conducted to test underlying assumptions and data inputs (Dimitropoulos, 2007; Sorrell, 2007). Multiple modeling approaches are sometimes used simultaneously (e.g., Salemdeeb et al., 2017; Vivanco et al., 2021), although this feature is relatively rare.

3 | DISCUSSION: CURRENT KNOWLEDGE GAPS AND RESEARCH AGENDA

Using the systemic framework for sustainability assessment from Sala et al. (2015), and according to the reviewed literature in this paper, we depict the current state of rebound research in Figure 2 based on the individual scores (on a scale from 1 [no fulfilment] to 3 [full fulfilment] for each sustainability dimension) for each document (see Supporting Information). On average, the reviewed literature shows the highest values for transparency (score of 2.28), comprehensiveness (2.23), integratedness (2.20), and strategicness (2.11), while stakeholders' involvement (1.03), scalability (1.67), and boundary orientedness (1.97) show the lowest values. The bottom 10% in terms of total score (summation over single dimension scores) shows no fulfilment of stakeholder's involvement and scalability (1) and a low score for integratedness (1.06). The top 10% show close to full fulfilment for integratedness (2.81), transparency (2.75), and comprehensiveness (2.75). Across studies, stakeholders' involvement and boundary orientedness show the lowest standard deviation (0.16 and 0.18, respectively) while integratedness and transparency show the highest standard deviation (0.69 and 0.68, respectively). Knowledge gaps in each aspect of the framework are described in the following section and are further used to outline a research agenda. The section concludes with a short discussion on interpretation.

3.1 | Comprehensiveness

Addressing at least both the economic and environmental dimensions is widespread in rebound studies (93% of scored studies) given that economic mechanisms, broadly related to consumption and/or production (Vivanco et al., 2016b), are generally associated with the consumption of resources, typically energy, and/or associated emissions to the environment. Even so, some articles (7%) focus solely on the consumption of products such as the use of appliances or consumption of automotive fuel without assessing their energy content, thus leaving the environmental dimension on a second plane. On the social dimension, recent literature increasingly focuses to some degree on aspects such as gender, inequality, and social structures on top of the economic and environmental dimensions (30%), thus covering all three dimensions of sustainability.

Additional environmental and social indicators are needed to identify relevant trade-offs. Specifically, while energy and related emissions enjoy great popularity among rebound researchers, other environmental issues are far less prominent. Specifically, the use of resources such as abiotic resources, marine resources, land and soil, water, generation of waste and several environmental impacts including biodiversity are still relatively unexplored (Vivanco et al., 2018), and obtaining empirical evidence of such rebound effects should be a focus of future research.

On the social dimension, knowledge gaps exist both at the level of social impacts and at the level of the role of social actors to influence rebound. For the last point, those gaps include how actors with different levels of social and political power influence decisions relevant to resource efficiency, and further research could focus on the relationship between such power relations and changes in social structure, regulations and everyday practices that inhibit reductions in resource-intensive practices. Moreover, much is still unknown about how specific consumer behavior affects the performance of sustainability-oriented policy.

3.2 | Integratedness

Most of the reviewed studies adopt a multidisciplinary approach (49% from the total scored) or transdisciplinary approach (35%), with most monodisciplinary studies published before 2000. Moreover, most monodisciplinary studies were authored by a single researcher, while transdisciplinary studies were generally authored by the largest number of researchers. Transdisciplinary approaches generally tackled more complex problems and involved deeper collaboration to combine theories and methods. Further integration is needed to bring together key disciplines, such as industrial ecology, ecological economics, micro and macroeconomics, behavioral sciences and sociology, including theories of social and political power. At the same time, more rebound studies along real-world settings are needed in order to overcome the limited explanatory power of rebound analysis only based on stylized facts, historical demand elasticities, or theoretical assumptions.

3.3 | Stakeholders' involvement

Close interaction with relevant stakeholders in all phases of a given rebound study may enhance the credibility and relevance of results (Sala et al., 2015). Relevant stakeholders are however seldom involved in rebound research, and true interaction (see Figure 2), particularly with academics and policymakers, only took place in the context of review rather than research. Such interaction has, however, not yet produced tangible results (Vivanco et al., 2016a). Moreover, only 3% of the scored literature resonated the need to involve stakeholders. The involvement of policymakers is particularly key to design policies that effectively mitigate undesired rebound effects, and the experience of past projects (e.g., Lange et al., 2019; Maxwell et al., 2011) sets a valuable reference. Among all stakeholder groups, those related to business have not been engaged in rebound research according to our review, and higher involvement would help to better quantify supply-side rebound effects related to improvements in productivity (Santarius, 2016b).

Potential outcomes of stakeholders' involvement in rebound studies include redefining goals and scopes to be better aligned with sustainability objectives, access to broader sets of data, and facilitating the communication of results to broader audiences. Moreover, stakeholders' involvement is highly interlinked with other sustainability dimensions such as transparency, strategicness, and boundary orientedness. For example, some studies claim that transparent models which explicitly reflect the relationship between cause and effect, such as system dynamic models, would facilitate the communication between modelers and relevant stakeholders (Dace et al., 2014). Also, the multidimensionality of results can be communicated through single scores (see Section 3.5) which often require the participation of multiple stakeholders to weight conflicting criteria. Lastly, science and policy goals which can be used to contextualize rebound estimates also involve a variety of stakeholders, from business to civil society. To summarize, higher interaction with stakeholders would greatly improve progress toward multiple sustainability dimensions simultaneously.

3.4 | Scalability

While only 4% of scored case studies focus on the world economy, the availability of global supply-chain databases has facilitated, at least indirectly, the inclusion of a global spatial scale. There is however a clear bias toward Europe (69% of the total) and the United States (16%) in regional case studies, with only 15% of studies focusing on other regions. Studies focusing on developing economies, where rebound estimates are thought to be largest (Chakravarty et al., 2013; Roy, 2000), are lacking, especially for Africa and Latin America, with only a few cases considered (e.g., Dufournaud et al., 1994; Lesme et al., 2021; Semboja, 1994; Vélez-Henao et al., 2020). Long-term analyses dealing with transformational effects are also lacking, even though transformational effects can be appraised using theories of technical change, as is done in the pioneering work of Sandén and Karlstrom

(2007). The possibility of upscaling site- or context-specific studies to larger scales is also an area in which further research is needed, especially as the transition toward sustainability forces any assessment to link what happen locally to consequences at higher scales, up to global scale. All these gaps in the temporal or regional scales constitute promising areas of future research.

3.5 | Strategicness

Our literature review reveals that few studies (18% of the total) consider the social dimension of rebound simultaneously with the economic and environmental dimensions. Among these studies, none quantify rebound in terms of social impacts (gender and income inequality, forced labor, etc.). Furthermore, the sustainability dimensions are often addressed in isolation. This leads to sometimes contradictory results which can confuse stakeholders and lead to a preference for oversimplistic solutions. For example, the dominating "efficiencyism" doctrine in policy spheres (Schaefer & Wickert, 2015) often induces policymakers to favor the positive economic impacts of rebound effects without properly factoring in their negative environmental consequences, which can lead to serious long-term social and economic consequences. Similarly, as described in Section 2.1.3, a focus on relative environmental indicators may obscure social aspects, for example, when backfire effects overshadow poverty alleviation. Further research could tackle all three dimensions—with the help of weighting and single-score metrics as currently done in life cycle sustainability assessment (Finkbeiner et al., 2010; Weidema, 2006)—as well as the interplay among dimensions. Such an approach would unveil and quantify trade-offs across sustainability dimensions, offering intuitive results to decision-makers about the overall impact of rebound effects.

