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How to deal with the rebound effect? A policy-oriented approach

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HIGHLIGHTS

- Policy inaction on the rebound effect issue is investigated for the case of Europe.
- Rebound mitigation strategies and policy pathways are proposed and analysed.
- Policy inaction is partly explained by the unsuccessful push from academics.
- The importance of policy design and policy mix for rebound mitigation is revealed.
- Economic instruments stand out in terms of rebound mitigation potential.

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ABSTRACT

Policy makers and environmental agencies have echoed concerns brought forward by academics about the need to address the rebound effect for achieving absolute energy and environmental decoupling. However, such concerns have generally not been translated into tangible policy action. The reasons behind this inaction are not fully understood, and much remains unknown about the status of the rebound effect issue on the policy agenda and policy pathways available. Such knowledge gaps may hamper the development of effective policies to address this issue. In this paper, we examine the extent to and ways in which the rebound effect is considered in policy documents and analyse thirteen specific policy pathways for rebound mitigation. The effectiveness of the pathways is scrutinised and conclusions are offered to mitigate rebound effects. The main policy conclusions of the paper are that an appropriate policy design and policy mix are key to avoiding undesired outcomes, such as the creation of additional rebound effects and environmental trade-offs. From the discussion, economy-wide cap-and-trade systems as well as energy and carbon taxes, when designed appropriately, emerge as the most effective policies in setting a ceiling for emissions and addressing energy use across the economy.

1. Introduction

Sustainable consumption policies worldwide are largely shaped by the notion of resource and environmental efficiency, i.e., seeking to reduce the amount of environmental pressures per unit of product (e.g., Kilowatt-hour) or function/service (e.g., energy services such as lighting) demanded. However, while energy and resource efficiency has been continuously increasing through history, largely due to technological innovation (Ayres and Warr, 2005; Smil, 2003), absolute environmental pressures for many indicators have continued to rise (e.g., primary energy consumption or raw material consumption) (Herring and Roy, 2007). This paradox can be explained using the IPAT equation concept devised by Ehrlich and Holdren (1971), which describes environmental impacts (I) as a product of population growth (P), affluence (A) and technology (T). Thus, according to the IPAT equation, technological improvements have not been able to offset pressures from increases in population and consumption.[1] In other words, while there has been a substantial relative decoupling (a decrease in the environmental impacts per unit of economic activity, observed through the 'technology' factor), absolute decoupling (an absolute decrease in environmental impacts, observed through the 'impact' factor) has not been achieved for most pressures. Moreover, an

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[1] While the term 'affluence', an indicator measuring economic activity as a whole, is generally measured in the literature as gross domestic product per capita, it is often assumed that it is consumption in a broader sense (economic activity other than the design, production and marketing of goods and services) that drives overall economic activity (Alcott, 2010).

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important body of scientific literature goes even further by describing a negative relationship between technology and consumption in some cases; that is, the rationale that improvements in technological efficiency (and, in a broader sense, efficiency improvements in general (Gillingham et al., 2015; Schaefer and Wickert, 2015)) have induced increases in consumption. This mechanism is generally known as the rebound effect theory, which has been defined as the additional energy consumption from overall changes in demand as a result of behavioural and other systemic responses to energy efficiency improvements (Binswanger, 2001; Brookes, 1990; Khazzoom, 1980; Saunders, 1992). An example of the rebound effect is the way in which fuel efficiency improvements in passenger cars have made driving cheaper, resulting in users driving more and buying bigger cars (direct effect) and/or spending the remaining savings on other products (indirect effect). As a result, total fuel and energy savings are reduced. In the latter case, we speak of a backfire effect (Saunders, 2000). When dealing with broader environmental aspects rather than energy use alone (as generally defined by the traditional energy economics literature), we speak of an environmental rebound effect. This re-interpretation of the original energy rebound effect allows for broader assessments as well as more comprehensive results in the context of environmental assessment (Font Vivanco et al., 2014a).

The existence and relevance of the energy or environmental rebound effect (hereafter referred to as the "rebound effect") has been acknowledged by many credible sources from both the academic and the public policy domains. Dozens of research studies have identified and empirically analysed the rebound effect since the early works of William Stanley Jevons (1865). Comprehensive and updated summaries of such findings can be found in Sorrell (2007), Jenkins et al. (2011). Likewise, various intergovernmental organisations and international agencies have also echoed concerns about the impact of the rebound effect on global sustainability. Some examples of concerned entities include the United Nations Environment Programme (UNEP, 2002), the International Energy Agency (IEA, 2012), the European Commission (EC, 2012b) and the European Environment Agency (EEA, 2013). These concerns, however, have generally not been translated into any tangible policy action (IRGC, 2013; Maxwell et al., 2011). The reasons behind this inaction are not fully understood, and much remains unknown about the status of the rebound effect issue on the policy agenda as well as the range of policy pathways[2] available. While qualitative research has yielded reasonable explanatory causes behind inaction (Levett, 2009; Nørgaard, 2008; Schaefer and Wickert, 2015), a still unexplored explanation relates to the role of the scientific community in shaping the policy agenda (Hempel, 1996). Regardless, the evidence currently available has spurred an emerging discussion on how to address the rebound effect through policy. Three policy strategies to mitigate the rebound effect can be distinguished: (1) economy-wide increases in environmental efficiency, (2) shifts to greener consumption patterns and (3) downsizing consumption (Girod et al., 2014). It is worth noting that while these strategies are also valid for broader environmental policies, in this article, they will be discussed only in the context of rebound mitigation. However, the complete range of policy pathways and how they relate to these strategies is generally unknown. Such knowledge gaps may hamper the development of effective policies to address the rebound effect.

This study aims to contribute to this growing field of research by addressing the following two general questions:

[2] By a policy pathway we mean the enforcement of any type of policy items from the policy cycle (e.g., agenda setting, formulation, decision-making, implementation and evaluation).

1. What is the state of play of the rebound effect issue on the policy agenda and what is the role of the scientific community?
2. What policy pathways are available and which of them could be more effective to mitigate the undesired consequences of the rebound effect?

