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The Rebound Effect: A Systematic Review of the Current State of Affairs

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Abstract

This publication is intended to present the current state of research on the rebound effect. First, a systematic literature review is carried out to outline (current) scientific models and theories. Research Question 1 follows with a mathematical introduction of the rebound effect, which shows the interdependence of consumer behaviour, technological progress, and interwoven effects for both. Thereupon, the research field is analysed for gaps and limitations by a systematic literature review. To ensure quantitative and qualitative results, a review protocol is used that integrates two different stages and covers all relevant publications released between 2000 and 2019. Accordingly, 392 publications were identified that deal with the rebound effect. These papers were reviewed to obtain relevant information on the two research questions. The literature review shows that research on the rebound effect is not yet comprehensive and focuses mainly on the effect itself rather than solutions to avoid it. Research Question 2 finds that the main gap, and thus the limitations, is that not much research has been published on the actual avoidance of the rebound effect yet. This is a major limitation for practical application by decision-makers and politicians. Therefore, a theoretical analysis was carried out to identify potential theories and ideas to avoid the rebound effect. The most obvious idea to solve this problem is the theory of a Steady-State Economy (SSE), which has been described and reviewed.

Keywords: Review, Critical, Systematic, Literature, Rebound-Effect, Sustainability, SSE) JEL Classification: O33

Introduction

Technology, efficiency gains, sustainability, and automation play an important role in today's economy and society. Disruptive technologies influence the way work is done, people are educated, and products are consumed. Many of the new technologies aim to reduce resource consumption through efficiency gains. In public perception, but also in politics, this approach is rarely questioned. In fact, however, this approach should be critically questioned, especially if the so-called "rebound effect" is taken into account when considering i.e. sustainable management. Already in the 19th century, William Stanley Jevons discovered that efficiency gains through technological progress can have a negative impact on the overall consumption of resources.

This finding became known as the Jevons Paradox (Jevons, 1865). Among other gradations, the Jevons paradox describes the highest degree of the rebound effect (X > 100%). Even though this case is rare, it is best to explain the effects of the rebound effect in and impressive way. The introduction and application of LED technology, for example, has led to a situation where a single LED consumes only one-twentieth of the power of an energy-saving lamp but has increased electricity consumption increase in many places. This was due to the fact that individual electricity costs were initially lower due to lower electricity consumption. However, consumers could either leave their lamps on longer at the same cost, use more lamps than before, and allow people to buy and install lighting fixtures that were previously too expensive. Both have increased the total power consumption caused by lighting (McRae, 2019).

The rebound effect is now measured by how strong the increase in total consumption is in compared to the savings potential. If, for example, the new consumption exceeds the savings achieved by the introduction of the new technology, this is called a rebound effect (Sorrell, Gatersleben, & Druckman, 2018). Depending on how strong and in what form this effect occurs, it can be classified differently. The present publication therefore attempts to present the fundamentals of research on the rebound effect, to outline the (current) scientific models and theories as well as to reveal research gaps and make limitations visible.

Review Method

This paper is based on the systematic review approach, which has been used to answer the research questions presented below. The aim of this working paper is, therefore, to identify all relevant studies of the rebound effect and to aggregate the current state of scientific research (Petticrew & Roberts, 2006). Therefore, an evaluation of relevant literature and an examination of the current state of affairs will be undertaken. In addition, knowledge of the terminology and the conceptual framework that determines the development of the rebound effect is analysed. To

provide a detailed overview, the focus should also, but not exclusively, be on the following objectives (Arksey & O'Malley, 2005):

RQ1: What are the general scientific fundamentals of the rebound effect?

RQ2: What are the limitations and gaps in current research on rebound effect?

Due to limitations in processing time, capacity, and scope, the paper cannot summarise all the investigations carried out in a mutually exclusive manner. Rather, this paper is intended as a summary and basis for further specific research in this area; for instance, how the rebound effect and econometrics can be used as a scientific framework for mathematical and quantitative analysis to predict and review operational business decisions. In line with (Kitchenham, 2004), a three-stage coherent review process was applied. Each phase has specific, cohesive, and clear objectives, which are visualized in Figure 1.

I. Planning: The first and overarching aim is to define a specific and clear review topic. This process is followed by developing the review protocol and generating research questions. The research protocol predefines all important components of the systematic review and must be adapted for each study. The research protocol will serve as a guide throughout the project and therefore already contains an estimated time frame. Furthermore, the predefined protocol is designed to avoid the possibilities of biased review based on the selection of individual studies or personal expectations. Due to the crucial importance of the review protocol, a review in medically relevant research topics and even peer-review is necessary.