3.6 | Transparency

Only 41% of the scored studies are considered fully transparent and 13% are considered a black box. The lack of transparency is largely associated with the lack of public availability of input data and/or model code/software, the availability of which would allow full replicability of results. Transparency is also associated with sensitivity and uncertainty analyses, which are rarely carried out in rebound studies to test key model and modeler assumptions, such as calibration parameters (e.g., elasticities), model closures (e.g., exogenous saving rates), and environmental multipliers (e.g., total emissions per unit of output), leading to untransparent and unreliable results that are less likely to be taken seriously by policymakers and other stakeholders. An option to address modeling uncertainty is to apply multiple modeling approaches simultaneously to test their underlying modeling assumptions: for example, through alternative ways of spending additional income (Salemdeeb et al., 2017; Vivanco et al., 2014), background input–output databases (Vivanco et al., 2016c), consumer heterogeneity (Kulmer & Seebauer, 2019), and substitution elasticities (Allan et al., 2007; Hanley et al., 2009). Such sensitivity analyses would generate more robust results that are transparent and credible to wider audiences.

3.7 | Boundary orientedness

Rebound results generally focus on relative metrics (e.g., percentage of environmental savings that are taken back) and are rarely contextualized with regards to science- and/or policy-based goals. Consequently, and erroneously in our view, most of the current debates focus on the relative magnitudes of rebound effects instead of their absolute impacts (Maxwell et al., 2011). Absolute estimates of rebound offer a much clearer idea of their magnitude and so whether such effects jeopardize science and policy goals. Note that although absolute rebound can be easily calculated given that the absolute initial savings are known, the issue is rather that absolute rebound is rarely the main focus when interpreting the implications of the results. Future research avenues could quantify the inefficiencies generated by rebound effects in the achievement of goals such as the SDG, climate agreements, or efforts toward keeping production and consumption systems within planetary boundaries.

Moreover, rebound studies generally focus on exogenous and costless technical changes that are disconnected from the policies governing them (Gillingham et al., 2016), such as the governmental incentives to kick-start electric powertrain technologies (2021). By disregarding the policy landscape, rebound estimates may overlook key aspects related to capital costs, finance, and broader macroeconomic dynamic adjustments. Some of such aspects can be included in existing macroeconomic models (e.g., computable general equilibrium models) by generating appropriate shocks (Vivanco et al., 2021), while others, such as modeling financial markets, require approaches which have not been used extensively for rebound analysis, such as post-Keynesian models (Barker et al., 2009; Godley & Lavoie, 2016).

3.8 | Interpretation

We suggest that future rebound research which is aligned with sustainability goals must address, to the extent possible, the seven dimensions of sustainability assessment. In doing so, however, it is important to differentiate between those dimensions which are dependent on the goal and scope of the rebound research and those which are not. In this sense, transparency, boundary orientedness, integratedness, and stakeholders' involvement should always be addressed and maximized regardless of the goal and scope. These four dimensions can be seen as quality checks which answer the following questions: How replicable are the results? What are the implications of the results? does the research team have the expertise to address complex problems? and Are relevant stakeholders involved in the decision-making within the research? Among these, stakeholders' involvement is currently the most lacking and must be prioritized, for two main reasons: first, to help clarify the parameters and characteristics of the situations in which rebounds are to be investigated, and second, to exploit the many synergies with other dimensions (see Section 3.3). On the other hand, strategicness, comprehensiveness, and scalability will be inherently delineated by the definition of the goal and scope of the study, which can be influenced by many external factors such as funding, resources, knowledge, and so on. We suggest that these simple recommendations be followed when weighting the importance of each dimension.

A key limitation in interpreting the results above is the fact that the critical review method is not based on a systematic literature review. It thus merits noting that the statistics, scores, and their interpretation relate solely to the selected literature and can only be indirectly attributed to the rebound literature as whole. According to our judgement, however, carrying out a systematic literature review would not yield significantly different conclusions as those which follow.

4 | CONCLUSIONS

Our review shows that rebound effect research systematically lacks goals and scopes that fully address the complexity of current sustainability challenges. With the help of key insights from sustainability assessment, we have identified specific areas that future research could address, specifically aspects related to comprehensiveness, scalability, strategicness, transparency, and boundary orientedness. Among these, key outstanding issues are the need to address the multidimensionality of rebound effects, whereby both negative and positive outcomes across areas of protection may arise simultaneously, and the shift toward absolute rebound metrics that allow contextualizing and quantifying its effect with respect to science and policy goals. Addressing such outstanding issues could help reformulate two rather unproductive debates commonly found in rebound research. The first is whether rebound is big or small, which should no longer depend on relative metrics but in relation to absolute references. The second is whether rebound is good or bad, which should no longer focus exclusively on isolated welfare effects but on comprehensive and transparent metrics that account for the divergent effects in different areas of protection, which need to be simultaneously recognized and acknowledged, even if they must then be held in tension.

Another outstanding issue is the lack of interaction between rebound research and behavioral science to address crucial knowledge gaps as to why certain policies fail, such as how the behavior of key actors generates important barriers to change. For example, research increasingly shows how a flagship policy strategy such as that based on the circular economy concept is greatly affected by detrimental rebound effects (Makov & Vivanco, 2018; Zink & Geyer, 2017). For example, actual displacement rates of primary production from reuse and sharing actions appear lower than expected (Cooper & Gutowski, 2017; Guide & Li, 2010; Makov et al., 2019; Thomas, 2003), yet the specific behavioral rebound mechanisms which might hinder such displacement, including moral licensing, diffusion of responsibility, and attenuated consequences (Santarius & Soland, 2018), have not been identified nor quantified. Further research could thus complement existing studies, for instance on car sharing (Clewlow & Mishra, 2017; Gong et al., 2017) and house sharing (Schor, 2020; Sheppard & Udell, 2016). Beyond rebound research, the ability to address behavioral features of key actors acting in the system, including at individual level, is a central aspect of sustainability assessment which is not directly addressed in the framework by Sala et al. (2015) yet merits greater attention.

We propose that better aligning rebound research with sustainability assessment, and placing more attention on behavioral aspects, will help rebound research gain explanatory power and increase its relevance to key decision-makers. In this sense, we envision that future rebound research could help understand why certain strategies such as those based on the circular economy are not as effective as expected, and why key goals and targets such as the SDGs are at high risk of not being achieved as a whole. This critical literature review offers some ideas on how to make rebound research more relevant, credible, and transparent to finally become a central aspect in policymaking.

ACKNOWLEDGMENTS

The authors would like to thank two anonymous reviewers for their comments.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the Supporting Information of this article.

ORCID

David Font Vivanco https://orcid.org/0000-0002-3652-0628
Jaume Freire-González https://orcid.org/0000-0002-5922-3255
Ray Galvin https://orcid.org/0000-0001-9279-4263
Tilman Santarius https://orcid.org/0000-0002-6026-3019
Tamar Makov https://orcid.org/0000-0001-7345-5864
Serenella Sala https://orcid.org/0000-0003-1919-9948

NOTE

[1] Alternative definitions describe more dimensions, such as the institutional (O'Connor, 2006), cultural (Nurse, 2006), and technological (Vos, 2007) dimensions of sustainability.

REFERENCES

Aall, C., Hall, C. M., & Groven, K. (2016). Tourism: Applying rebound theories and mechanisms to climate change mitigation and adaptation. In Santarius, T., Walnum, H., & Aall, C. (Eds.). *Rethinking climate and energy policies: New perspectives on the rebound phenomenon* (pp. 209–225). Springer International Publishing. https://link.springer.com/chapter/10.1007/978-3-319-38807-6_12

Alcott, B. (2008). The sufficiency strategy: Would rich-world frugality lower environmental impact? *Ecological Economics*, *64*(4), 770–786. http://www.sciencedirect.com/science/article/pii/S0921800907002728

Alcott, B. (2010). Impact caps: Why population, affluence and technology strategies should be abandoned. *Journal of Cleaner Production*, *18*(6), 552–560. http://www.sciencedirect.com/science/article/pii/S095965260900242X

Alcott, B. (2014). Research caps, not rebound. *GAIA*, *23*(4), 304–305.

Alfredsson, E. C. (2004). Green consumption—No solution for climate change. *Energy*, *29*(4), 513–524. http://www.sciencedirect.com/science/article/pii/S0360544203002640

Allan, G., Hanley, N., McGregor, P. G., Swales, J. K., & Turner, K. (2006). *The macroeconomic rebound effect and the UK economy: Final report to The Department of Environment Food and Rural Affairs*. University of Strathclyde.

