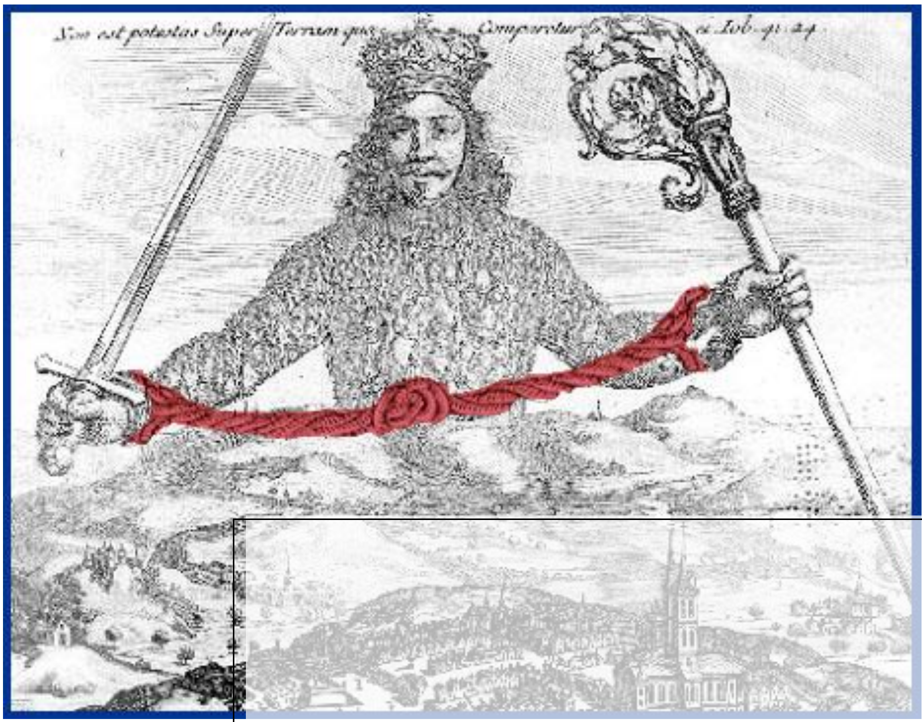

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Challenges for sustainable environmental policy - Influencing factors of the rebound effect in energy efficiency improvements *

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1. Introduction

In the light of climate change, topics of sustainability and environmental protection are becoming increasingly important. In particular, the pursuit of technological advances and efficiency gains, coupled with steady economic growth, has become an integral part of policies worldwide. Also at this year's G20 summit were "economic growth, sustainable development and prosperity [..] at the center of cooperation" (Die Bundesregierung, 2017), whereby the promotion of energy efficiency was explicitly taken into account. However, often the projected energy savings are not as high as expected and the targets set cannot be achieved. The freed-up resources as a result of increased energy efficiency, lead to an increase in demand for energy services and thus to increased energy consumption[1]. This phenomenon is called the Jevons' paradox or rebound effect. Although technological progress generates efficiency gains and the potential for savings reduces overall consumption, the rebound effect leads to more energy and resource consumption[2]. Since the earliest mention of this effect by the economist William Jevons in 1865 in his prestigious work *The Coal Question* and the resumption of this discussion by Khazzoom (1980) and Brookes (1978) in the 1980s, numerous notions of the rebound effect have been developed. For example, Santarius (2012, p. 11) mentions 13 different rebound effects, Madlener & Alcott (2009, p. 372) claim to have even compiled 28 definitions.

However, not only the large number of scientific studies and the different classifications of the rebound effect, but also measures such as the handbook published by the Federal Environment Agency in 2016[3], show how important the rebound effect is for energy and environmental policy.

This paper explores the factors that influence the emergence and extent of rebound effects and the challenges that arise for a sustainable environmental policy. The focus here is on increasing energy efficiency and the energy consumption decisions on the consumer side. The starting point of this investigation is the concept of the rebound effect, whose definition is based on the most common classification in the much-cited works by Greening et. al. (2000) and Berkhout et. al. (2000). Based on this, the main part of this paper is dedicated to the different factors influencing the rebound effect. The last section addresses the challenges arising for an environmental policy to promote energy efficiency.