The remainder of this article is organised as follows. Section 2 addresses the first research question and investigates the reasons behind policy inaction through a case study on the European Union (EU). The second research question is addressed in Section 3, which presents a number of general strategies and specific pathways for rebound mitigation and discusses their potential effectiveness. Section 4 presents a general discussion on the success of the European scientific community in introducing the rebound effect issue into the policy agenda and how to make rebound policies more effective. Section 5 concludes the article by discussing the value, limitations and potential impact of the findings.

2. The rebound effect as a policy issue: the case of the European Union

In this section, we address the first research question by seeking insight into the current policy inaction to address the rebound effect issue, focusing on the impact of the scientific community. For this, we focus on the EU legislation as a case study. While the EU states retain considerable legislative initiative on energy and other environmental issues, the exploratory nature of this study justifies the decision not to broaden the scope of our analysis. The objective of this exercise is to uncover to what extent the rebound effect is considered in EU policies (as revealed through policy document analysis), as well as to gain insight into the role of the scientific community. It is not the aim of this paper to systematically address the causes underlying policy inaction but rather to complement and contextualise previous qualitative research (Levett, 2009; Nørgaard, 2008; Schaefer and Wickert, 2015). The methodology consists primarily of a keyword search of the term 'rebound effect' through the EUR-Lex search engine (EC, 2014b) and a detailed analysis of the identified documents. Only those documents in which the term is used in the context of energy/environmental assessment are included, thus excluding alternative understandings (e.g., pharmacological). The EUR-Lex is an official service that allows the consultation of the Official Journal of the EU and provides the ability to search all types of legal acts, including treaties, international agreements, legislation and preparatory acts. Cross-citation analysis from the documents identified through the previous approach has also been carried out to survey other relevant documents in which the rebound effect is not explicitly mentioned, but alternative labels such as the 'take-back effect'. Lastly, experts with a publication record on the topic of rebound effect and policy analysis have been consulted to ensure that no relevant documents have been omitted in the previous analysis.

As of the writing of this study, a total of 35 legal acts acknowledge the existence of the rebound effect. From this survey, we observe that the rebound effect has increasingly found its way into the EU policy documents over almost two decades. The first mention of the rebound effect in a legal act appears in the year 1996 in a communication from the former Commission of the European Communities (CEC) entitled 'The information society: From Corfu to Dublin. The new emerging priorities' (CEC, 1996). In this communication, the CEC voiced concerns over the creation of additional demand for material consumption as a consequence of developments in information and communication technology (ICT). The issue was then ignored for a decade until it was brought

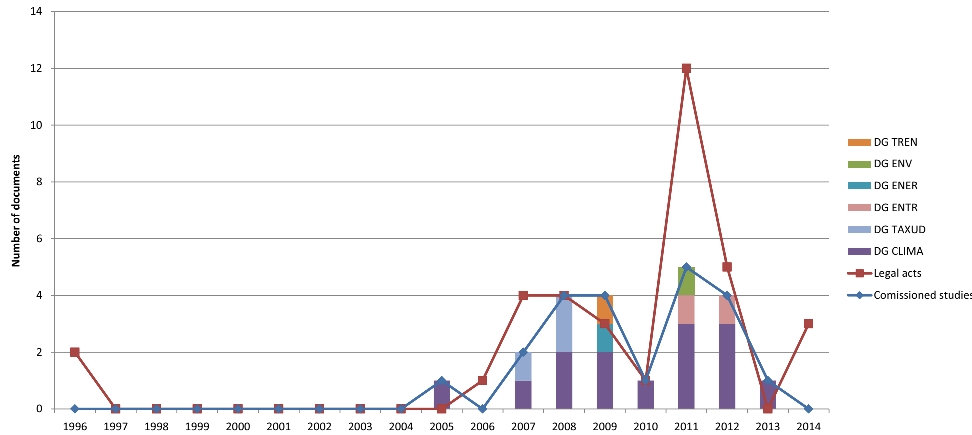

Fig. 1. Number of European Union legal acts and cooperative research studies commissioned by the European Commission in which the rebound effect is mentioned. Source: European Commission (2014b).

up again in 2006 in a Commission staff working document accompanying an impact assessment report for the Action Plan for Energy Efficiency 2006 (CEC, 2006). From then on, the rebound effect has been increasingly mentioned in various legal acts (see Appendix A for a complete list), mainly in working documents and opinions. The rebound effect is also mentioned (albeit briefly) in the report 'Global Europe 2050' by the European Commission (EC, 2012b). Only 6 legal acts can be considered to recommend some form of policy action to mitigate the rebound effect. For instance, the EC (2011b) suggested in a working document to manage demand by implementing appropriate measures in several policy areas to take full advantage of resource efficiency improvements. Also, another working document from the EC (2014a) outlined the need for a close monitoring of possible rebound effects and adequate action to address them. Finally, the EC (2009, 2012a) suggested economic mechanisms such as energy taxation to counteract the rebound effect. No binding act (regulation, directive or decision), however, explicitly mentions to the rebound effect and thus no corrective policy action has yet enforced.

While the rebound effect issue seems to be on the European policy agenda, how has it been introduced is still largely unknown. A plausible hypothesis is that the issue was actively promoted by the scientific community, as has happened with many other environmental issues (Hempel, 1996). In the European context, one of the most important channels between science and policy are cooperative research projects commissioned by the EC, the outcomes of which generally convey policy recommendations. To test whether such research projects have been used as a platform to introduce the issue into the policy agenda, we have analysed the correlation between legal acts and commissioned research studies that both mention the rebound effect (see Fig. 1; for a complete list, see Appendix A). The correlation is found to be positive and striking. To further analyse the causality, we have investigated whether the calls for tenders of the commissioned studies explicitly requested to address the rebound effect. We have found no reference to the rebound effect in those calls that are publicly available, which leads us to believe that the outcomes of these studies in terms of recommendations regarding the rebound effect somehow induced policy responses, and not the other way around. Policy recommendations have mainly targeted the Directorates Climate Action (DG CLIMA) and Taxation and Customs Union (DG TAXUD), with 14 studies (64% of the total) and 3 studies (14% of the total), respectively. It can be thus interpreted that these agencies are considered by the scientific community to be the most suitable to forward policy recommendations on the rebound effect issue.