Allan, G., Hanley, N., McGregor, P., Swales, K., & Turner, K. (2007). The impact of increased efficiency in the industrial use of energy: A computable general equilibrium analysis for the United Kingdom. *Energy Economics*, *29*(4), 779–798. http://www.sciencedirect.com/science/article/pii/S0140988306001514

Andrés, S. A., Mir, L. C., van den Bergh, J. C. J. M., Ring, I., & Verburg, P. H. (2012). Ineffective biodiversity policy due to five rebound effects. *Ecosystem Services*, *1*(1), 101–110. https://www.sciencedirect.com/science/article/pii/S2212041612000083#s0030

Ayres, R. U., & Warr, B. (2005). Accounting for growth: The role of physical work. *Structural Change and Economic Dynamics*, *16*(2), 181–209. http://www.sciencedirect.com/science/article/pii/S0954349X03000778

Bahn-Walkowiak, B., Bleischwitz, R., Distelkamp, M., & Meyer, M. (2012). Taxing construction minerals: A contribution to a resource-efficient Europe. *Mineral Economics*, *25*(1), 29–43. http://link.springer.com/10.1007/s13563-012-0018-9

Barker, T., Dagoumas, A., & Rubin, J. (2009). The macroeconomic rebound effect and the world economy. *Energy Efficiency*, *2*(4), 411–427. http://link.springer.com/10.1007/s12053-009-9053-y

Barker, T., Ekins, P., & Foxon, T. (2007). The macro-economic rebound effect and the UK economy. *Energy Policy*, *35*(10), 4935–4946. http://www.sciencedirect.com/science/article/pii/S0301421507001565

Becker, G. S. (1965). A theory of the allocation of time. *The Economic Journal*, *75*(299), 493–517.

Benedetto, G., Rugani, B., & Vázquez-Rowe, I. (2014). Rebound effects due to economic choices when assessing the environmental sustainability of wine. *Food Policy*, *49*, Part 1(0): 167–173. http://www.sciencedirect.com/science/article/pii/S0306919214001250

Berbel, J., Gutiérrez-Martín, C., Rodríguez-Díaz, J. A., Camacho, E., & Montesinos, P. (2015). Literature review on rebound effect of water saving measures and analysis of a Spanish case study. *Water Resources Management*, *29*(3), 663–678. http://link.springer.com/10.1007/s11269-014-0839-0

Berbel, J., & Mateos, L. (2014). Does investment in irrigation technology necessarily generate rebound effects? A simulation analysis based on an agro-economic model. *Agricultural Systems*, *128*, 25–34.

Berkhout, P. H. G., Muskens, J. C., & Velthuijsen, W. (2000). Defining the rebound effect. *Energy Policy*, *28*(6–7), 425–432. http://www.sciencedirect.com/science/article/pii/S0301421500000227

Binswanger, M. (2001). Technological progress and sustainable development: What about the rebound effect? *Ecological Economics*, *36*(1), 119–132. http://www.sciencedirect.com/science/article/pii/S0921800900002147

Blanke, K., Ehling, M., & Schwarz, N. (1996). *Zeit im Blickfeld: Ergebnisse einer repräsentativen Zeitbudgeterhebung*. Kohlhammer.

Blanken, I., van de Ven, N., & Zeelenberg, M. (2015). A meta-analytic review of moral licensing. *Personality and Social Psychology Bulletin*, *41*(4), 540–558. https://doi.org/10.1177/0146167215572134

Borenstein, S. (2012). *In praise of energy efficiency rebound*. https://energyathaas.wordpress.com/2012/09/30/in-praise-of-energy-efficiency-rebound

Bouzarovski, S., Herrero, S. T., Petrova, S., & Ürge-Vorsatz, D. (2016). Unpacking the spaces and politics of energy poverty: Path-dependencies, deprivation and fuel switching in post-communist Hungary. *Local Environment*, *21*(9), 1151–1170.

Brenčič, V., & Young, D. (2009). Time-saving innovations, time allocation, and energy use: Evidence from Canadian households. *Ecological Economics*, *68*(11), 2859–2867.

Brent, A. C., Oelofse, S., & Godfrey, L. (2008). Advancing the concepts of industrial ecology in South African institutions. *South African Journal of Science*, *104*(1), 9–12.

Briceno, T., Peters, G., Solli, C., & Hertwich, E. (2004). Using life cycle approaches to evaluatesustainable consumption programs: Car-sharing. Reports and Working Papers from Norwegian University of Science and Technology (NTNU) Industrial Ecology Programme (IndEcol) Working Papers no. 2/2005ISSN 1504-3681. Trondheim, Norway.

Brookes, L. (1979). A low energy strategy for the UK. *Atom*, *269*, 3–8.

Brookes, L. (1990). The greenhouse effect: The fallacies in the energy efficiency solution. *Energy Policy*, *18*(2), 199–201. http://www.sciencedirect.com/science/article/pii/030142159090145T

Buhl, J. (2016). Indirect effects from resource sufficiency behaviour in Germany. In Santarius, T., Walnum, H., & Aall, C. (Eds.). *Rethinking climate and energy policies. New perspectives on the rebound phenomenon* (pp. 37–54). Springer International Publishing.

Buhl, J., & Acosta, J. (2016). Labour markets: Time and income effects from reducing working hours in Germany. In Santarius, T., Walnum, H., & Aall, C. (Eds.). *Rethinking climate and energy policies*, Springer, Cham. http://doi.org/10.1007/978-3-319-38807-6_10

Cayre, E., Allibe, B., Laurent, M., & Osso, D. (2011). There are people n the house! How misleading for energy policies are the results of purely technical analysis of residential energy consumption. *ECEEE Summer Study*, Presquîle de Giens, France.

CCC. (2019). *Net zero: The UK's contribution to stopping global warming*. https://www.theccc.org.uk/publication/net-zero-technical-report/

Cellura, M., Guarino, F., Longo, S., Mistretta, M., & Orioli, A. (2013). The role of the building sector for reducing energy consumption and greenhouse gases: An Italian case study. *Renewable Energy*, *60*(0), 586–597. http://www.sciencedirect.com/science/article/pii/S0960148113003121

Ceolotto, S. (2016). *The rebound effect. From classic economic theory to behavioural economics: An experiment on hyperbolic discounting*. Università Ca' Foscari Venezia. http://dspace.unive.it/handle/10579/8596

Chakravarty, D., Dasgupta, S., & Roy, J. (2013). Rebound effect: How much to worry? *Current Opinion in Environmental Sustainability*, *5*(2), 216–228. http://www.sciencedirect.com/science/article/pii/S1877343513000134

Chen, K., Li, Z., Lu, T. P., Rau, P. L. P., & Huang, D. (2018). Influence of rebound effect on energy saving in smart homes. In Rau, P. L. (Eds.). *Cross-cultural design. Applications in cultural heritage, creativity and social development. CCD 2018. Lecture notes in computer science* (Vol. 10912). Springer, Cham. https://doi.org/10.1007/978-3-319-92252-2_21

Cheng, M., Chen, G., Wiedmann, T., Hadjikakou, M., Xu, L., & Wang, Y. (2020). The sharing economy and sustainability–Assessing Airbnb's direct, indirect and induced carbon footprint in Sydney. *Journal of Sustainable Tourism*, *28*(8), 1083–1099.

Chitnis, M., Sorrell, S., Druckman, A., & Firth, S.. 2012. The rebound effect: to what extent does it vary with income? Sustainable Lifestyles Research Group. Working Paper 01–12. Centre for Environmental Strategy, University of Surrey. https://www.biee.org/wp-content/uploads/Chitnis-Estimating-Direct-And-Indirect-Rebound-Effects-For-UK-Householdsfinal.pdf

Chitnis, M., Sorrell, S., Druckman, A., Firth, S. K., & Jackson, T. (2014). Who rebounds most? Estimating direct and indirect rebound effects for different UK socioeconomic groups. *Ecological Economics*, *106*(0), 12–32. http://www.sciencedirect.com/science/article/pii/S0921800914002055

Cleveland, C. J., Hall, C. A. S., & Kaufmann, R. (1986). Energy and the US economy: A biophysical perspective. *Science*, *225*(4665), 890–897.