[1] cf: (Hertwich, 2005, S. 86); (Maxwell, McAndrew, Muehmel, & Neubauer, 2011, S. 30); (Santarius, 2015, S. 39).
[2] cf: (Berkhout, Muskens, & Velthuijsen, 2000, S. 425); (Santarius, 2015, S. 48).
[3] cf: (Semmling, Peters, Marth, Kahlenborn, & De Haan, 2016).

2. The rebound effect of energy efficiency improvements

Since the rebound effect occurs as a result of efficiency increases, the concept of energy efficiency should first be briefly considered. This is understood to mean the ratio between the amount of input and output, with input in the form of energy or raw materials, such as electricity and gasoline. The output defines the resulting energy service, such as the luminosity and burning time of a lamp or the distance traveled by car. Consequently, if one requires less input while maintaining the same output or one achieves a higher output while maintaining the same input, there is an increase in efficiency[4].

Santarius (2015, p. 48) defines the rebound effect as "[...] an increased demand for an energy service that was conditioned or at least made possible by an increase in energy efficiency". Holding all other factors as constant, the rebound effect is thus understood as the deviation of the potential savings from the indeed realized decline in consumption. For example, replacing a light bulb with an LED would reduce energy consumption for identical lighting performance without the presence of a rebound effect. But if a higher consumption occurs in response to the more efficient lighting, such as a longer burning time per day or by the installation of multiple lights, it is called a rebound effect[5].

In most cases, not only the demand for energy but also the use of energy-driven technologies, the so-called energy services, is regarded. Sorrell and Dimitropoulos (2008, p. 637) also define the concept of energy service as "useful work", in what a rebound effect occurs. The changes in consumer behavior lead to a compensation of the efficiency measures and the potential for savings cannot be fully exploited. The rebound effect is usually stated as the percentage deviation of the actual energy savings from the expected savings[6]. If the possible savings are overcompensated by an increased consumption and thus the rebound effect is over 100%, this is referred to as a so-called "backfire"[7].

Most definitions of the rebound effect include only the positive correlation between resource efficiency and increasing consumption, with a positive rebound effect for the increased consumption of energy[8]. Schleich, Mills, & Dütschke (2014, p. 37) argue that even negative

[4] cf: (Herring & Roy, 2007, S. 195); (Santarius, 2015, S. 30); (Sorrell, 2009, S. 1459); (Sorrell & Dimitropoulos, 2008, S. 638).
[5] cf: (Schipper & Grubb, 2000, S. 369); (Schleich, Mills, & Dütschke, 2014, S. 36).
[6] cf: (Berkhout, Muskens, & Velthuijsen, 2000); (Greening, Greene, & Difiglio, 2000) (Sorrell, 2007).
[7] cf: (Jenkins, Nordhaus, & Shellenberger, 2011); (Saunders, 2000); (Sorrell, 2009).
[8] cf: (Madlener & Alcott, 2011); (Peters, Sonnberger, & Deuschle, 2012).

rebound effects are possible in principle. These occur when, as a result of an increase in efficiency, demand is lower than before and the expected savings are even surpassed.

Although there are a multitude of definitions, the most common three categories of the rebound effect, the direct, the indirect and the macroeconomic rebound effect, are presented below. A direct rebound effect is understood to be the increased demand for the same product or service, which has become more efficient as a result of technological progress[9]. The energy using good is therefore used more frequently, or more intensively and thus directly compensates a part of the potential energy savings. A common example of the direct rebound effect is the use of a car. If a more efficient car requires less fuel, then a direct rebound effect occurs if the more fuel-efficient car is driven for longer distances, or if the consumer buys a more powerful car.