The peak in 2011, with 12 legal acts and 5 studies, has been partly attributed to the impact of 'The Rebound Effect Report' by the UK Energy Research Centre (Sorrell, 2007), which spurred debate among academics, the media and policymakers (US, 2014). Also released in 2011 was the report of the project 'Addressing the rebound effect' (Maxwell et al., 2011), commissioned by DG Environment, which, summarises potential policy measures to address the rebound effect based on the outcomes of previous studies. This project can be interpreted as a turning point regarding the introduction of the rebound effect issue in the European policy agenda, serving as a reference for a number of posterior legal acts. From the year 2011 onwards, a sharp decrease in the presence of the issue in both legal acts and commissioned studies can be observed. The reasons for this decline are unclear.

3. Policy pathways for rebound mitigation

This section addresses the second research question posed in the introductory section by mapping the policy options available to address with the rebound effect and reflecting on their potential effectiveness. Section 3.1 exposes general strategies to mitigate detrimental rebound effects,[3] and Section 3.2 expands on this by describing how these strategies can be operationalised through specific policy pathways.

3.1. General strategies for rebound mitigation

The causes behind macro-level environmental pressures can be grouped under three general explanatory effects: technology, structure and demand effects (Leontief, 1970). Strategies to mitigate environmental issues can thus be classified according to the specific effect they aim to improve. Following this classification, and in the context of consumption-oriented rebound effects,[4] the available rebound mitigation strategies can be described as:

[3] In line with the general literature, this study focuses on the environmental consequences of the rebound effect. It is important to note, however, that rebound effects also have economic and social implications, and that in some contexts they can be seen as a way to manage social issues, such as energy poverty (Ürge-Vorsatz and Tirado Herrero, 2012). It is also important to note that 'positive' or 'conservation' rebound effects are also possible (Saunders, 2005), that is, cases in which the rebound effect actually leads to a net decrease in energy use and other environmental pressures.

[4] As explained in footnote 1, consumption can be understood as the main driver behind overall economic activity, and consumption-oriented policies can therefore be seen as more effective in addressing rebound effects.

(1) increases in environmental efficiency across consumption sectors, (2) shifts to greener consumption patterns and (3) downsizing consumption (Jackson, 2014). In simple terms, these can be referred to as 'consuming more efficiently', 'consuming differently' and 'consuming less', respectively (Sorrell, 2010). Below, we develop such strategies and their relevance in the context of rebound mitigation.

The strategy 'consuming more efficiently' aims at reducing the overall magnitude of positive rebound effects by improving, for instance, via technology, the environmental intensity (environmental pressures per monetary unit[5]) of consumption as a whole. An example would be the introduction of an energy efficiency improvement, for instance, a new transport fuel, which would lower the embodied energy intensity of all sectors. In such a case, the rebound effects stemming from other sectors (e.g., heating) would have a lower magnitude because the impact intensity of the liberated income will decrease and thus have a lower capacity to offset environmental gains. Being an efficiency-oriented measure, however, one potential issue is the creation of additional rebound effects through additional demand. The effectiveness of this strategy would thus largely rely on whether overall environmental gains are obtained, or in other words, on whether additional rebound effects are relatively smaller than the ones that are mitigated.

The strategy 'consuming differently' also targets decreasing the magnitude of rebound effects, but by inducing changes in consumption patterns towards products with less environmental intensity (e.g., electricity obtained solely from renewable energies). By doing so, the indirect rebound effect from other technological changes is expected to decrease. Another advantage is that it can induce changes in the consumption determinants (e.g., income) in a way that can minimise or even reverse the own rebound effect (negative rebound effect). For instance, the cost of electricity is likely to increase when it shifts to renewable sources, thus binding income and consumption. A shortcoming of this strategy, however, is that because environmental efficiency is not improved through innovation, rebound mitigation is limited by the current technology stock and the possibility of shifting between consumption products. An additional potential downside of this strategy is that reductions in the demand for products associated with high rebound effects do not necessarily lead to an overall decrease in environmental pressures, as economic savings can be allocated to other consumption with similar or even higher environmental intensities.

The strategy 'consuming less' aims at downsizing individual consumption. In the context of rebound mitigation, it seeks to avoid or minimise rebound effects by means of non-consumption, that is, by avoiding rebound effects from consuming new, improved products or minimising indirect rebound effects by self-limiting one's purchasing power (e.g., by reducing working hours). It can be achieved by either voluntary means (voluntary frugal behaviour, see Section 3.1) or involuntary means (e.g., command-and-control or economic instruments) resulting in an effective reduction of the purchasing power. While this strategy offers a simple and effective way to reduce rebound effects, a number of issues must be considered. For example, this strategy is not immune to new rebound effects (Alcott, 2008), and, regardless of whether it is voluntary or not, seems to be a strategy better suited for the wealthy, as only they have sufficient financial security to renounce their non-essential welfare.

[5] While we focus on price rebound effects, the same concept also applies to non-economic rebound effects (e.g. time or space).

3.2. Policy pathways for rebound mitigation

Published studies regarding policy pathways for rebound mitigation have been scarce to date, and efforts have generally focused on market-based instruments, mainly carbon and energy pricing (Saunders, 2011). Some authors, however, have identified a number of potential policy pathways, including non-market instruments. For instance, van den Bergh (2011) identifies five policy pathways for rebound mitigation in the context of energy conservation: (1) information provision and "moral suasion", (2) command-and-control, (3) price regulation, (4) subsidies and (5) tradable permits. Santarius (2012) describes four pathways: efficiency standards, ecotaxes, absolute caps and sustainability communication. Lastly, Maxwell et al. (2011) define six pathways: (1) design, evaluation and performance of policy instruments, (2) sustainable lifestyles and consumer behaviour, (3) awareness raising and education in business, (4) technology and innovation, (5) economic instruments and (6) new business models. The latter can be considered the most comprehensive study in terms of mapping and discussing policy alternatives for rebound mitigation known to date. Other relevant studies include the works of Sorrell (2007), the International Risk Governance Council (IRGC, 2013); Azevedo (2014), Ouyang et al. (2010), Levett (2009), Herring (2011), Freire-González and Puig Ventosa (2015).