Cleveland, C. J., Kaufmann, R. K., & Stern, D. I. (2000). Aggregation and the role of energy in the economy. *Ecological Economics*, *32*(2), 301–317. http://www.sciencedirect.com/science/article/pii/S0921800999001135

Clewlow, R. R., & Mishra, G. S. (2017). *Disruptive transportation: The adoption, utilization, and impacts of ride-hailing in the United States*. https://escholarship.org/uc/item/82w2z91j

Cooper, D. R., & Gutowski, T. G. (2017). The environmental impacts of reuse: A review. *Journal of Industrial Ecology*, *21*(1), 38–56. https://doi.org/10.1111/jiec.12388

Crane, R. (2007). Is there a quiet revolution in women's travel? Revisiting the gender gap in commuting. *Journal of the American Planning Association*, *73*(3), 298–316.

Dace, E., Bazbauers, G., Berzina, A., & Davidsen, P. I. (2014). System dynamics model for analyzing effects of eco-design policy on packaging waste management system. *Resources, Conservation and Recycling*, *87*, 175–190. http://www.sciencedirect.com/science/article/pii/S0921344914000901

Dimitropoulos, J. (2007). Energy productivity improvements and the rebound effect: An overview of the state of knowledge. *Energy Policy*, *35*(12), 6354–6363. http://www.sciencedirect.com/science/article/pii/S0301421507003357

Dolan, P., & Galizzi, M. M. (2015). Like ripples on a pond: Behavioral spillovers and their implications for research and policy. *Journal of Economic Psychology*, *47*, 1–16.

Druckman, A., Buck, I., Hayward, B., & Jackson, T. (2012). Time, gender and carbon: A study of the carbon implications of British adults' use of time. *Ecological Economics*, *84*, 153–163.

Druckman, A., Chitnis, M., Sorrell, S., & Jackson, T. (2011). Missing carbon reductions? Exploring rebound and backfire effects in UK households. *Energy Policy*, *39*(6), 3572–3581. http://www.sciencedirect.com/science/article/pii/S0301421511002473

Duarte, R., Sánchez-Chóliz, J., & Sarasa, C. (2018). Consumer-side actions in a low-carbon economy: A dynamic CGE analysis for Spain. *Energy Policy*, *118*, 199–210. https://www.sciencedirect.com/science/article/pii/S0301421518301988

Dufournaud, C. M., Quinn, J. T., & Harrington, J. J. (1994). An Applied General Equilibrium (AGE) analysis of a policy designed to reduce the household consumption of wood in the Sudan. *Resource and Energy Economics*, *16*(1), 67–90. http://www.sciencedirect.com/science/article/pii/0928765594900140

Ehrenfeld, J. R. (2004). Can industrial ecology be the "science of sustainability"? *Journal of Industrial Ecology*, *8*(1–2), 1–3.

Eskine, K. J. (2012). Wholesome foods and wholesome morals?: Organic foods reduce prosocial behavior and harshen moral judgments. *Social Psychological and Personality Science*, *4*(2), 251–254. https://doi.org/10.1177/1948550612447114

Fang, L., Wu, F., Yu, Y., & Zhang, L. (2020). Irrigation technology and water rebound in China's agricultural sector. *Journal of Industrial Ecology*, *24*(5), 1088–1100.

Finkbeiner, M., Schau, E. M., Lehmann, A., & Traverso, M. (2010). Towards life cycle sustainability assessment. *Sustainability*, *2*(10), 3309–3322.

Finnveden, G., Hauschild, M. Z., Ekvall, T., Guinee, J., Heijungs, R., Hellweg, S., Koehler, A., Pennington, D., & Suh, S. (2009). Recent developments in life cycle assessment. *Journal of Environmental Management*, *91*(1), 1–21. http://www.sciencedirect.com/science/article/pii/S0301479709002345

Fouquet, R. (2008). *Heat, power and light* (p. 4061). Edward Elgar Publishing. https://econpapers.repec.org/RePEc:elg:eebook

Freire-González, J. (2017). A new way to estimate the direct and indirect rebound effect and other rebound indicators. *Energy*, *128*, 394–402.

Freire-González, J. (2019). Does water efficiency reduce water consumption? The economy-wide water rebound effect. *Water Resources Management*, *33*, 1–12. http://link.springer.com/10.1007/s11269-019-02249-0

Freire-González, J., & Font Vivanco, D. (2017). The influence of energy efficiency on other natural resources use: An input-output perspective. *Journal of Cleaner Production*, *162*, 336–345. https://www.sciencedirect.com/science/article/pii/S0959652617312209

Frondel, M., Ritter, N., & Vance, C. (2012). Heterogeneity in the rebound effect: Further evidence for Germany. *Energy Economics*, *34*(2), 461–467.

Galvin, R. (2014). Making the "rebound effect" more useful for performance evaluation of thermal retrofits of existing homes: Defining the "energy savings deficit" and the "energy performance gap. *Energy and Buildings*, *69*, 515–524.

Galvin, R. (2015a). The rebound effect in home heating: A guide for policymakers and practitioners. CRC Press. https://books.google.be/books?id=mETeCQAAQBAJ

Galvin, R. (2015b). The rebound effect, gender and social justice: A case study in Germany. *Energy Policy*, *86*, 759–769. http://www.sciencedirect.com/science/article/pii/S0301421515300719

Galvin, R. (2019). Letting the Gini out of the fuel poverty bottle? Correlating cold homes and income inequality in European Union countries. *Energy Research and Social Science*, *58*, 101–255.

Galvin, R. (2020). Who co-opted our energy efficiency gains? A sociology of macro-level rebound effects and US car makers. *Energy Policy*, *142*, 111548.

Galvin, R., & Gubernat, A. (2016). The rebound effect and Schatzki's social theory: Reassessing the socio-materiality of energy consumption via a German case study. *Energy Research and Social Science*, *22*, 183–193.

Geels, F. W. (2014). Regime resistance against low-carbon transitions: Introducing politics and power into the multi-level perspective. *Theory, Culture & Society*, *31*(5), 21–40.

Georgescu-Roegen, N. (2013). *The entropy law and the economic process*. Cambridge, MA and London, England: Harvard University Press. https://doi.org/10.4159/harvard.9780674281653

Giampietro, M., & Mayumi, K. (1998). Another view of development, ecological degradation, and north-south trade. *Review of Social Economy*, *56*(1), 20–36. https://doi.org/10.1080/00346769800000002

Giampietro, M., & Mayumi, K. (2008). The Jevons paradox: The evolution of complex adaptive systems and the challenge for scientific analysis. In Polimeni, J. M., Mayumi, K., Giampietro, M., & Alcott, B. (Eds.). *The Jevons paradox and the myth of resource efficiency improvements* (pp. 79–140). Earthscan.

Giddens, A. (1984). *The constitution of society: Outline of the theory of structuration*. University of California Press.