While the direct rebound effect examines the demand for the immediate benefit of increasing efficiency, the indirect rebound effect summarizes all other impacts and behavioral changes[10]. This includes any increase in demand for other goods or services related to the energy savings of the directly affected good[11]. For example, the savings realised by using a more efficient car will be re-invested in air travel. In most cases, direct and indirect rebound effects are not clearly separated, which makes consistent determination and measurement difficult. Thus, a more frequent use of a car does not exclude that due to the savings achieved additional vacation trips are made by plane.

The direct and indirect rebound effect sum up to the macroeconomic rebound effect. This describes the effects of efficiency-induced additional demand on the entire market and its production structures[12]. In some cases, it is also called a structural rebound effect[13] or market price effect[14]. The prices of intermediate and end products in the market are changing following an increase in efficiency resulting in price and quantity adjustments for energy-intensive sectors[15].. However, the focus of this paper is on the microeconomic level, thus on the factors influencing the direct and indirect rebound effect.

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[9] cf: (Santarius, 2015, S. 50).
[10] cf: (Madlener & Alcott, 2011, S. 7)
[11] cf: (Druckman, Chitnis, Sorrell, & Jackson, 2011, S. 3573); (Sorrell, 2007, S. 41).
[12] cf: (Peters, Sonnberger, & Deuschle, 2012, S. 4f).
[13] cf: (Berkhout, Muskens, & Velthuijsen, 2000, S. 425).
[14] cf: (Jenkins, Nordhaus, & Shellenberger, 2011, S. 22).
[15] cf: (Sorrell & Dimitropoulos, 2008, S. 637).

3. Factors influencing the rebound effect

The following section presents the factors influencing the rebound effect. A distinction is made here between economic factors and psychological factors. These factors are intended to define challenges for an environmental policy that deals with energy efficiency measures to promote a sustainable economy. It is clear from the overview in Table 1 that some factors can trigger a rebound behavior both economically and psychologically and therefore cannot be clearly assigned to one category.

Table 1: Economic and psychological factors of rebound behavior

Economic Factors	**Psychological Factors**
Price Effect	Moral Hazard & Moral Leaking
Household Income	Personal Norms
Preferences and Needs	Moral Lizensing
Time Saving	Mental Accounting
Lack of Information	

Reference: Own contribution.

The analysis of economic rebound effects assumes the rational decision-making of individuals under utility maximization behavior. Frequently mentioned as a driving factor for rebound effects is the reduction of the operation costs or the decrease in the price for energy services. In this context, we talk also about financial rebound effects. [16]

Price effects, household income and needs

The economic analysis of the rebound effect is often based on the factor of price elasticity, which is the ratio of a percentage change in demand to the percentage change in price. To calculate the rebound effect, it is also possible to take other elasticities into account.[17]

If a product becomes more efficient, the operation costs decrease, and the consumer is given a higher real income while the budget remains constant. In turn that can lead to increasing consumption of other energy-intensive products[18]. But not only the actual, but also the perceived

[16] cf: (Berkhout, Muskens, & Velthuijsen, 2000); (Birol & Keppler, 2000); (Freire-González, 2017); (Greening, Greene, & Difiglio, 2000).
[17] cf: (Frondel, Ritter, & Vance, 2012); (Schleich, Mills, & Dütschke, 2014); (Sorrell & Dimitropoulos, 2008).
[18] cf: (Madlener & Alcott, 2011); (Nässén & Holmberg, 2009); (Sorrell, 2007).

costs are important for the amount of rebound effects. Semmling, et. al. (2016, p. 10) state that the more consumers are aware of savings through efficiency gains compared to previous operating costs, the more likely they are to provoke rebound effects. Consumers perceive energy efficiency improvements as a price reduction of the energy service. As a result, a rational consumer chooses an optimal bundle of goods that meets the new relative prices. Thus, the change in the price of a good has economically two effects, the income effect and the substitution effect. These two effects are often presented as a subcategory of the direct rebound effect.[19]

The level of the direct rebound effect is mainly determined by the price-elasticity of demand, in response to the price reduction, as well as the substitution possibilities of a good. The higher the price-elasticity of demand and the higher the elasticity of substitution, the greater will be the rebound effect[20].