II. Implementation: Once the planning process is successfully completed, the implementation phase can begin. The implementation of a systematic review is based on the research protocol and a research strategy, which are the guidelines throughout the process. However, the selection of inclusion and exclusion criteria must be provisional, based on the research question, and documented in the review protocol. Within the defined boundaries, as many subject-related primary studies as possible must be identified, reviewed, categorized, and subsequently reported.

III. Reporting: The composition of a systematic review report depends on the review topic and audience. An individual composition of contents is therefore necessary.

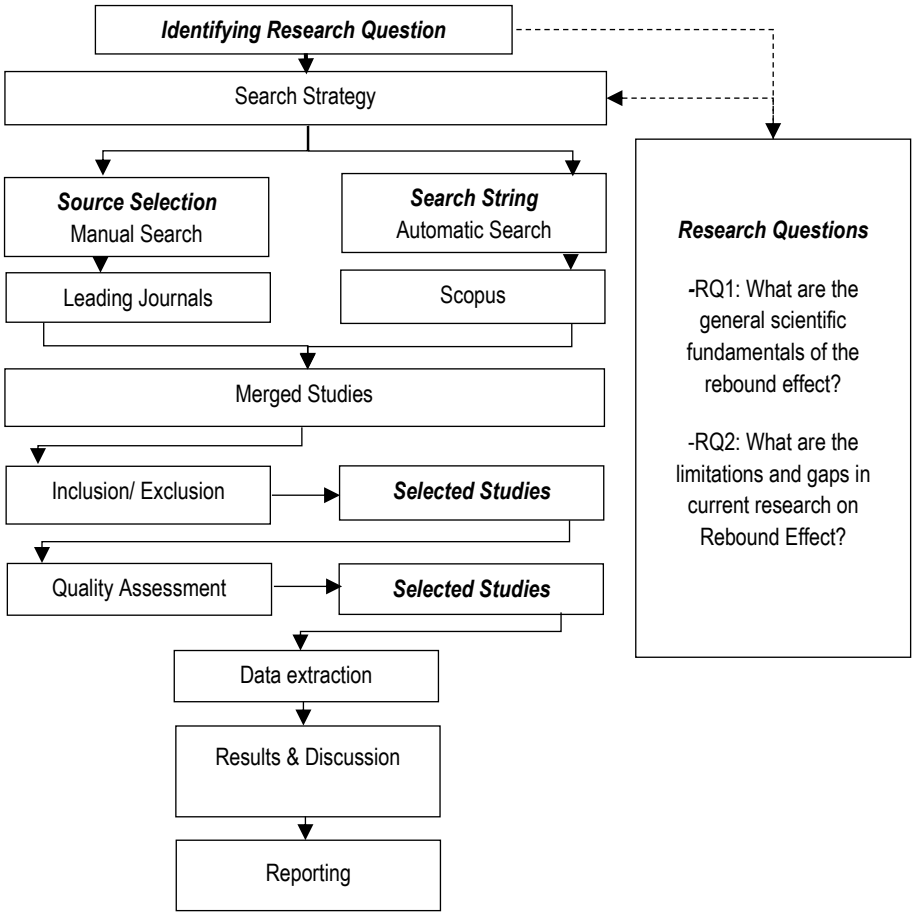


Figure 1: Systematic review – Structure and concept

Source: Own illustration

Two research questions have been identified for this paper, which are to be answered in a conclusive order.

Results of Research Question I

This chapter answers the question of how the rebound effect is defined, what the general principles of the rebound effect are, and to what extent the rebound effect can be subdivided, applied, and abstracted. In addition, a systematic overview of the framework, concepts, and current state of affairs relevant to the theory of rebound effect will be given. The chapter concludes with an overview of studies that show the intensity and extent of the rebound effect in different areas using various parameters.

Research Question 1: What are the general scientific principles of the rebound effect?

The rebound effect (R) is generally understood to be the interstice between potential energy savings from energy efficiency improvements (P) and actual energy savings (A).

The rebound effect is therefore mathematically represented by the formula:

$$R = [1 - \frac{A}{P}]$$

Furthermore, the authors Chitnis & Sorrell et al. (2015) have mathematically decomposed the rebound effect. The rebound effect is mathematically represented in a shortened form as follows:

$$R_T = n_{qs,qp} - \sum_{i(i \neq s)} Uin_{qi,ps}$$

$$R_D = -n_{\mathrm{qs,ps}}$$

$$R_1 = \sum_{i(i \neq s)} Uin_{qi,ps}$$

$$x = p_s q_s + \sum_{\mathrm{i=1,2...N}} pi\ qi$$

$x = Total\ household\ expenditure$

$R_T = Total\ Rebound\ Effect$

$R_D = Direct\ Rebound\ Effect$

$R_1 = Indirect\ Rebound\ Effect$

$p_i = Price\ per\ unit\ of\ good\ i$

$q_i = Quantity\ per\ unit\ of\ good\ i$

$p_s = Energy\ cost\ of\ energy\ service\ (i.e.\ \$\ lumen)$

$q_s = Energy\ efficiency\ of\ energy\ service\ (i.e.\ lumen\ kWh)$

According to Saunder's paper "Fuel conserving (and using) production functions" (Saunders, 2008), the rebound effect is divided into 5 gradations. These can be described as follows (Saunders, 2008):

1. Super conservation (RE < 0): Efficiency gains lead to resource savings that are higher than previously expected. This type of rebound effect is negative. This specification always occurs when the increase in efficiency sustainably reduces the overall resource consumption.