Gillingham, K., Rapson, D., & Wagner, G. (2016). The rebound effect and energy efficiency policy. *Review of Environmental Economics and Policy*, *10*(1), 68–88. https://doi.org/10.1093/reep/rev017

Girod, B., & de Haan, P. (2009). GHG reduction potential of changes in consumption patterns and higher quality levels: Evidence from Swiss household consumption survey. *Energy Policy*, *37*(12), 5650–5661. http://www.sciencedirect.com/science/article/pii/S0301421509006156

Girod, B., Haan, P., & Scholz, R. (2011). Consumption-as-usual instead of ceteris paribus assumption for demand. *International Journal of Life Cycle Assessment*, *16*(1), 3–11. https://doi.org/10.1007/s11367-010-0240-z

Girod, B. V. S. (2008). Environmental impact of Swiss household consumption, and estimated income rebound effects. Ed. by NSSI - Natural and Social Science Interface Eidgenössische TechnischeHochschule Zürich, IED - Institute for Environmental Decisions. Zurich, Switzerland. https://www.research-collection.ethz.ch/handle/20.500.11850/152328

Gneezy, A., Imas, A., Brown, A., Nelson, L. D., & Norton, M. I. (2011). Paying to be nice: Consistency and costly prosocial behavior, *Management Science*, *58*(1), 179–187. https://pubsonline.informs.org/doi/abs/10.1287/mnsc.1110.1437

Godley, W., & Lavoie, M. (2006). *Monetary economics: anintegrated approach to credit, money, income, production and wealth*. Palgrave Macmillan London. https://doi.org/10.1057/9780230626546

Gong, J., Greenwood, B. N., & Song, Y. A. (2017). Uber might buy me a mercedes benz: An empirical investigation of the sharing economy and durable goods purchase. Available at SSRN: https://ssrn.com/abstract=2971072 or https://doi.org/10.2139/ssrn.2971072

Grabs, J. (2015). The rebound effects of switching to vegetarianism. A microeconomic analysis of Swedish consumption behavior. *Ecological Economics*, *116*, 270–279. http://www.sciencedirect.com/science/article/pii/S0921800915002153

Greene, D. L., Kahn, J. R., & Gibson, R. C. (1999). Fuel economy rebound effect for US household vehicles. *The Energy Journal*, *20*(3), 1–31.

Greening, A., Greene, D. L., & Difiglio, C. (2000). Energy efficiency and consumption – The rebound effect – A survey. *Energy Policy*, *28*(6–7), 389–401. http://www.sciencedirect.com/science/article/pii/S0301421500000215

Grubb, M. (2014). Planetary economics: Macroeconomics and international implications. Lecture held at the ESRC Festival of Social Science. www.lse.ac.uk/GranthamInstitute/event/planetary-economics-macroeconomics-and-international-implications

Guide Jr., V. D. R., & Li, J. (2010). The potential for cannibalization of new products sales by remanufactured products. *Decision Sciences*, *41*(3), 547–572. https://doi.org/10.1111/j.1540-5915.2010.00280.x

Gutierrez-Martin, C., & Gomez, C. M. G. (2011). Assessing irrigation efficiency improvements by using a preference revelation model. *Spanish Journal of Agricultural Research*, *4*, 1009–1020.

Haar, L. (2019). Is energy security really too important to leave to markets? *Economic Affairs*, *39*(3), 330–345.

Haas, R., & Biermayr, P. (2000). The rebound effect for space heating empirical evidence from Austria. *Energy Policy*, *28*(6–7), 403–410.

Hanley, N., McGregor, P. G., Swales, J. K., & Turner, K. (2009). Do increases in energy efficiency improve environmental quality and sustainability? *Ecological Economics*, *68*(3), 692–709. https://www.sciencedirect.com/science/article/pii/S0921800908002589

Hanson, S. (2010). Gender and mobility: New approaches for informing sustainability. *Gender, Place and Culture*, *17*(1), 5–23.

Hens, H., Parijs, W., & Deurinck, M. (2010). Energy consumption for heating and rebound effects. *Energy and Buildings*, *42*(1), 105–110. http://www.sciencedirect.com/science/article/pii/S037877880900142X

Herring, H. (2008). Rebound effect. Retrieved from http://editors.eol.org/eoearth/wiki/Rebound_effect

Hertwich, E. G. (2005). Consumption and the rebound effect: An industrial ecology perspective. *Journal of Industrial Ecology*, *9*(1–2), 85–98. https://doi.org/10.1162/1088198054084635

Hicks, A., & Theis, T. (2014). An agent based approach to the potential for rebound resulting from evolution of residential lighting technologies. *The International Journal of Life Cycle Assessment*, *19*(2), 370–376. https://doi.org/10.1007/s11367-013-0643-8

Hicks, A. L., Theis, T. L., & Zellner, M. L. (2015). Emergent effects of residential lighting choices: Prospects for energy savings. *Journal of Industrial Ecology*, *19*(2), 285–295. https://doi.org/10.1111/jiec.12281

Howarth, R. B. (1997). Energy efficiency and economic growth. *Contemporary Economic Policy*, *15*(4), 1–9. https://doi.org/10.1111/j.1465-7287.1997.tb00484.x

Hymel, K. M., Small, K. A., & Van Dender, K. (2010). Induced demand and rebound effects in road transport. *Transportation Research Part B: Methodological*, *44*(10), 1220–1241.

Jain, S. S. L. (2002). Urban errands: The means of mobility. *Journal of Consumer Culture*, *2*(3), 385–404.

Jakob, M. (2007). The drivers of and barriers to energy efficiency in renovation decisions of single-family home-owners. CEPE Working Paper Series 07-56, CEPE Center for Energy Policy and Economics, ETH Zurich.

Jalas, M. (2002). A time use perspective on the materials intensity of consumption. *Ecological Economics*, *41*(1), 109–123. http://www.sciencedirect.com/science/article/pii/S0921800902000186

Jenkins, J., Nordhaus, T., & Shellenberger, M. (2011). Energy emergence: Rebound and backfire as emergent phenomena. Breakthrough Institute.

Jevons, W. S. (1865). *The Coal Question. An inquiry concerning the progress of the nation and the probable exhaustion of our coal-mines.*Macmillan and Co.

Jones, H. G. (1975). *An introduction to modern theories of economic growth*. Nelson.

Kaklamanou, D., Jones, C. R., Webb, T. L., & Walker, S. R. (2013). Using public transport can make up for flying abroad on holiday: Compensatory green beliefs and environmentally significant behavior. *Environment and Behavior*, *47*(2), 184–204. https://doi.org/10.1177/0013916513488784

Kates, R. W., Clark, W. C., Corell, R., Hall, J. M., Jaeger, C. C., Lowe, I., McCarthy, J. J., Schellnhuber, H. J., Bolin, B., Dickson, N. M., Faucheux, S., Gallopin, G. C., Grübler, A., Huntley, B., Jäger, J., Jodha, N. S., Kasperson, R. E., Mabogunje, A., Matson, P., … Mooney, H. (2001). Environment and development. Sustainability science. *Science*, *292*(5517), 641–2. http://www.ncbi.nlm.nih.gov/pubmed/11330321

Kelly, S. (2011). Do homes that are more energy efficient consume less energy?: A structural equation model of the English residential sector. *Energy*, *36*(9), 5610–5620.

Khan, U., & Dhar, R. (2006). Licensing effect in consumer choice. *Journal of Marketing Research*, *43*(2), 259–266. https://doi.org/10.1509/jmkr.43.2.259

Khazzoom, J. D. (1980). Economic implications of mandated efficiency in standards for household appliances. *Energy Journal*, *1*(4), 21–40.

Khazzoom, J. D. (1987). Energy saving resulting from the adoption of more efficient appliances. *The Energy Journal*, *8*(4), 85–91.

Khazzoom, J. D. (1989). Energy savings from more efficient appliances: A rejoinder. *The Energy Journal*, *10*(1), 157–166.

Kivetz, R., & Simonson, I. (2002). Earning the right to indulge: Effort as a determinant of customer preferences toward frequency program rewards. *Journal of Marketing Research*, *39*(2), 155–170. https://doi.org/10.1509/jmkr.39.2.155.19084

Klöckner, C. A. (2013). A comprehensive model of the psychology of environmental behaviour—A meta-analysis. *Global Environmental Change*, *23*(5), 1028–1038. https://www.sciencedirect.com/science/article/pii/S095937801300099X

Kuhn, S., Ihmels, M., & Kutzner, F. (2021). Organic defaults in online-shopping: Immediate effects but no spillover to similar choices. *Journal of Consumer Behaviour*, *20*(2), 271–287. https://onlinelibrary.wiley.com/doi/full/10.1002/cb.1850

Kulmer, V., & Seebauer, S. (2019). How robust are estimates of the rebound effect of energy efficiency improvements? A sensitivity analysis of consumer heterogeneity and elasticities. *Energy Policy*, *132*, 1–14.

Labanca, N., & Bertoldi, P. (2018). Beyond energy efficiency and individual behaviours: Policy insights from social practice theories. *Energy Policy*, *115*, 494–502.