While highly insightful, previous studies present scope for improvement as some potential policy pathways and relevant discussions were not approached. In this section, we attempt to complement the existing knowledge base in this regard. Moreover, we aim to establish the relationship between such pathways and the proposed general strategies described in the previous section. By doing so, we intend to gain insights into the effectiveness of policy pathways by analysing aspects such as potential synergies and trade-offs. Such an approach is framed within the second research question posed in the introductory section, which addresses the possible policy pathways for rebound mitigation and their potential effectiveness. Using a variant of the classification developed by Maxwell et al. (2011), we identify a number of policy pathways and classify them according to the type of instrument and the strategy that is ultimately targeted (see Table 1).

In the following sections, each pathway will be further explained and discussed drawing from practical cases and simulations from the literature. Each pathway is presented using the following structure: first, a general overview of the pathway, including a brief justification of why it is useful for rebound mitigation and a description with the help of practical cases; second, a discussion of the pathway's potential to effectively reduce rebound effects, including potential disadvantages, such as the creation of additional rebound effects, and, if possible, ways to overcome them.

3.3. Policy design

3.3.1. Recognition in policy design

The rebound effect issue has always been the object of academic debate, with multiple definitions and analytical approaches available (Sorrell, 2007). This has led to "very sparse empirical evidence that is currently sustaining the strong dispute over the importance of the rebound effects", which has often been "translated into the exclusion of the rebound effect matter in official policy analysis" (Mudgal et al., 2008: 144). Moreover, as introduced in Section 2, these uncertainties have been used by policymakers as a rationale to support inaction (CSES, 2012; EC, 2011a). Although this rationale seems widespread in the European context, some national governmental bodies have included rebound effect estimates in policy strategies and targets. After reviewing various empirical studies and consulting stakeholders (Maxwell et al.,

Table 1
Policy pathways for rebound mitigation according to the type of instrument and general strategy.

Type of policy pathway	Rebound mitigation strategy		
	Increased environmental efficiency – "consuming more efficiently"	**Consumption shifting – "consuming differently"**	**Downsize consumption – "consuming less"**
Policy design	Recognition in policy design		
	Broader definitions and toolkit		
	Benchmarking tools		
Sustainable consumption and behaviour		Consumption information Identity signalling Standardisation	Autonomous frugal behaviour
Innovation	Targeted eco-innovation		
Environmental economic policy	Energy/carbon tax		
	Bonus-malus schemes		
	Cap and trade schemes		
	Rebates and subsidies		
New business models	Product service systems		

2011), the United Kingdom (UK) Department of Energy and Climate Change decided to take into account the direct rebound effect when estimating the potential energy savings from domestic insulation and other measures. Concretely, such energy savings are reduced by 15% to account for the "comfort taking" effect (that is, the increase in internal temperature as a response to energy efficiency improvements). Another example is the Ireland's "National Energy Efficiency Action Plan 2014" (DCENR, 2014), which assumes a high rebound effect of 70% associated with the "comfort taking" effect in low-income households when calculating the outcomes of energy saving measures. Outside Europe, the U.S. Department of Energy includes a 10% rebound effect from car standards into its energy forecasting according to the IRGC (2013).

By acknowledging the energy and broader environmental savings that are lost due to the rebound effect, its recognition can aid in achieving environmental goals from policy measures, either by allocating extra resources or by fostering different technologies with lower associated rebounds (e.g., technologies with smaller changes in their total cost of ownership [TCO]). Empirical evidence supporting the effectiveness of this pathway, however, is not currently available. The potential disadvantages of this pathway include the expenditure of additional public resources dedicated to the calculation of rebound effects and the achievement of more ambitious objectives.

3.3.2. Broader definitions and toolkit

The rebound effect debate has often focused on its very definition, for instance, regarding the type of technical changes that can cause the effect (e.g., energy efficiency alone or wider environmental efficiency changes) or the consumption determinants leading to it (e.g. only economic factors related to prices and income or broader factors, such as time costs) (Font Vivanco and van der Voet, 2014). By defining the rebound effect in a way that broader effects can be included, for example through the 'environmental rebound effect' concept (Font Vivanco et al., 2014a), trade-offs can be considered in the policy design and additional resources can be allocated to mitigate unwanted effects. Moreover, the academic literature offers a panoply of methods to estimate the rebound effect, some being relatively complex and opaque, as is often the case with macroeconomic models (Sorrell, 2007). This makes communication and public engagement challenging and could deter policymakers from addressing the rebound effect. There is thus a need for relatively simple, transparent and ready-to-use tools to estimate rebound effects from policies. One example of such a tool is that developed by the UK Department of Energy and Climate Change (2014), which estimates the direct rebound effect or "comfort taking" effect from relevant energy-saving policies in its policy evaluation. This is done through a publicly available spreadsheet that allows users to enter estimates of direct rebound effects for different commodities such as electricity, gas and road transport and for domestic, commercial and industrial uses, either in absolute or relative terms. However, we have found no evidence of other similar tools to calculate other indirect or macro-economic effects.

There is currently no evidence supporting the effectiveness and feasibility of this pathway in terms of rebound mitigation. Some disadvantages may relate to the acceptance of broader definitions of the rebound effect considering current uncertainties and debate in both the scholarly and policy spheres, as well as the risk of overlooking complex macroeconomic rebound effects by developing tools that only capture narrow microeconomic effects.

3.3.3. Benchmarking tools

Rebound effect models sometimes require large amounts of data, e.g., data on environmental profiles or economic costs, to calculate magnitude estimates. Modelling exercises can thus become quite resource intensive. Given that any technological change or innovation can potentially lead to rebound effects, one challenge is to identify which of those innovations can lead to the most detrimental rebound effects (or the most favourable negative rebound effects) without having to compile all of the necessary data to run a model. One way to screen multiple innovations and benchmark them according to their relevance is to identify which parameters most influence the magnitude estimates and gather data only for those. This approach has been developed by Font Vivanco et al. (2015) in the form of an "enhancement/offsetting potential indicator" that places innovations in a two-dimensional indicator based on: (1) the change in available income from the use of an innovation and (2) the difference between the environmental intensity of the innovation and that of general consumption. By applying such a benchmarking tool, innovations that require policy attention can be identified more easily.