2. Zero rebound (RE = 0): If the resource savings correspond to the expected savings, the rebound effect is neutralized.

3. Partial rebound (0 < RE < 1): In case of a partial rebound, the resource savings are less than previously expected. The rebound effect in this classification is between 0% and 100%. This is sometimes referred to as "take-back" and is most common in the economy or in "real world" applications.

4. Full rebound (RE = 1): Classified if the actual measured resource savings correspond exactly to the increased resource consumption. The rebound effect is therefore exactly 100%.

5. Backfire (RE > 1): The actual resource savings are negative, or the resource savings are less than the increased consumption triggered by efficiency gains. To the extent that consumption increases beyond the initial savings potential generated by efficiency gains, the rebound effect is higher than 100%. As already noted in the introduction, this state is also classified as Jevon's paradox.

According to papers of Andreas Goldthau, H. Herring, and S. Sorell, the classification of rebound effect can also be described as follows (Goldthau, 2013):

Economy-wide rebound effect: A fall in the real prices of energy services will reduce the prices of intermediate and final products throughout the economy and lead to a number of price and volume adjustments for energy-intensive goods. Improvements in energy efficiency can also increase economic growth, which in turn can lead to an improvement in energy consumption (Greening, Greene, & Difiglio, 2000; Goldthau, 2013; Roy & Hering, 2006). The economy-wide rebound effect is represented by the following direct and indirect forms of the rebound effect (Sorrell & Herring, 2009).

Direct rebound effect: Improved energy efficiency for a given service will reduce the effective price of that service and lead to an increase in energy consumption. This will compensate for the expected reduction in energy consumption due to efficiency gains (Greening, Greene, & Difiglio, 2000; Goldthau, 2013; Roy & Hering, 2006). The direct rebound effect itself is further divided into direct rebound effects for consumers and direct rebound effects for producers (Sorrell & Herring, 2009).

Direct Rebound Effects for Consumers:

- Substitution: A substitution effect where the use of the energy service replaces the use of other goods and services for the same benefit or consumer satisfaction.
- Income Effect: Increasing real income by improving energy efficiency will allow higher levels of utilization and consumption by increasing the level of consumption of all goods and services, including energy services.

Direct Rebound Effects for Producers:

- Substitution effect: The more inexpensive energy service supersedes the use of capital, labour, and inputs to achieve a constant level of production.

- Output effect: The cost reductions achieved by improving energy efficiency make it feasible to deliver a higher level of performance – and thus increase the consumption of all inputs, including energy services.
- Indirect rebound effect: A lower effective price of energy services will lead to changes in demand for other improvements in goods and services (Greening, Greene, & Difiglio, 2000; Goldthau, 2013; Roy & Hering, 2006). Furthermore, the indirect rebound effect can be split further into the embodied energy effect and the secondary effects in addition to the direct rebound effect (Sorrell & Herring, 2009).
- Embodied energy: Indirect energy consumption required to improve energy efficiency, such as the energy required to construct and install thermal insulation. (Roy & Hering, 2006)
- Side effects: These result from the improvement of energy efficiency, including supply and demand mechanisms or the increase in demand in the event of a price reduction.

Table 1: Economic estimates of the direct rebound effect for consumer energy services in the OECD

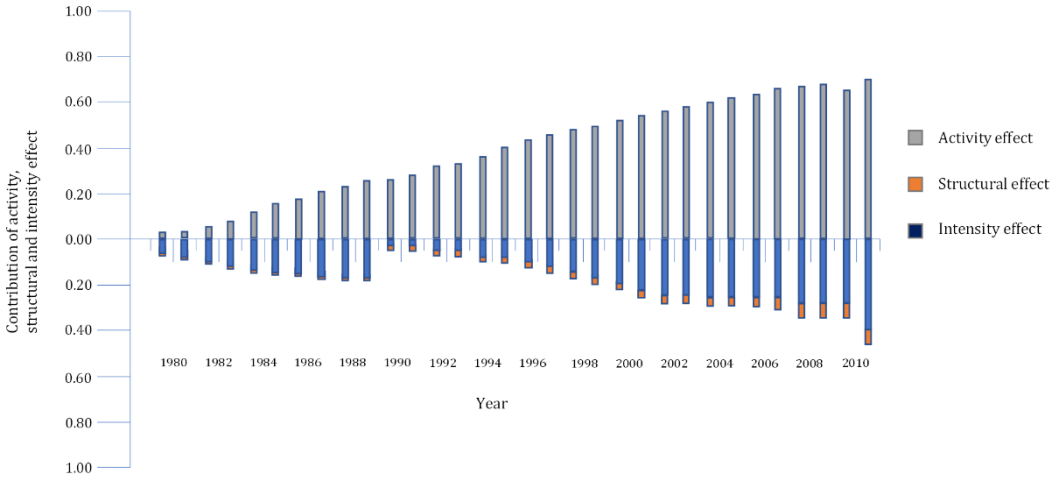
End-use	Range of values in evidence base (%)	Best guess (%)	Number of studies	Degree of confidence
Personal automotive transport	3-87	10-30	17	high
Space heating	0.6 – 60	10 – 30	9	Medium
Space cooling	1 – 16	1 – 26	2	Low
Other consumer energy services	0 – 41	X < 20	3	Low