Lange, S., Banning, M., Berner, A., Kern, F., Lutz, C., Peuckert, J., Santarius, T., & Silbersdorff, A. (2019). *Economy-wide rebound effects: State of the art, a new taxonomy, policy and research gaps.* https://www.ioew.de/fileadmin/user_upload/BILDER_und_Downloaddateien/Publikationen/2019/ReCap_discussion_paper_1.pdf

Larson, W., Liu, F., & Yezer, A. (2012). Energy footprint of the city: Effects of urban land use and transportation policies. *Journal of Urban Economics*, *72*(2–3), 147–159. https://www.sciencedirect.com/science/article/pii/S0094119012000332

Lauren, N., Fielding, K. S., Smith, L., & Louis, W. R. (2016). You did, so you can and you will: Self-efficacy as a mediator of spillover from easy to more difficult pro-environmental behaviour. *Journal of Environmental Psychology*, *48*, 191–199. https://www.sciencedirect.com/science/article/pii/S0272494416300913

Lesme, M. B., Freire-González, J., & Rosa, E. P. (2021). The direct rebound effect for two income groups: The case of Paraguay. Working Papers wpdea2103, Department of Applied Economics at Universitat Autonoma of Barcelona.

Linder, S. B. (1970). *The harried leisure class*. Columbia University Press.

Lovins, A. B. (1988). Energy saving resulting from the adoption of more efficient appliances: Another view. *The Energy Journal*, *9*(2), 155–162.

Ma, B., Li, X., Jiang, Z., & Jiang, J. (2019). Recycle more, waste more? When recycling efforts increase resource consumption. *Journal of Cleaner Production*, *206*, 870–877.

Madlener, R., & Turner, K. (2016). After 35 Years of rebound research in economics: Where do we stand? In Santarius, T., Walnum, H., & Aall, C. (Eds.). *Rethinking climate and energy policies*. Springer, Cham. https://doi.org/10.1007/978-3-319-38807-6_2

Makov, T., Fishman, T., Chertow, M. R., & Blass, V. (2019). What affects the secondhand value of smartphones: Evidence from eBay. *Journal of Industrial Ecology*, *23*(3), 549–559.

Makov, T., & Vivanco, D. (2018). Does the circular economy grow the pie? The case of rebound effects from smartphone reuse. *Frontiers in Energy Research*, *6*, 39. http://journal.frontiersin.org/article/10.3389/fenrg.2018.00039/full

Maxwell, D., Owen, P., McAndrew, L., Muehmel, K., & Neubauer, A. (2011). *Addressing the rebound effect, a report for the European Commission DG Environment.* European Commission.

Mazar, N., & Zhong, C. B. (2010). Do green products make us better people? *Psychological Science*, *21*(4), 494–498. https://journals.sagepub.com/doi/abs/10.1177/0956797610363538

Merritt, A. C., Effron, D. A., & Monin, B. (2010). Moral self-licensing: When being good frees us to be bad. *Social and Personality Psychology Compass*, *4*(5), 344–357.

Mihelcic, J. R., Crittenden, J. C., Small, M. J., Shonnard, D. R., Hokanson, D. R., Zhang, Q., Chen, H., Sorby, S. A., James, V. U., Sutherland, J. W., & Schnoor, J. L. (2003). Sustainability science and engineering: The emergence of a new metadiscipline. *Environmental Science and Technology*, *37*(23), 5314–5324.

Miola, A., Borchardt, S., Neher, F., & Buscaglia, D. (2019). *Interlinkages and policy coherence for the Sustainable Development Goals implementation: An operational method to identify trade-offs and co-benefits in a systemic way*. Publications Office of the European Union.

Mundella, A. J. (1878). What are the conditions on which the commercial and manufacturing supremacy of Great Britain depend, and is there any reason to think they have been, or may be, endangered? *Journal of the Statistical Society of London*, *41*(1), 87–134. http://www.jstor.org/stable/2339204

Murray, C. K. (2009). *New insights into rebound effects: Theory and empirical evidence* [Master's Thesis, School of Economics and Finance].

Næss, P. (2016). Urban planning: Residential location and compensatory behaviour in three Scandinavian cities. In Santarius, T., Walnum, H., & Aall, C. (Eds.), *Rethinking Climate and Energy Policies* (pp. 181–207). Springer.

Nurse, K. (2006). Culture as the fourth pillar of sustainable development. *Small States: Economic Review and Basic Statistics*, *11*, 28–40.

O'Connor, M. (2006). The "Four Spheres" framework for sustainability. *Ecological Complexity*, *3*(4), 285–292.

Obermayer, H. J., & Maier, M. (1994). Internationaler Schnellverkehr: Superzüge in Europa und Japan. Franckh-Kosmos. https://books.google.es/books?id=gHjNAAAACAAJ

Ornetzeder, M., Hertwich, E. G., Hubacek, K., Korytarova, K., & Haas, W. (2008). The environmental effect of car-free housing: A case in Vienna. *Ecological Economics*, *65*(3), 516–530. http://www.sciencedirect.com/science/article/pii/S0921800907004090

Paré, G., & Kitsiou, S. (2017). Chapter 9 Methods for Literature Reviews. In Lau F, Kuziemsky C, editors. *Handbook of eHealth Evaluation: An Evidence-based Approach [Internet]*. Victoria (BC): University of Victoria. Available from: https://www.ncbi.nlm.nih.gov/books/NBK481583/

Peters, A., & Dütschke, E. (2016). Exploring rebound effects from a psychological perspective. In Santarius, T., Walnum, H., & Aall, C. (Eds.). *Rethinking climate and energy policies*. Springer, Cham. https://doi.org/10.1007/978-3-319-38807-6_6

Peters, A., Sonnberger, M., Dütschke, E., & Deuschle, J. (2012). Theoretical perspective on rebound effects from a social science point of view: Working paper to prepare empirical psychological and sociological studies in the REBOUND project, Working Papers "Sustainability and Innovation" S2/2012, Fraunhofer Institute for Systems and Innovation Research (ISI).

Pfeiffer, L., & Lin, C. Y. C. (2014). Does efficient irrigation technology lead to reduced groundwater extraction? Empirical evidence. *Journal of Environmental Economics and Management*, *67*(2), 189–208.

Polimeni, J. M., Mayumi, K., Giampietro, M., & Alcott, B. (2008). *The Jevons paradox and the myth of resource efficiency improvements*. Earthscan.

Princen, T. (2005). *The logic of sufficiency* (Vol. 30). MIT Press.

Rajagopal, D., Hochman, G., & Zilberman, D. (2011). Indirect fuel use change (IFUC) and the lifecycle environmental impact of biofuel policies. *Energy Policy*, *39*(1), 228–233. http://www.sciencedirect.com/science/article/pii/S0301421510007214

Røpke, I. (2009). Theories of practice – New inspiration for ecological economic studies on consumption. *Ecological Economics*, *68*(10), 2490–2497.

Rosa, H. (2013). *Social acceleration: A new theory of modernity*. Columbia University Press.

Roth, I. F., & Ambs, L. L. (2004). Incorporating externalities into a full cost approach to electric power generation life-cycle costing. *Energy*, *29*, 2125–2144. http://www.sciencedirect.com/science/article/pii/S0360544204000945

Roy, J. (2000). The rebound effect: Some empirical evidence from India. *Energy Policy*, *28*(6–7), 433–438. http://www.sciencedirect.com/science/article/pii/S0301421500000276

Ruzzenenti, F., & Basosi, R. (2008). The rebound effect: An evolutionary perspective. *Ecological Economics*, *67*(4), 526–537. http://www.sciencedirect.com/science/article/pii/S0921800908003509

Ruzzenenti, F., Vivanco, D., Galvin, R., Sorrell, S., Wagner, A., & Walnum, H. J. (2019). The rebound effect and the Jevons' paradox: Beyond the conventional wisdom. *Frontiers in Energy Research*, *7*, 90.

Ruzzenenti, F., & Wagner, A. (2018). Efficiency and the rebound effect in the hegemonic discourse on energy. *Nature and Culture*, *13*(3), 356–377.