Again, due to the lack of experience in the use of such tools, there is currently no empirical evidence supporting their effectiveness in reducing rebound effects. Some disadvantages of this type of tool relate to the use of resources to gather all necessary data and the risk of overlooking additional key variables.

3.4. Sustainable consumption and behaviour

3.4.1. Consumption information

Modern literature from the social sciences considers the social and cultural dimension of consumption (Jackson, 2005), in contrasti with the traditional economic theories of consumer behaviour, which attributed exclusive explanatory power to income levels and prices (Brekke and McNeill, 2003). From this perspective, the existence of socio-psychological costs has been theorised, that is, the theory that any consumption entails non-economic costs to consumers (the value of a consumption factor other than money [e.g., time and information]) that are culturally and socially defined, including environmental values and attitudes (de Haan et al., 2005; Hofstetter et al., 2006; Jackson, 2005). In the context of rebound mitigation, an action with high potential to increase environmental awareness is to confront consumers with their individual consumption levels, such as through smart meters[6] and enhanced billing with additional information on consumption. The objective of this action is to reduce the direct rebound effect from efficiency improvements, especially for those products with high environmental intensity, such as heating, with the goal of allocating more resources to less environmentally harmful products through re-spending.

Smart meters and enhanced billing are found to reduce non-essential energy and water consumption in households. Concretely, Darby (2006) describes energy savings of approximately 5–15% due to the use of smart meters and up to 10% via enhanced billing, and Wright et al. (2000) reports energy savings of up to 10% due to enhanced billing. Further, according to House (2010), smart water meters would have decreased water consumption an average of 17%. As stated in Section 3.1, however, economic savings can be allocated to other consumption with similar or even higher environmental intensities (e.g., air travel), thus only partially decreasing the associated rebound effects. Therefore, it is important to raise awareness in both households and businesses so that reductions in consumption for the improved products (direct effect) are not invested in environmentally intensive consumption categories (Maxwell et al., 2011; Nørgaard, 2008; Druckman et al., 2011). There is also a need to counteract adverts that perhaps unknowingly aggravate rebound effects. Relevant examples are Tesco's campaign “Turn lights into flights” (Gillespie, 2009b) or Air miles' “Mobile recycling that gives you Airmiles” campaign (Gillespie, 2009a). A similar case is that of a power utility that encouraged customers to use the energy savings from low energy lamps to increase lighting consumption (Nørgaard, 2000). Policies aimed at correcting perverse green advertising are thus needed in combination with consumption information actions to achieve the desired environmental savings.

3.4.2. Identity signalling

Following modern theories of consumer behaviour, evidence shows that consumption does not only exclusively aim at fulfilling functional needs, but also at reinforcing conceptions of identity (Brekke and McNeill, 2003; Hurth, 2010). Products thus become a symbol through which to communicate or signal individual values to others (Levy, 1959). To function as a symbol, however, a product, or more precisely, the act of consuming it, must be visible to others (Sirgy, 1982). Visibility becomes thus crucial to determine the effect of identity signalling on product choices (Belz and Peattie, 2009). For people with an environmentalist identity (Hurth, 2010), signalling pro-environment values can be an effective way to promote the consumption of products associated with lower rebound effects.

There is evidence of the effectiveness of measures related to identity signalling. For example, Griskevicius et al. (2010) studied consumer choices for green products under various visibility constraints, concluding that a product's visibility is positively correlated with the chances of consumers switching to green products. For instance, participants were more likely to purchase a green product while shopping in a mall than when shopping online. One way to promote shifts towards more sustainable consumption may therefore be to increase the visibility of green products. This becomes especially crucial for those products whose purchase or consumption is barely observable, such as electricity. In this sense, Hanimann (2013) studied whether the presence of a visible symbol would influence consumers to choose renewable energy services instead of conventional electricity. The author concluded that a welcome gift with various visible elements (sticker, doorplate, email signature and a magnet) would increase demand for renewable electricity by 10–14% with respect to a control group. A key disadvantage of identity signalling measures are the high use of resources involved in consumer awareness campaigns, such as personnel and materials, as well as the need to coordinate the measures with the appropriate industrial sectors.

3.4.3. Standardisation

Standardisation has proven to be a successful tool in shaping behaviour towards more sustainable consumption patterns in several cases and can therefore be used to mitigate the size of direct rebound effects from efficiency-oriented innovations. Among the various types of standards, we focus on two in the context of rebound mitigation: technical standards and labelling standards. Technical standards lay down uniform engineering or technical criteria, methods, processes and practices, whereas labelling standards pertain to uniform labelling systems for consumer products. To be more effective, standardisation should be prioritised in those product categories with high environmental intensities, such as heating or transport, to offset the direct rebound effect.

Some relevant examples of technical standards in the context of energy use are those for the energy transmittance of glass in buildings (EN 410 and ISO 9050) or the thermal performance of solar collectors (ISO 9459); however, many options for technical standardisation still remain unexplored. For instance, Biermayr and Schriefl (2005) propose creating a standard for central heating systems so that they automatically turn down at night and regulate the indoor temperature according to the exterior temperature. The aim is to limit the amount of energy used to achieve similar levels of comfort. For transport, European emission standards have already been introduced (Kågeson, 2005), and future transport-related standards may relate to intelligent transport systems (ITS) (Williams, 2008), for instance, to public transport planning. Such standards could have an effect on reducing car travel.

Regarding labelling standards, according to Ecolabel Index (2014), there are at least 458 environment-related labelling standards (broadly referred as ecolabels) in the world and 235 in Europe. Some examples of widespread ecolabels in Europe are the EU ecolabel, the EMAS and the EU Energy Label. Ecolabels, however, are rarely based on life cycle data (only 23 in the world), which describes all of the upstream and downstream environmental impacts from products. These type of labels, also known as “footprint labels” (Weidema et al., 2008), can help consumers shift to more sustainable products on a life cycle basis. In the context of rebound mitigation, footprint labels can reduce the so-called life-cycle or embodied rebound effects (Sorrell, 2009), which are related to the upstream and downstream processes involved in the additional consumption.