While the income effect represents the increased consumption of energy services as a consequence of the change in real income, the substitution effect is understood to be the increased demand for the more efficient commodity, where previously an alternative (inefficient) good was consumed[21]. Lancaster (1966, p. 140f) calls this "efficiency substitution." The substitution effect thus shifts the consumption allocation within the same utility level. For example, a commuter would now use the more efficient car instead of the train more frequently. The income effect, on the other hand, reflects the change in behavior as a reaction to improving the efficiency of a good. Here, the consumer reaches a higher level of utility. The more efficient car of the commuter allows the consumer to realize real savings. These savings could be compensated, for example by driving longer distances and thus generate additional utility for the consumer. Greening et. al. (2000, p. 395) argue that the increase in utility can also be achieved by switching to a more comfortable car, which is for example provided by an air conditioner and thus consumes more gasoline than the previous car. Peters et. al. (2012) concludes that the main reason for the new acquisition of more efficient mobility products is the economic reason and thus the reduction of costs per energy service.

In addition to the price effect, household income is also an important economic factor for the emergence and extent of rebound effects. Several studies conclude that low-income households generate higher rebound effects than households with higher incomes[22]. One explanation for this

[19] cf: (Greening, Greene, & Difiglio, 2000); (Jenkins, Nordhaus, & Shellenberger, 2011); (Sorrell, 2007).
[20] cf: (Birol & Keppler, 2000, S. 461).
[21] cf: (Chitnis, Sorrell, Duckman, Firth, & Jackson, 2013, S. 235).
[22] cf: (Chitnis, Sorrell, Duckman, Firth, & Jackson, 2014); (Galvin, 2015); (Roy, 2000).

is the aspect mentioned by Murray (2013, p. 247) that low-income households generally have less scope for investing in efficiency gains. Boardman and Milne (2000, p. 412), on the other hand, using the example of household heating costs and room temperature. They argue that direct rebound effects are higher in lower income classes because these households are still far from the saturation level of most relevant energy services. Galvin (2015, p. 766) also notes that a general statement on rebound effects and income levels should be made cautiously, as low-income households generate higher direct rebound effects, but the total energy consumption does not necessarily have to be greater than the share of consumption of high-income households.

When looking at the economic factors influencing rebound behavior, it quickly becomes clear that a restriction to the financial analysis is not sufficient to adequately explain rebound effects. For example, the needs of consumers must be taken into account. They reflect consumers' preferences and are therefore essential for rational decision-making. From a purely economic point of view, an increase in demand takes place until the satisfaction of needs reaches a maximum in compliance with the given restrictions. A rebound effect in the economic sense thus goes hand in hand with a rational decision-making process. The overconsumption compared to the initial level thus reflects the new consumption choice of the individual, brought about by a change in the restrictions.

Theoretical considerations on the relationship between unsatisfied needs and observed rebound effects suggest that the efficient product offers greater comfort, costs less, or is less burdensome to the environment[23]. Greening et. al. (2000, p. 391) further argue that technological change and progress can also influence consumer needs. It therefore seems necessary to incorporate the change in need perception in the estimation of possible rebound effects.

Time savings

The time saving factor does not come into play in every energy efficiency improvement. For example, replacing a conventional incandescent lamp with an LED does not save time for a consumer. However, if a consumer purchases an electric car and consequently drives more distances by car, which he had previously mastered by bicycle or on foot, the use of a more energy-efficient technology constitutes real savings of time for the consumer. Brenčič and Young (2009), in their study of time-saving household appliances and services, conclude that the time savings resulting from an increase in efficiency generate higher rebound effects. The time saved, such as

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[23] cf: (Semmling, Peters, Marth, Kahlenborn, & De Haan, 2016, S. 8).

the use of a dishwasher, can be used to engage in other energy-intensive activities, such as the more frequent use of the television. In his analysis, Binswanger (2001) describes the time savings as a side effect, generating a rebound effect because it allows for more consumption elsewhere. In Sorrell & Dimitropoulos (2008, p. 644f) study, time is considered a cost item with increasing value, which should be taken into account when estimating rebound effects. If the cost of time increases relatively more than the cost of energy for the consumer, a substitution of time-consuming to energy-intensive consumption activities can take place.