Source: Data derived and modified from (Sorrell & Herring, 2009)

Table 1, based on the book "Energy Efficiency and Sustainable Consumption: The Rebound Effect" (Sorrell & Herring, 2009), shows various gradations of the rebound effect in consumer energy services. It is based on various studies, a range of the rebound effect results, which contributes to a rough estimate or classification of the rebound effect.

Due to its concept, the rebound effect is always closely interwoven with technology and technological developments. As a result, the total energy consumption of the

world between 1980 and 2010 is shown in the following diagram. Efficiency gains and technological progress should, in principle, lead to a reduction in relative energy consumption since a larger output should be generated from a constant input.



Source: Figure derived from (Goldthau, 2013)

However, Figure 2 shows that energy consumption is constantly increasing, taking into account various factors such as technological development and behavioural aspects. According to the author Goldthau, activity growth increases energy consumption by 3.5% under exclusion of technology and behaviour. However, technological progress (energy intensity) reduces energy consumption by 2.4%, and structural changes reduce consumption by 0.13% (Goldthau, 2013). From this perspective, which does not initially consider the rebound effect, both technological progress and structural changes in society have a positive impact on energy consumption.

Table 2 shows a composition of estimated rebound effects from several studies collected and analysed by the authors (Sorrell, Gatersleben & Druckman, 2018) for different areas and metrics. The studies use income and price elasticities to estimate how households allocate the cost savings from efficiency gains to different resources, and they use expenditure intensities to estimate the corresponding energy usage and related emissions.

Table 2: Studies to estimate combined direct and indirect rebound effects for households (income effects only)

Author	Region	No. Of expenditure categories	Measure	Area	Rebound measure	Estimated rebound effect (%)
Lenzen & Day	Australia	150	Effiency	Food & heating	Energy & GHGs	45 - 123
Alfred-sson	Sweden	300	Suff-iciency	Transport, electricity, heating, food	CO_2	7 - 300
Thomas & Azevedo	US	428	Effiency	Transport, electricity, heating	Energy & GHGs	15 - 27
Murray	Australia	36	Effiency & Suff-iciency	Transport & lightning	GHGs	4 - 24
Chitnis et al	UK	17	Effiency	Electricity & heating	GHGs	5 - 15
Freire-Gonzalez	EU-27	163	Effiency	Transport, electricity, heating	Energy	30 -300
Bjelle et al.	Norway	12	Effiency	Transport, electricity, heating, food,	GHGs	40 - 58

Author	Region	No. Of expenditure categories	Measure	Area	Rebound measure	Estimated rebound effect (%)
				waste, other		

Source: Own table derived with data from (Sorrell, Gatersleben, & Druckman, 2018)

Similar to Table 2, Table 3 shows a number of studies on the rebound effect. However, unlike Table 2, this table integrates both income and substitution effects of households.

Table 3: Studies estimating combined direct and indirect rebound effects for households (income and substitution effects)

Author	Region	No. of resources categories	Measure	Area	Rebound Metric	Estimated rebound effect (in %)
Brannlund et al	Sweden	13	Efficiency	Transport; utilities	CO_2	120
Mizobuchi	Japan	13	Efficiency	Transport; utilities	CO_2	12
Lin & Liu	China	10	Efficiency	Transport; utilities	CO_2	37
Kratena & Wuger	Austria	6	Efficiency	Transport; heating, electricity	Energy	37 - 86
Chitnis & Sorrell	UK	12	Efficiency	Transport; heating, electricity	GHGs	41 - 78

Source: Own table derived with data from (Sorrell, Gatersleben & Druckman, 2018)

The authors of the study Sorell, Gatersleben and Druckman come to the following conclusion when evaluating the available studies in the tables shown:

It is difficult to draw concrete conclusions from the available data, as both the methodological limitations and unknown factors not taken into account may have an influence on the determined rebound effect.