Technical standards have often proven to be effective in shifting towards sustainable consumption patterns. For instance, in the context of transport, the European emission standards have proven to be successful in inducing technology change to limit automobile exhaust emissions (Kågeson, 2005). Regarding footprint labels, in a study on the effectiveness of carbon labelling of food, Gadema and Oglethorpe (2011) found a stated preference rate of 72% from supermarket shoppers for carbon labels. Ozkan (2011)

[6] Smart meters refer to consumption recording devices that enable two-way communication with the user or utility company and offer real time feedback on consumption.

studied the effects of carbon footprint labelling on the consumption of milk, finding that approximately 32% of the sample stated a preference to pay up to 5% for the milk they typically purchase if a label showed notable carbon reductions. The same study also found that approximately 21% of organic milk consumers would switch to conventional milk if a label showed that the latter entailed carbon reductions of more than 5%. A potential downside of technical standards is the decrease in economic competitiveness from key industrial sectors by forcing technical change. For labelling standards, a key issue could be the transmission of a clear message to consumers, or as noted by Gadema and Oglethorpe (2011), confusion in interpreting and understanding labels, which can significantly hinder their effectiveness.

3.4.4. Autonomous frugal behaviour

Autonomous frugal behaviour is based on the principle of sufficiency, which relies upon the notions of restraint and moderation of individual consumption (Princen, 2005). Sufficiency behaviour is based on two concepts: (1) it presupposes purchasing power, so that essential consumption (e.g., food or heating) is still possible after downsizing consumption and (2) it is driven by environmental motivation (Alcott, 2008). Sufficiency can be achieved by reducing one's purchasing power, for instance, by means of working or earning less (ibid). Such measures, often proposed within the 'degrowth' movement (Martínez-Alier et al., 2010), can notably reduce rebound effects by limiting one's real income and thus the impact of re-spending effects.

The effectiveness of sufficiency measures in terms of reducing environmental burdens from consumption, as well as of social benefits, has been demonstrated in the context of the reduction of working hours in developed countries (Hayden and Shandra, 2009; Knight et al., 2013; Rosnick and Weisbrot, 2007). While being a simple and effective way to mitigate the rebound effect, one of the principal barriers to the adoption of sufficiency-based strategies is its social acceptance, mainly because of the "consumption lock-in" phenomenon and various consumption habits that are difficult to overcome (Sorrell, 2010). To increase its social acceptance, it will likely require "collectively agreed objectives, priorities, procedures and constraints that are institutionalised through government action" (Sorrell, 2010: 1794). Additionally, these strategies are not immune to new rebound effects, as the decrease in demand for some products can lower their price and induce extra demand (Alcott, 2008).

3.5. Technological innovation

3.5.1. Targeted eco-innovation

The existence of the rebound effect should not hinder technological development aimed at increasing the environmental efficiency of products (eco-innovation), but rather shed light on which innovation areas have greater potential to achieve absolute decoupling. Existing evidence on the drivers of the rebound effect can help to determine which aspects are most important to prioritise between innovation areas. For instance, as Sorrell (2007), Herring and Sorrell (2009) note, the rebound effect tends to be larger for general purpose technologies, such as fuels, as they have strong complementarities with existing and new technologies and are transversally applied, leading to economy-wide rebound effects. Additionally, innovations that entail large cost savings[7] are also prone to larger rebound effects. For instance, Font Vivanco et al. (2014b) found that the notable cost reductions from diesel engines were an important explanatory factor of a backfire effect. In this sense, policies should focus on fostering innovations that entail moderate cost reductions or even cost increases to avoid large rebound effects. It bears noting that cost increases are not necessarily associated with decreases in utility, as higher quality products can be consumed, e.g., more durable products or mobility products, such as public transportation, that allow consumers to increase their comfort or save time (e.g., by means of tele working).

Evidence shows that targeted eco-innovation can effectively reduce the occurrence and size of rebound effects. Font Vivanco et al. (2015) analysed seven alleged eco-innovations in the context of passenger transport, from which only three would result in net environmental gains in terms of greenhouse gas (GHG) emissions due to the impact of re-spending effects. Thus, by analysing potential rebound effects, a selective promotion of effective eco-innovation is possible. This pathway, however, does not tackle systemic issues leading to rebound effects, such as market prices and consumer behaviour, and is thus limited by the existing technology stock.

3.6. Environmental economic policy instruments

3.6.1. Environmental taxation

When applied appropriately, pricing mechanisms,have proven to be a successful way to push consumers' and businesses' behaviour towards more sustainable practices (Sterner, 2003). In the context of the rebound effect, many authors claim that appropriate taxes could mitigate its magnitude, with energy and carbon taxes being the most popular formulations (Saunders, 2011). Two types of taxation approaches can be identified in the rebound literature: a product or sector-specific tax and a transversal tax across economic sectors. The first aims primarily at mitigating the direct effect from specific products or sectors, whereas the second aims at curbing both direct and indirect effects by means of general improvements in the environmental intensity of the economy as a whole.

Few studies have analysed the effects of environmental taxes from the point of view of rebound mitigation. Kratena et al. (2010) applied a micro-econometric approach to calculate the tax levels necessary to offset a combination of the direct and indirect effects from Austrian households for fuel (gasoline and diesel), heating and electricity. The tax levels required were found to be 7%, 80% and 60% of the pre-tax price, respectively. Further macroeconomic effects, however, were not studied. Saunders (2011) used a macroeconometric approach to estimate the sector-specific energy tax levels necessary to offset historic direct rebound effects in the U.S. economy. The study found differing tax levels between economic sectors, ranging from approximately 10% to more than 300%. The study concluded that a uniform tax would have differing success among sectors with respect to rebound mitigation. Additionally, the results of a uniform tax would result in a decrease of approximately 5% in economic output, unemployment and profits.

The results from Saunders (2011) show the detrimental consequences of a uniform tax on the economy, leading the author to suggest the use of sector-specific tax levels. Such individual taxes would minimise the decreases in total output, unemployment and profits, although they raise a number of practical issues (Maxwell et al., 2011). The author further suggests that these negative effects could also be mitigated by "using the tax proceeds to reduce employers' payroll taxes, thus reducing their labor costs" (Saunders, 2011: 10), similarly to the Climate Change Levy adopted in the UK[8]

[7] In the context of a broadly defined rebound effect, not only cost savings, but also any reduction in the consumption factors (e.g., time or space) would apply.