Sala, S., Ciuffo, B., & Nijkamp, P. (2015). A systemic framework for sustainability assessment. *Ecological Economics*, *119*, 314–325.

Salemdeeb, R., Vivanco, D. F., Al-Tabbaa, A., & Zu Ermgassen, E. K. H. J. (2017). A holistic approach to the environmental evaluation of food waste prevention. *Waste Management*, *59*, 442–450.

Sandén, B., & Karlstrom, M. (2007). Positive and negative feedback in consequential life-cycle assessment. *Journal of Cleaner Production*, *15*(15), 1469–1481. http://www.sciencedirect.com/science/article/pii/S0959652606001442

Santarius, T. (2012). *Green growth unravelled. How rebound effects baffle sustainability targets when the economy keeps growing*. Heinrich Boell Foundation and Wuppertal Institute for Climate, Environment and Energy.

Santarius, T. (2016a). Energy efficiency and social acceleration: Macro-level rebounds from a sociological perspective. In Santarius, T., Walnum, H., Aall, C. (Eds.). *Rethinking Climate and Energy Policies*. Springer, Cham. https://doi.org/10.1007/978-3-319-38807-6_9

Santarius, T. (2016b). Investigating meso-economic rebound effects: production-side effects and feedback loops between the micro and macro level. *Journal of Cleaner Production*, *134*, 406–413.

Santarius, T., & Soland, M. (2018). How technological efficiency improvements change consumer preferences: Towards a psychological theory of rebound effects. *Ecological Economics*, *146*, 414–424. https://www.sciencedirect.com/science/article/pii/S0921800917306511

Santarius, T., Walhum, H. J., & Aall, C. (2016). *Rethinking climate and energy policies. New Perspectives on the Rebound Phenomenon*. Springer.

Santarius, T., Walnum, H. J., & Aall, C. (2018). From unidisciplinary to multidisciplinary rebound research: Lessons learned for comprehensive climate and energy policies. *Frontiers in Energy Research*, *6*, 104. https://www.frontiersin.org/article/10.3389/fenrg.2018.00104/full

Saunders, H. D. (1992). The Khazzoom-Brookes postulate and neoclassical growth. *The Energy Journal*, *13*(4), 131–148.

Saunders, H. D. (2000). A view from the macro side: Rebound, backfire, and Khazzoom-Brookes. *Energy Policy*, *28*(6–7), 439–449. http://www.sciencedirect.com/science/article/pii/S0301421500000240

Schaefer, S., & Wickert, C. (2015). The efficiency paradox in organization and management theory. In *The 4th European Theory Development Workshop*. Cardiff, United Kingdom. https://doi.org/10.5465/AMBPP.2015.10958abstract

Schipper, L., & Grubb, M. (2000). On the rebound? Feedback between energy intensities and energy uses in IEA countries. *Energy Policy*, *28*(6–7), 367–388. http://www.sciencedirect.com/science/article/pii/S0301421500000185

Schipper, L., & Meyers, S. (1992). *Energy efficiency and human activity: Past trends, future prospects*. Cambridge University Press.

Schivelbusch, W. (2014). *The Railway Journey: The Industrialization of Time and Space in the Nineteenth Century* (1st ed.). University of California Press. http://www.jstor.org/stable/10.1525/j.ctt6wqbk7

Schor, J. B. (1991). Global equity and environmental crisis: An argument for reducing working hours in the North. *World Development*, *19*(1), 73–84.

Schor, J. (2020). *4 "The Shared Economy Is a Lie". After the Gig: How the Sharing Economy Got Hijacked and How to Win It Back*, Berkeley: University of California Press, pp. 105–121. https://doi.org/10.1525/9780520974227-007

Sears, L., Caparelli, J., Lee, C., Pan, D., Strandberg, G., Vuu, L., & Lawell, C. Y. C. L. (2018). Jevons' paradox and efficient irrigation technology. *Sustainability*, *10*(5), 1590.

Semboja, H. H. H. (1994). The effects of an increase in energy efficiency on the Kenya economy. *Energy Policy*, *22*(3), 217–225. http://www.sciencedirect.com/science/article/pii/0301421594901600

Sheller, M. (2004). Automotive emotions: Feeling the car. *Theory, Culture & Society*, *21*(4–5), 221–242. http://journals.sagepub.com/doi/10.1177/0263276404046068

Sheppard, S., & Udell, A. (2016). Do Airbnb properties affect house prices. *Williams College Department of Economics Working Papers*, *3*(1), 43. https://web.williams.edu/Economics/wp/SheppardUdellAirbnbAffectHousePrices.pdf

Skelton, A. C. H., Paroussos, L., & Allwood, J. M. (2020). Comparing energy and material efficiencyrebound effects: an exploration of scenarios in the GEM-E3 macroeconomic model. *Ecological Economics*, *173*(July): 106544.

Small, K. A., & Van Dender, K. (2007). Fuel efficiency and motor vehicle travel: The declining rebound effect. *The Energy Journal*, *28*(1), 25–51.

Smeets, E., & Weterings, R. (1999). *Environmental indicators: Typology and overview*. European Environment Agency. https://www.eea.europa.eu/publications/TEC25

Song, J., Guo, Y., Wu, P., & Sun, S. (2018). The agricultural water rebound effect in China. *Ecological Economics*, *146*, 497–506.

Sonnberger, M., & Gross, M. (2018). Rebound effects in practice: An invitation to consider rebound from a practice theory perspective. *Ecological Economics*, *154*, 14–21.

Sorrell, S. (2007). *The rebound effect: An assessment of the evidence for economy-wide energy savings from improved energy efficiency. Project report*. UKERC.

Sorrell, S. (2009). Jevons' paradox revisited: The evidence for backfire from improved energy efficiency. *Energy Policy*, *37*(4), 1456–1469. http://www.sciencedirect.com/science/article/pii/S0301421508007428

Sorrell, S. (2010). Energy, economic growth and environmental sustainability: Five propositions. *Sustainability*, *2*(6), 1784–1809. http://www.mdpi.com/2071-1050/2/6/1784

Sorrell, S., & Dimitropoulos, J. (2007). *UKERC review of Evidence for the rebound effect: Technical report 5-energy productivity and economic growth studies*. UK Energy Research Centre.

Sorrell, S., & Dimitropoulos, J. (2008). The rebound effect: Microeconomic definitions, limitations and extensions. *Ecological Economics*, *65*(3), 636–649. http://www.sciencedirect.com/science/article/pii/S0921800907004405

Sovacool, B. K., & Brisbois, M. C. (2019). Elite power in low-carbon transitions: A critical and interdisciplinary review. *Energy Research and Social Science*, *57*, 101242. https://doi.org/10.1016/j.erss.2019.101242

Spielmann, M., de Haan, P., & Scholz, R. W. (2008). Environmental rebound effects of high-speed transport technologies: a case study of climate change rebound effects of a future underground maglev train system. *Journal of Cleaner Production*, *16*(13), 1388–1398. http://www.sciencedirect.com/science/article/pii/S0959652607001758

Spreng, D. (2013). Interactions between energy, information and growth. In First International Conference on Information and Communication Technologies for Sustainability, 6. http://2013.ict4s.org/wp-content/uploads/paper/Spreng_Interactions_between_Energy_Infromation_Growth.pdf

Suffolk, C., & Poortinga, W. (2016). Behavioural changes after energy efficiency improvements in residential properties. In Santarius, T., Walnum, H., & Aall, C. (Eds.). *Rethinking climate and energy policies* (pp. 121–142). Springer International Publishing. http://link.springer.com/10.1007/978-3-319-38807-6_8

Sun, M., & Trudel, R. (2017). The effect of recycling versus trashing on consumption: Theory and experimental evidence. *Journal of Marketing Research*, *54*(2), 293–305. http://journals.ama.org/doi/10.1509/jmr.15.0574

Sunikka-Blank, M., & Galvin, R. (2012). Introducing the prebound effect: The gap between performance and actual energy consumption. *Building Research and Information*, *40*(3), 260–273.