If, however, the evaluation is limited to the available figures, the following summary and evaluation can be made: The Jevons paradox (rebound effects above 100%) is visible and obvious in the available data; furthermore, it is obvious that the indirect rebound effect is inversely proportional to the direct effect. Moreover, the direct and indirect effects appear to be greater for measures affecting road transport than for measures concerning electricity or heating oil. This could possibly be explained by the fact that road transport fuels tend to be taxed more heavily and thus have a greater impact on the range and intensity of the rebound effect. Finally, the rebound effects within a country tend to be greater for low-income groups in that country.

Result of Research Question II

The multifaceted research question has determined the search strategy and leads to a separation into a manual and automated search. The manual search is limited to leading journals related to sustainability, while the automated search string is more widespread and is performed by Scopus (Scopus, 2019a). The aim is to identify limitations and gaps in the literature on the rebound effect. In addition, research papers, studies, and researchers dealing with the rebound effect are analysed and evaluated. Building on this, this should be possible to systematically integrate the theory of the rebound effect into current affairs.

Research Question 2: What are the limitations and gaps in current research on the rebound effect?

A selection of the journals chosen for manual research is shown in Table 4.

Table 4: Reporting overview

Author	Title	Citations	Year
Lorna Greening, David L. Greene & Carmen Difiglio (Greening, Greene & Difiglio, 2000)	Energy efficiency and consumption: The rebound effect – A survey	915	2000
Steve Sorrell, John Dimitropoulos & Matt Sommerville (Sorrell, Dimitropoulos & Sommerville, 2009)	Empirical estimates of the direct rebound effect: A review	421	2009

Author	Title	Citations	Year
Peter H. G. Berkhout, Jos C. Muskens & Jan W. Velthuijsen (Berkhout, Muskens & Velthuijsen, 2000)	Defining the rebound effect	390	2000
Kenneth Small, Kurt Van Dender (Small & Van Dender, 2007)	Fuel efficiency and motor vehicle travel: The declining rebound effect	386	2007
Steve Sorrell & John Dimitropoulos (Sorrell & Dimitropoulos, 636-649, 2008)	The rebound effect: Microeconomic definitions, limitations and extensions	367	2008
Mathias Binswanger (Binswanger, 2001)	Technological progress and sustainable development: What about the rebound effect?	354	2001
Edgar G. Hertwich (Hertwich, 2005)	Consumption and the rebound effect: An industrial ecology perspective	308	2005

Source: Own table

The selected keywords for the automated Scopus search are listed in Table 5.

Table 5: Reporting overview for selected keywords

Rebound effect	Energy efficiency
Sustainability	Energy
Economy-wide rebound effect	Efficiency side effects
Energy paradox	Energy consumption

Source: Own table

The identified studies must then be combined and form the basis for more detailed analyses. By matching inclusion and exclusion factors with the combined studies, the relevant unity for the following quality assessment is defined.

Therefore, the factors defined in this study are listed in Table 6.

Table 6: Inclusion and exclusion criteria for defining relative unity

Inclusion criteria	Exclusion criteria
Publication date between 2000 and 2019	Publication earlier than 2000
Link to the research question	Irrelevant for the research question
Written in English	Written in a language other than English
Full text	Not peer-reviewed
Published in the selected database	Articles outside inclusion criteria

Source: Own table

In addition to the general inclusion/exclusion criteria, a quality assessment is carried out:

- To have a secondary quality level according to inclusion/exclusion criteria,
- To reveal whether differences in quality lead to differences in study results,
- To weigh up the significance of individual studies in the synthesis of results,
- To guide recommendations for further research.

Once an article has passed the listed criteria and been identified as acceptable, it is included in the systematic review.

Data extraction and synthesis

Based on Scopus (Scopus, 2019a), 686 papers are identified in the period from 1957 to 2019 that deal with the rebound effect. (Figure 3)