The consideration of the time savings in the use of energy-consuming products thus also represents an economic factor in the evaluation of the factors influencing the rebound effect. The consumer thereby weighs the costs of the energy-saving alternative against the cost of the time-efficient alternative. Thus, rebound behavior can arise when the consumer, adjusts his time allocation and switches from a time consuming to an energy consuming action.

Lack of information

The problem of incomplete information represents both an economic and a psychological factor for rebound effects. Economically speaking, complete information is a necessary condition for rational decision-making. For example, if a consumer does not have the knowledge of how the more efficient technology is comparable to the inefficient technology already in use, it may unconsciously create a rebound effect. Schleich et. al. (2014, p. 40f) concluded from their research that the ignorance of how different types of lamps are to be substituted for one another leads to purchases of stronger lighting intensities when choosing a more efficient light source.

Peters et. al. (2012, p. 38f) also argue that even ignorance of the proper operation of energy-efficient products can trigger rebound effects. For example, the presumption of a shortened life of energy-saving lamps by switching on and off more often can lead consumers to burn them longer and thus produce a direct rebound effect. Steg (2008) argues that consumer heuristics can often be wrong and consumers underestimate the actual energy consumption, for example, when heating water with a kettle. Aside from the rational, economic decision-making, inadequate consumer knowledge also leads to psychological caused rebound effects.

Moral Hazard and Moral Leaking

If products become more efficient and more environmentally friendly, they not only generate a monetary benefit for the consumer, but also change their symbolic content[24]. The increased use of an energy service becomes tolerable, since, for example, the lighting consumes less energy and is therefore more resource-efficient than before. Santarius (2012) mentions the moral hazard effect as an explanation for the direct rebound effect. This arises when the increase in efficiency causes disincentives for individuals, that they change their energy consumption behavior in favor of the rebound effect. The moral leaking effect is not dissimilar to the moral hazard effect. The energy savings are considered away from monetary savings and their effect on consumer consumption. If the change to an energy-efficient product brings savings in time and effort, then this saving can lead to as less careful use of the energy consuming product. Attention is not paid to whether the window is closed or the light is switched off[25]. The moral leaking effect then causes an increase in consumption of the more efficient product, as its use has become more convenient for the consumer. The time and effort saved by consuming the new product is then more important to the consumer than ecological motives. Peters et. al. (2012, p. 41), for example, find that users use the lower-power product more often for convenience reasons[26].

Personal Norms, Moral Lizensing and Mental Accounting

The normative motivation and a strong environmental awareness play an important role in the energy saving of consumers. Thus, rebound effects may be lower, if consumers have a strong environmental awareness or a moral norm for the conscious use of energy, since energy consumption decisions are initiated away from the economic utility maximization[27]. Semmling et. al. (2016, p. 8) also point out that the moral obligation of an individual can also be weakened by the knowledge of using a more energy-efficient good. This leads to a re-evaluation of behavior, as it has changed the personal, financial and environmental consequences for the consumer.

Not only the individual norm, but also the social norm can affect the level of potential savings achieved. Thus, increased social acceptance of resource-saving products can also lead to rebound behavior. However, if social and personal norms are that strongly internalized that an increase in

[24] cf: (Santarius, 2015, S. 87).
[25] cf: (Peters, Sonnberger, & Deuschle, 2012, S. 32).
[26] For example, to use a scooter instead of a car, increasingly for shorter distances, which were previously mastered by bicycle.
[27] cf: (Lindenberg & Steg, 2007); (Semmling, Peters, Marth, Kahlenborn, & De Haan, 2016); (Steg, 2008); (Steg & Vlek, 2009).

energy efficiency has no effect on consumption decisions on the energy service, they represent a factor that can reduce the rebound[28].