Takahashi, K. I., Tatemichi, H., Tanaka, T., Nishi, S., & Kunioka, T. (2004). Environmental impact of information and communication technologies including rebound effects. *IEEE International Symposium on Electronics and the Environment, 2004. Conference Record. 2004*, pp. 13–16. https://doi.org/10.1109/ISEE.2004.1299680

Takase, K., Kondo, Y., & Washizu, A. (2005). An analysis of sustainable consumption by the waste input-output model. *Journal of Industrial Ecology*, *9*(1–2), 201–219. https://doi.org/10.1162/1088198054084653

Thiesen, J., Christensen, T., Kristensen, T., Andersen, R., Brunoe, B., Gregersen, T., Thrane, M., & Weidema, B. (2008). Rebound effects of price differences. *The International Journal of Life Cycle Assessment*, *13*(2), 104–114. https://doi.org/10.1065/lca2006.12.297

Thøgersen, J. (1999). Spillover processes in the development of a sustainable consumption pattern. *Journal of Economic Psychology*, *20*(1), 53–81. https://www.sciencedirect.com/science/article/pii/S0167487098000439

Thøgersen, J., & Ölander, F. (2003). Spillover of environment-friendly consumer behaviour. *Journal of Environmental Psychology*, *23*(3), 225–236. https://www.sciencedirect.com/science/article/pii/S0272494403000185

Thomas, B. A., & Azevedo, I. L. (2013). Estimating direct and indirect rebound effects for U.S. households with input-output analysis. Part 2: Simulation. *Ecological Economics*, *86*, 188–198. http://www.sciencedirect.com/science/article/pii/S0921800912004715

Thomas, V. M. (2003). Demand and dematerialization impacts of second-hand markets. *Journal of Industrial Ecology*, *7*(2), 65–78. https://doi.org/10.1162/108819803322564352

Tiefenbeck, V., Staake, T., Roth, K., & Sachs, O. (2013). For better or for worse? Empirical evidence of moral licensing in a behavioral energy conservation campaign. *Energy Policy*, *57*, 160–171. https://www.sciencedirect.com/science/article/pii/S0301421513000281

Tigchelaar, C., Daniëls, B., & Menkveld, M. (2011). *Obligations in the existing housing stock: Who pays the bill?* ECN.

Tukker, A., Goldbohm, R. A., De Koning, A., Verheijden, M., Kleijn, R., Wolf, O., Pérez-Domínguez, I., & Rueda-Cantuche, J. M. (2011). Environmental impacts of changes to healthier diets in Europe. *Ecological Economics*, *70*(10), 1776–1788. http://www.sciencedirect.com/science/article/pii/S092180091100190X

TWI2050. 2018. Transformations to Achieve the Sustainable Development Goals - Report prepared by The World in 2050 initiative. International Institute for Applied Systems Analysis. https://pure.iiasa.ac.at/id/eprint/15347/1/TWI2050_Report081118-web-new.pdf

Ürge-Vorsatz, D., & Tirado Herrero, S. (2012). Building synergies between climate change mitigation and energy poverty alleviation. *Energy Policy*, *49*, 83–90. http://www.sciencedirect.com/science/article/pii/S0301421511009918

van den Bergh, J. J. M. (2011). Energy conservation more effective with rebound policy. *Environmental and Resource Economics*, *48*(1), 43–58. https://doi.org/10.1007/s10640-010-9396-z

Vélez-Henao, J. A., García-Mazo, C. M., Freire-González, J., & Vivanco, D. F. (2020). Environmental rebound effect of energy efficiency improvements in Colombian households. *Energy Policy*, *145*, 111697.

Vivanco, D. F., Freire-González, J., Kemp, R., & Van Der Voet, E. (2014). The remarkable environmental rebound effect of electric cars: A microeconomic approach. *Environmental Science and Technology*, *48*(20), 12063–12072.

Vivanco, D. F, Kemp, R., & Van Der Voet, E. (2015). The relativity of eco-innovation: Environmental rebound effects from past transport innovations in Europe. *Journal of Cleaner Production*, *101*, 71–85.

Vivanco, D. F, Kemp, R., & van der Voet, E. (2016a). How to deal with the rebound effect? A policy-oriented approach. *Energy Policy*, *94*, 114–125. https://www.sciencedirect.com/science/article/pii/S0301421516301586

Vivanco, D. F., & Makov, T. (2020). The role of technology and rebound effects in the success of the sustainable development goals framework. In Adenle, A., Chertow, M. R., Moors, E. H. M., & Pannell, D. J. (Eds.). *Science, technology, and innovation for sustainable development goals: Insights from agriculture, health, environment, and energy*. Oxford University Press.

Vivanco, D. F., McDowall, W., Freire-González, J., Kemp, R., & van der Voet, E. (2016b). The foundations of the environmental rebound effect and its contribution towards a general framework. *Ecological Economics*, *125*, 60–69.

Vivanco, D. F., Nechifor, V., Freire-González, J., & Calzadilla, A. (2021). Economy-wide rebound makes UK's electric car subsidy fall short of expectations. *Applied Energy*, *297*, 117–138.

Vivanco, D. F., Sala, S., & McDowall, W. (2018). Roadmap to rebound: How to address rebound effects from resource efficiency policy. *Sustainability*, *10*(6), 2009. http://www.mdpi.com/2071-1050/10/6/2009

Vivanco, D. F., Tukker, A., & Kemp, R. (2016c). Do methodological choices in environmental modeling bias rebound effects? A case study on electric cars. *Environmental Science and Technology*, *50*(20), 11366–11376.

Font Vivanco, D., & van der Voet, E. (2014). The rebound effect through industrial ecology's eyes: a review of LCA-based studies. *Int J Life Cycle Assess*, *19*, 1933–1947. https://doi.org/10.1007/s11367-014-0802-6

Vos, R. O. (2007). Defining sustainability: A conceptual orientation. *Journal of Chemical Technology & Biotechnology*, *82*(4), 334–339. https://doi.org/10.1002/jctb.1675

Wajcman, J. (2015). *Pressed for time: The acceleration of life in digital capitalism*. University of Chicago Press.

Walnum, H. J., & Aall, C. (2016). Transportation: Challenges to Curbing Greenhouse Gas Emissions from Road Freight Traffic. In Santarius, T., Walnum, H., Aall, C. (Eds.). *Rethinking Climate and Energy Policies*. Springer, Cham. https://doi.org/10.1007/978-3-319-38807-6_14

Warmington-Lundström, J., & Laurenti, R. (2020). Reviewing circular economy rebound effects: The case of online peer-to-peer boat sharing. *Resources, Conservation and Recycling: X*, *5*, 100028.

Weidema, B. P. (2006). The Integration of Economic and Social Aspects in Life Cycle Impact Assessment. *Int J Life Cycle Assessment*, *11*, 89–96. https://doi.org/10.1065/lca2006.04.016

Weidema, B. P., Wesnaes, J., Hermansen, J., Kristensen, T., & Halberg, N., (2008). Environmental improvement potentials of meat and dairy products. In Eder, P., & Delgado, L. (Eds.). *JRC scientific and technical reports*. European Commission.

Whitefoot, K. S., Grimes-Casey, H. G., Girata, C. E., Morrow, W. R., Winebrake, J. J., Keoleian, G. A., & Skerlos, S. J. (2011). Consequential life cycle assessment with market-driven design. *Journal of Industrial Ecology*, *15*(5), 726–742. https://doi.org/10.1111/j.1530-9290.2011.00367.x

Winters, J. A. (2011). *Oligarchy*. Cambridge University Press.

Wirl, F. (1997). *The economics of conservation programs*. Kluwer Academics Publishers.

Zink, T., & Geyer, R. (2017). Circular economy rebound. *Journal of Industrial Ecology*, *21*(3), 593–602. https://doi.org/10.1111/jiec.12545

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Font Vivanco, D., Freire-González, J., Galvin, R., Santarius, T., Walnum, H. J., Makov, T., & Sala, S. (2022). Rebound effect and sustainability science: A review. *Journal of Industrial Ecology*, 1–21. https://doi.org/10.1111/jiec.13295