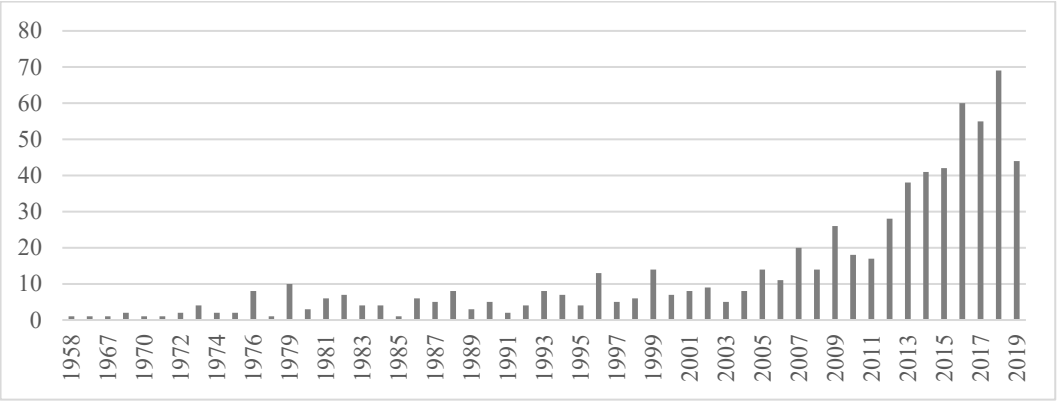


Figure 2: Total number of rebound effect papers from 1957 to 2019

Source: Own illustration

Overview of publication sources

A total of 387 journals and 5 conference papers are selected for analysis. This literature review focuses on the database Scopus (Scopus, 2019a) and excludes a small number of publications before 2000 on the rebound effect. Using the Scopus database and omitting these papers does not mean that there is no multidisciplinary view of the rebound effect. The scientific work is given by a large number of papers to minimize distortion. The inclusion of a small number of related papers published before 2000 would not have changed the overview of the literature on the rebound effect. (Table 7)

Table 7: Dissemination of the rebound effect

Year	Number of Journal papers	Number of conference papers	Total
2000	6	-	6
2001	3	-	3
2002	2	-	2
2003	2	-	2
2004	5	-	5
2005	6	-	6
2006	7	-	7
2007	14	-	14

Year	Number of Journal papers	Number of conference papers	Total
2008	10	-	10
2009	13	-	14
2010	11	1	12
2011	14	-	14
2012	24	-	24
2013	26	1	27
2014	31	-	31
2015	29	-	29
2016	48	1	49
2017	42	1	43
2018	57	1	58
2019	37	-	37
Total	*387*	*5*	392

Source: Own table; Scopus 2019a

Temporal view of the publications

Table 7 shows that a total of 392 journal and conference papers were published in the last 19 years. In the years 2013 to 2018, the publication figures were highest. However, as only half of 2019 has passed, further publications may follow. It is therefore not entirely clear whether there will be a positive or negative trend in publication figures on the subject of the 'rebound effect' in the following years. However, it is clear that almost exclusively journal papers and hardly any conference papers were published. This has also been observed in many other areas in recent years. The reasons for this would have to be examined separately.

The first objective was to develop a system for accurate data processing. Second, a total of 392 publications were reviewed, and data were extracted using Microsoft Excel. The following lines have therefore been selected: Authors, Title, Year, Cited by, Source title, DOI and Link (Table 8).

Table 8: Dissemination of the rebound effect

Extracted Data	Description
Authors	Names of all the authors
Title	The name of the paper which appeared in the searching stage
Year	Year of publishing the paper (2000–2019)
Cited by	The number of citations for that study obtained from Scopus
Source title	For instance: journal, conference proceedings
DOI	Digital object identifier
Link	The link to Scopus platform

Source: Own table

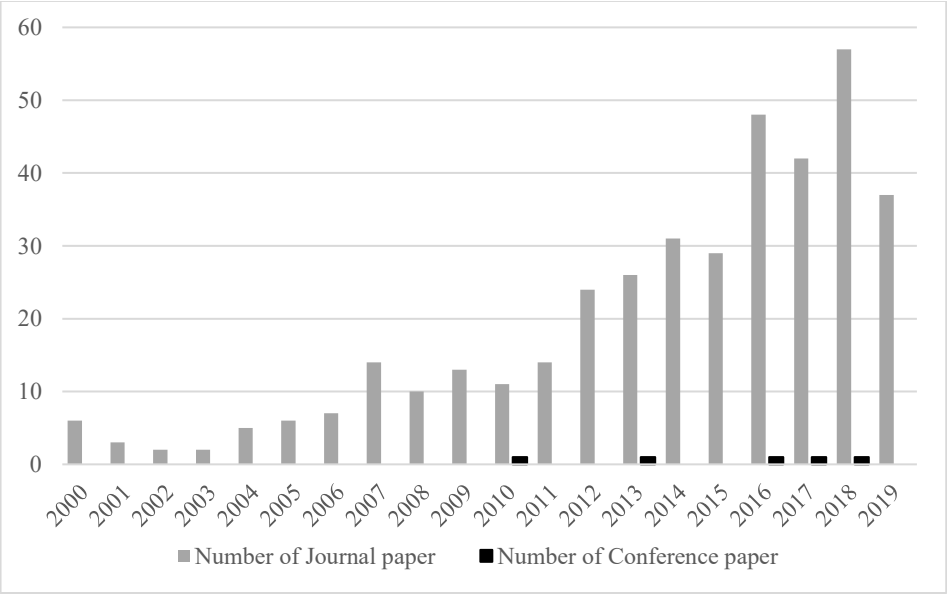


Figure 3: Number of conference and journal papers of the Rebound Effect

Source: Own illustration, data derived from (Scopus, 2019a)

Citation status

To assess quality and impact, a citation-statistical review was carried out, which was visualized in Figure 5. The corresponding statistics were compiled by Scopus and are intended to identify publications with high impact and reach.