[8] The Climate Change Levy is an energy tax imposed on most energy users except domestic users, charities and low energy-intensive commercial users. The rates are applied on the basis of the consumption of electricity, gas and solid fuels. The revenue is used to fund various energy efficiency investments as well as to

(Pearce, 2006). Moreover, Saunders (2011) also simulated the impact of this redistributing scheme in the same case study, concluding that the economic costs of a uniform GHG tax on the macroeconomic indicators studied would have not only been effectively undone, but improved. Other authors suggest that the reinvestment of the tax proceeds should, in any case, avoid inducing economic growth, and propose additional options such as public investment in clean energy sources that help to achieve absolute decoupling or other natural capital enhancements (Druckman et al., 2011; Jenkins et al., 2011; Maxwell et al., 2011). The existing evidence, though scarce, suggests that a sector-specific environmental tax could be an optimal economic solution to mitigate the rebound effect, although how the tax proceeds are invested seems to be a crucial factor. Moreover, Sorrell (2007) argues that carbon/energy pricing must be calculated endogenously according to relevant variables (e.g., behavioural and market aspects), so that it increases progressively to accommodate new rebound effects.

3.6.2. Bonus-malus schemes

Bonus-malus schemes, also known as feebates or hypothecated taxes, are a variant of environmental taxes in which the tax proceeds are used to incentivise more sustainable choices, for instance, through subsidies. They have been proposed as a more flexible instrument for rebound mitigation than taxes owing to the possibility of both incentives and disincentives (Maxwell et al., 2011). Some examples of bonus-malus schemes can be found in the purchase of new appliances and cars.

The success of bonus-malus schemes appears limited. At first sight, a scheme applied to the purchase of new cars in France, through which buyers of CO_2 intensive cars were charged a tax whose proceeds are invested in subsidies for less carbon intensive cars, appeared environmentally beneficial in in terms of the CO_2 emissions per km of new vehicles (D'Haultfœuille et al., 2014). By performing a decomposition analysis based on empirical data, however, D'Haultfœuille et al. (2014) concluded that the scheme did not achieve the desired goal by leading to an overall increase in absolute CO_2 emissions, mainly due to the increase in the fleet size and the direct rebound effect. The authors also argued that the 'pivot point' dividing penalties from incentives and the magnitude of the rebates were inappropriately set and that a re-adjustment could lead to overall decreases in CO_2 emissions. Bonus-malus schemes can thus increase the efficacy of taxes but also add an extra layer of complexity in their design.

3.6.3. Cap and trade schemes

Cap and trade schemes share certain traits with environmental taxes. Under similar circumstances, the main difference is that while taxes set a price for a given product and the market determines the quantity of the associated environmental pressures, cap and trade schemes set a ceiling on a given pressure. The market then sets the price for the pressure and ultimately the products (Durning, 2009). Although similar in theory, a panoply of practical issues can make any one instrument more feasible than another (Hovi and Holtsmark, 2006). Cap and trade schemes are more attractive than taxes because they focus on the desired end (e.g., a decrease in absolute environmental pressures), rather than potentially problematic means (e.g., increased environmental efficiency) (Alcott, 2010; van den Bergh, 2011). In the context of rebound mitigation, cap and trade schemes are sometimes claimed to be "immune to rebound effects", as should "a rebound effect occur within one sector, the sector in question would have to buy allowances on the market, thus contributing to reductions elsewhere" (EC, 2014a: 29).

Cap and trade schemes have proven to be a cost-effective option to limit GHG emissions; one example is the EU Emissions Trading System (EU ETS) (Ellerman and Buchner, 2007). Some authors, however, reflect on the risk that the EU ETS and other schemes would discourage efficiency improvements and in some cases actually induce increases in overall energy and GHG emissions because allowances remain constant irrespective of the overall efficiency of the affected system (Chitnis et al., 2013; Sorrell and Sijm, 2003). Thus, if a participant implemented an efficiency improvement, allowances would free up and be available for other participants in the scheme. The limited scope of this scheme has also been subject to discussion. For instance, some authors propose its extension to road transportation, which is currently not included (Flachsland et al., 2011). Such an extension could be a technically feasible and effective way to reduce economy-wide GHG emissions (EC, 2014a). Regarding the statement that these schemes are immune to rebound effects, this would hold true only if (1) the cap and trade scheme encompasses all of the economic sectors, (2) only direct emissions are considered and (3) other environmental pressures are disregarded. Otherwise, the rebound effect could appear in other economic sectors through indirect effects, in upstream processes of the supply chain (e.g., situated in other countries) or through other environmental pressures. Therefore, the design of the cap and trade scheme will largely determine whether rebound effects would in fact be completely offset. Moreover, their impact on other indicators, such as the total output or employment, remains largely unknown (Jorgenson, 1984; Sorrell and Dimitropoulos, 2007).

3.6.4. Rebates and subsidies

Environmental rebates and subsidies incentivise changes in consumption by rewarding consumers choosing environmentally friendly products. These rewards can be in the form of refunds or reductions in the effective price of products (e.g., via purchasing cost). Some examples in the European context are energy efficiency rebates (Speck, 2008) or subsidises for the purchase costs of electric cars (Kley et al., 2012). Rebates and subsidies present the advantage of being generally more socially accepted than other "command and control" instruments such as taxes or cap and trade schemes (Nilsson et al., 2004).

The effectiveness of these instruments in the context of rebound effect mitigation is largely unknown. While they have been praised for reducing relative environmental pressures in some cases (Andersen and Sprenger, 2000), they also have been criticised for sometimes failing to address absolute decoupling, for instance, by inducing rebound effects, including the stimulation of economic growth (Chandra et al., 2010; Kampman et al., 2011). In this sense, some aspects need to be considered in their design. First, direct rebound effects can be minimised by conditioning the rebate magnitude to the use of the product. For example, the rebate for energy-efficient products can be determined according to the quantity of energy consumed (Irrek et al., 2010). Second, rebates can reduce the TCO of more efficient products, leading to both direct and indirect rebound effects. Moreover, because consumers have a subjective perception of costs and benefits, the concept of economic reward may change the equilibrium point between alternatives (Kampman et al., 2011). Rebates and subsidies can thus be a socially accepted way to induce changes in consumption, but the potential for creating new rebound effects via re-spending is high unless, for instance, the revenues for such programmes come from the taxation of environmental harmful activities. In contrast to environmental taxes, the responsibility for how the additional expenditure is spent lands with the consumers, which may not prioritise the reduction of rebound effects or environmental pressures in general. Therefore, the overall benefit

(*footnote continued*)
reduce the employer's rate in the National Insurance by 0.3%.

would depend upon whether the new rebound effects are larger or smaller than the decrease in magnitude of the existing ones.