In addition to affecting direct rebound effects, psychological factors can produce indirect rebound effects. Thus Girod & de Haan (2009) develop a model according to Thaler (1999), in which individuals generate a rebound effect through the evaluation of actions by means of mental accounting. In this so-called mental accounting or moral accounting, goods, actions and transactions are mentally recorded in different accounts in order then to relate the aggregated costs and benefits to each other[29]. As a result, the purchase of a more efficient and more environmentally friendly product leads to a higher demand for other, more energy-intensive goods, as their consumption is now considered justified[30]. Accordingly, behavioral changes arise through the evaluation or balancing of ecologically motivated acts that conscientiously affect morally questionable behavior[31]. It is the construction of an inner moral account that balances altruistic and self-interested actions. In some cases, therefore, a moral licensing effect is used[32].

3. Challenges for environmental policy making

The previous analysis has shown that rebound effects can emerge and be influenced both economically and psychologically. It should be noted that different factors simultaneously influence the rebound behavior of consumers and these factors are often inseparable.

As the price effect comes from reducing the cost of energy services, it seems intuitive to use fiscal resources such as taxes to reduce rebound effects. These counteract cost reduction and thus overconsumption by keeping the prices for energy services at a constant level[33]. In the Handbook published by the Federal Environment Agency (2016), taxes and fees are explicitly recommended as a measure that can reduce the rebound effect. These are intended to reduce, in whole or in part, the financial savings due to efficiency, with the aim of reducing the additional purchasing power of the consumer. Furthermore, these fiscal measures generate an incentive for the consumer to consciously and economically use the taxed resources[34]. Santarius (2012, p. 20) also concludes that the use of an eco-tax to reduce rebound effects is expedient, whereby it refers

[28] cf: (Peters, Sonnberger, & Deuschle, 2012, S. 39f).
[29] cf: (Thaler, Mental Accounting Matters, 1999, S. 184f).
[30] cf: (Girod & De Haan, 2009, S. 11f).
[31] cf: (Santarius, 2015, S. 109).
[32] cf: (Santarius, 2012, S. 14).
[33] cf: (Sorrell, 2007, S. 93).
[34] cf: (Semmling, Peters, Marth, Kahlenborn, & De Haan, 2016, S. 19f).

exclusively to eco-taxes, while the Handbook of the Federal Environment Agency also takes into account taxes on renewable energies such as electricity. An approach to calculate the amount of a hypothetical tax on carbon dioxide (CO_2) is provided by the work of Brännlund et. al. (2007). Based on data from Swedish households, the authors estimate that in order to completely eliminate a rebound effect of 25%, the CO_2 tax would have to be increased by about 130%. With the help of this tax, the gasoline prices are designed in such a way that, despite efficiency improvements, a constant total CO_2 emission is generated. However, it must be remembered that such measures alone are associated with low political acceptance by consumers.[35] However, the use of tax measures can not only prevent disincentives from price signals, but also change consumers' awareness of energy saving and counteract possible behavioral changes[36].

Tradable certificates are another way of achieving an increase in the price of an asset by creating an absolute cap. The effectiveness of this measure depends on the substitution possibilities of the higher-priced good with other goods.[37] However, the creation of an absolute pollution threshold may raise concerns, given the unsatisfied needs of consumers. In this regard, the study of Roy (2000) in the introduction of electrically powered solar lights in Indian households, which previously had no access to electrical energy, could show that among other things due to unsatisfied needs, in developing countries particularly high rebound effects from 50% to sometimes even 80% arise. Although low-income households have higher rebound effects, the focus of policymakers on rebounding measures should be on high-income households. Not only do they have greater room for consumption in general, but they also cause greater environmental pollution as a result of higher overall energy consumption[38]. A stronger burden of low-income households by fiscal instruments does not appear to be compelling, as only a low level of acceptance can be expected from this consumer group[39]. It is therefore important for environmental policies to account for the potentially unsatisfied needs of consumers. Thus, anticipatory and targeted energy-saving alternatives for satisfying needs must be identified and provided.