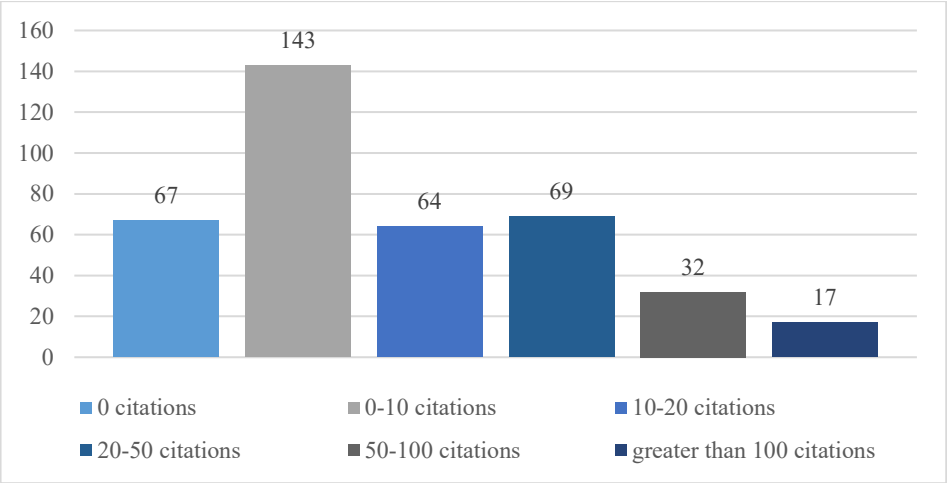


Figure 4: **Number of citations from 2000 to 2019**

Source: Scopus, 2019a

About 49 selected publications have more than 50 citations. 69 of the publications were cited between 20 and 50 times, while 64 were cited between 10 and 20 times. In addition, 210 publications were cited less than 10 times. However, as some publication have only recently been published, the citation rate cannot be used exclusively for quality assessments.

A central theme to be investigated in research papers is a research topic (Liang &Turban, 2011). In the following, the literature reviews are divided into three research topics: Definitions & benefits, Adoption, and Approaches & strategies for the rebound effect. Table 7 illustrates the research topics and the description of the papers on the rebound effect.

Table 9: Rebound effect research topics and descriptions.

Research Themes	Description
Definitions & benefits	Papers focusing on the definition and benefits of applying the rebound effect, e.g. energy efficiency or cost savings
Adoption	Papers focusing on the processes for avoiding the

Research Themes	Description
	rebound effect and on factors that motivate and influence individuals to avoid rebound effects, such as policies and taxes
Approaches & strategies	Papers that offer different approaches to avoid and manage rebound effects without government regulations

The following selection focuses on the second research question and examines the literature on possible research gaps. In a secondary systematic, abstract overview, the basis of 392 publications was analysed with regard to content aspects to avoid the rebound effect.

1. Definitions & benefits

The majority of the 275 (70%) publications in this paper focused on the definition and the potential benefits of the rebound effect. Nevertheless, the choice of definitions varies from author to author. Greening et al. provide "definitions and […] sources including direct, secondary, and economy-wide sources" (Greening, Greene, & Difiglio, 2000). Sorrell et al. focus on the "overview of the theoretical and methodological issues relevant to estimating the direct rebound effect" (Sorrell, Dimitropoulos, & Sommerville, 2009), while Berkhout et al. describe "the state of the art of empirical estimation of the rebound effect" (Berkhout, Muskens, & Velthuijsen, 2000). The paper by Small & Van Dender develops a "model [that] accounts for endogenous changes in fuel efficiency" (Small & Van Dender, 2007). Sorrell analyses the "theoretical work to provide a rigorous definition of the rebound effect" (Sorrell & Dimitropoulos, 2008). Binswanger shows "the potential relevance of the rebound effect to ecological economics" (Binswanger, 2001). The paper by Hertwich points out "[…] that the current focus on the rebound effect is too narrow and needs to be extended to cover co-benefits, negative side effects, and spillover effects" (Hertwich, 2005).

2. Adoption

The second category constitutes of 115 (29%) publications, focusing on the avoidance of the rebound effect through the implementation of restrictions and individual boundaries, consolidated as policies and taxes as a subsequent strategy to avoid the rebound effect. This approach is widespread among many authors and is based on the theory that individual or collective savings generated by technological progress are reinvested in increased usage (Birol & Keppler, 2000). Accordingly, some earlier savings are eaten up, and a rebound effect is created. Some authors such as Herring and Roy go even further by stating that energy reduction at the microeconomic level

will ultimately lead to increased energy consumption at the macroeconomic level (Roy & Hering, 2006). Therefore, according to Santarius, a distinction must be made in policy-making between individual consumers, commercial consumers, and governmental agencies in order to reduce the rebound effect (Santarius, 2015). Another area of research identified is the impact of policies on actual energy consumption and the rebound effect. Leading authors include Gillingham, Rapson, and Wagner, who have critically examined the effects on overall energy consumption (Gillingham, Rapson, & Wagner, 2015). While different policy approaches are discussed by various authors, the main idea is to invent or extend a tax related to energy consumption (Roy & Hering, 2006).

3. Approaches and strategies

Only two studies (1%) provided a solution on how to avoid the rebound effect without governmental regulations. For example, Johannes Buhl speaks of shortening working hours in order to reduce the rebound effect. "The results show that time savings due to a reduction in working time trigger relevant rebound effects in terms of resource use" (Buhl, 2015), while Jørgen S. Nørgård pointed out that the problem with the rebound effect is not the increase in energy efficiency that results from the reduced consumption of resources, but the economy that recoups the savings by consuming the saved resources. His proposal to avoid the consumption of resources savings is a steady-state economy (Nørgård, 2009), which means 3.5% annual GDP growth and requires an improvement eco-efficiency by a factor of 80 in 2060 compared to 2000. At an annual GDP growth rate of 2%, the factor would be 35. In a steady-state economy, GDP is a constant 1%, and the factor is 10 (Schmidt-Bleek, 2000).

On the basis of the systematic literature research, the authors have concluded that the rebound effect and its impact on versatility have been clarified. Nevertheless, a significant gap was identified in terms of avoiding the rebound effect. The main research approach concentrates on the course and effects of the rebound effect, while avoidance is rarely targeted. It was found that only two studies (1%) had a relationship to avoidance. In-depth research has shown that the majority of authors have geared their avoidance theory towards the implementation of higher taxes and stricter policies. Although the fiscal and policy approach will avoid the repercussions of the rebound effect, it is not directly related to the elevated course indicated in RQ1. Therefore, further research has been conducted, focusing on the identification of alternative approaches to avoid rebound effects.

A limitation of these SLRs is that probably not all relevant assessments of the rebound effect that exist in literature are identified or have been biased by personal background and opinions when studies are manually included or excluded. These are limitations to which SLRs are generally subject. The risk of biased results was minimized by deriving only robust results. Like Mallet et al. defined, SLRs should be seen as "helping to get a robust and sensible answer to a focused research question". (Mallett, Hagen-Zanker, Slater, & Devendack, 2012)

Conclusion

In summary, a hybrid system of literature analysis and general description and derivation of the rebound effect was applied. This has the advantage that the procedures, methods, and findings elaborated in the reviewed literature can be placed directly in a scientific context and evaluated within the set limits and conditions.

In mathematical terms, the rebound effect can be simply understood as a gap between possible energy savings through increased energy efficiency through technological progress and the actual energy savings influenced by consumer behaviour. In the general analysis of the rebound effect, it was found that various gradations, derivations, and applications of the rebound effect have been used and developed in the literature. In addition to the mathematical subdivision, the comprehensibility of the rebound effect was clarified on the basis of the gradations made by Saunders and Sorell. Starting with a negative rebound effect ($X < 0$), the maximum expansion level culminates in the Jevons Paradox ($X > 1$). Due to its conception and the close interdependence with technology and technological developments, the rebound effect is also dynamic in its field of application and effect. From the diagrams and values shown, in particular from the Goldthau breakdown, it is clear that consumer behaviour leads to increased consumption as opposed to technological resource savings. Therefore, in the current economic system, a reduction in resource consumption is not reconcilable with economic growth.

Finally, RQ2 provided an overview of recent research on the rebound effect within the previously developed and defined scientific framework. A systematic review approach was chosen to answer RQ2 in order to investigate rebound effects. The research questions place scientific papers published between 2000 and 2019 on the rebound effect in the context of a holistic view of the state of research. After carrying out various systematic processes, 392 papers were selected with a focus on the rebound effect. The remaining studies were not included in this review because they could not meet the eligibility criteria and were therefore considered irrelevant or scientifically value-bearing. After data analysis, the selected studies were clustered into three research topics: Definitions & benefits, Adoption, and Approaches & strategies. The results of this review showed that the 'Definitions & benefits' cluster was the most pronounced (70%), followed by 'Adoption' (29%).

Finally, for the paper as a whole, it should be noted that research on the rebound effect is not yet comprehensive enough and focuses mainly on the effect itself rather than on solutions to avoid it. The main deviation, and thus the limitations, is that not much research has been published on the actual avoidance of the rebound effect. This is a significant limitation for practical application by decision-makers and policymakers.

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