In addition to the economic factors, measures must also consider psychological factors of rebound effects. A change in the personal and social norms of the consumer can have a stabilizing effect on consumer behavior. This can be achieved by so-called *Nudging*. Nudging is a form of libertarian

[35] cf: (Sonnberger & Deuschle, 2014); (Mennel & Sturm, 2008).
[36] cf: (Wang, Han, & Lu, 2016, S. 360).
[37] cf: (Madlener & Alcott, 2011); (Semmling, Peters, Marth, Kahlenborn, & De Haan, 2016).
[38] cf: (Chitnis, Sorrell, Duckman, Firth, & Jackson, 2014); (Galvin, 2015); (Murray, 2013).
[39] cf: (Wang, Han, & Lu, 2016, S. 360).

paternalism designed to steer consumers in a particular direction without the need to enforce decisions through the use of regulations or prohibitions. While these non-monetary incentives in decision-making situations should help people make more rational choices, ultimately individuals still have a free choice as to whether or not to follow these incentives[40]. Sunstein (2014, p. 586) argues that most people use the behavior of others, which is commonly considered normal, as the benchmark for their own moral sense. A possible approach to nudging would be, for example, to provide consumers with the anonymous billing of energy and water consumption of comparable households. These data then provide a kind of orientation mark for the individual and can change their norms in such a way that rebound effects are reduced.

Otto et. al. (2014, p. 104) conclude with regard to the personal norm that the attitude of a person and the resulting actions are decisive for environmentally friendly behavior. They argue that only by a strong intrinsic motivation to save energy the rebound effect can be combated, otherwise time and resources are used to increase one's own benefit.

In the light of the psychological factors for rebound behavior, consumers should be alerted to this issue of indirect rebound effects as a result of their behavioral choices[41] and consumers' environmental awareness strengthened[42].

Finally, consumers should be able to obtain clearer information in order to facilitate the optimal use of efficient technologies[43]. One possibility would be to provide consumers, through labeling requirements such as energy labels or labeling standards, with the necessary information about the products to prevent unconscious rebound effects[44]. However, these must be defined that clear that consumers do not need much time or effort when making a purchase decision in order to make a suitable and energy-efficient choice[45].

In addition to the policy measures already mentioned, various scientific research calls for a combination of different instruments as a means of limiting rebound effects[46].

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[40] cf: (Sunstein & Reisch, 2014, S. 582).
[41] cf: (Maxwell, McAndrew, Muehmel, & Neubauer, 2011, S. 61).
[42] cf: (Girod & De Haan, 2009, S. 22).
[43] cf: (Peters, Sonnberger, & Deuschle, 2012, S. 61).
[44] cf: (Vivanco, Kemp, & van der Voet, 2016, S. 119).
[45] cf: (Sonnberger & Deuschle, 2014, S. 25).
[46] cf: (Birol & Keppler, 2000); (Madlener & Alcott, 2011); (Santarius, 2012); (Vivanco, Kemp, & van der Voet, 2016); (Wang, Han, & Lu, 2016).

4. Conclusion

It has been shown that the factors influencing the rebound effect are diverse and complex, and therefore the implications of energy and environmental policies to counteract the rebound effect call for a mixed strategy of different instruments. Since the factors of influence are not mutually exclusive in their different forms, an increase in efficiency of an energy service can be caused by both financial and psychological incentives or a combination of both.

The reduction of rebound effects on the consumer side must therefore be considered interdisciplinarily with means and measures of economics, social science and psychology. As technological advances change the possibilities and thus the needs of consumers, it is necessary to supplement the conventional standard models accordingly. Likewise, above all, uniform measurement methods are required in order to be able to effectively combat the influencing factors and thus the development of rebound effects.

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