3.7. New business models

3.7.1. Product service systems

Product service systems (PSS) have been defined as “a marketable set of products and services capable of jointly fulfilling a user’s needs” (Goedkoop et al., 1999: 18), and PSS-oriented business models have been proposed as an alternative to achieve the material and energy decoupling of the economy (Goedkoop et al., 1999). Some relevant examples are car sharing schemes or laundry services, among many others (Mont, 2004). In the context of rebound effects, PSS have the potential to reduce indirect effects by enabling consumers to meet their needs using less resource intensive options (Maxwell et al., 2011).

The environmental performance of PSS in the context of rebound effects has been not explored. Being a generally efficiency-oriented measure, however, warnings about induced rebound effects have been raised (Manzini and Vezzoli, 2003). For instance, outsourcing can lead to careless behaviours (Manzini and Vezzoli, 2003), and economic savings can lead to direct and indirect rebound effects. Font Vivanco et al. (2015) studied the direct and indirect rebound effects in terms of global warming (GW) emissions (in CO_2 eq.) from car sharing schemes in Europe for the period from 2000 to 2010. The results showed a combined rebound effect of 135%, meaning that all GW emissions savings were offset and emissions even increased (backfire effect). The authors explained the notable rebound magnitude mainly as a result of large decreases in the TCO and differences between the GW intensity (emissions per €) of CSS with respect to that of general consumption, which drove up the indirect rebound effect. Heiskanen and Jalas (2003); Suh (2006) also concluded that the environmental benefits of a shift towards a service-based economy are modest to none. The application and diffusion of PSS has also proven to a challenge, partly because of the difficulties in changing routinised behaviour (Tischner et al., 2010). According to one estimate, approximately 80% of daily consumption choices stems from routinised behaviour (Tischner, 2012). This challenge must be considered and addressed in policy design. In any case, similarly to previous instruments, PSS will be successful in mitigating the rebound effect inasmuch as significant new rebounds are not induced as a result of increases in the environmental efficiency of providing services. To achieve absolute decoupling, PSS can be combined with other tools, such as those based on consumer behaviour (see Section 3.2) or economic instruments (see Section 3.4).

4. Discussion

This section presents a general discussion of the research questions posed in the introductory section by analysing the insights gained in Sections 2 and 3. Section 4.1 reflects on the success of the scientific community in influencing the policy agenda, while Section 4.2 discusses ways to make rebound mitigation policies more effective.

4.1. The unsuccessful push from the scientific community to introduce the rebound effect issue into the policy agenda

The scientific community has been successful in raising attention about the rebound effect in science and in policy circles, but unsuccessful in inducing policy makers to introduce measures to contain and prevent rebound effects. Rebound effects are not considered in most environmental appraisals for policy and only occasionally in energy-environment-economy models. Notwithstanding a decade of warnings, research projects’ calls for tender rarely prompt the study of the rebound effect, limiting the policy activity to opinions and working documents that merely react to such warnings and rarely urge any tangible policy action. The rebound effect issue is thus far from being a consolidated, priority issue on the European policy agenda, and no legally binding legal act on the matter has yet been enforced. Although we have no knowledge of similar exercises in other geographical scopes, a simple search shows that this inaction may be generalised. For instance, the search for the term “rebound effect” in the United States Code of the U.S. House of Representatives (2014), the consolidated database of general and permanent laws of the United States (US), yields no results. Similarly, the same search in the Australian Government's “ComLaw” database (2014), a comprehensive collection of Commonwealth legislation, also yields no results.

The reasons for such inaction are likely to be manifold and of a diverse nature and scope. Ongoing academic debates about the definition and uncertainties of rebound estimates related to the complexity of the modelling approaches are often referred to in legal acts as reasons for inaction (CSES, 2012; EC, 2011a). However, the experience of national governments, for instance the UK, Ireland and the US (see Section 3.1), show that it is possible to actively address the rebound effect through policy under such circumstances. The ulterior motives may therefore be different, for instance, the difficulty of combining policies aimed at constraining demand with the current widespread GDP-based economic growth paradigm (Sorrell, 2010). Indeed, the predominant efficiency-oriented policies (those aimed at improving environmental burdens per economic output without questioning the latter) seem to offer an apparent win-win situation for governments. On the one hand, they generally offer relative decoupling of various environmental pressures, which is credited as proof of a successful environmental policy (e.g., decrease in passenger cars’ GHG emissions per km). On the other hand, they incentivise economic activity via increased demand (rebound effect) and technological innovation, which increases social welfare and drives up the GDP. Furthermore, the endorsement of efficiency by policymakers, in contrast to sufficiency strategies such as taxes, entails low levels of political risk because it does not challenge the existing status quo (Princen, 2005).

The bias towards efficiency-based policies can also be explained because they are better aligned with prevailing discourses of managerial and business efficiency (Levett, 2009; Schaefer and Wickert, 2015). This could explain, for instance, why the terms “energy conservation” and “energy savings” were progressively replaced by “energy efficiency”, because “this was more acceptable to conventional economics and established interests” (Nørgaard, 2008: 211). In this sense, Schaefer and Wickert (2015: 34) argue that efficiency has become “an unquestioned end in itself that organisations and managers relentlessly pursue, without realizing potentially counterfactual effects”, leading to an “efficiencysm” doctrine. The authors also describe two enabling conditions of this doctrine: (1) “interpretive flexibility”, or the social construction of efficiency potentials, leading to the erosion of established meaning structures and the reduction of reflexivity, among others; (2) and the “maximisation imperative” or the view of efficiency as a legitimate organisational goal (Roberts and Greenwood, 1997). Levett (2009) also suggests several other reasons why policy-makers struggle to deal with the rebound effect, such as the unpredictability of policy actions and the difficulty of obtaining evidence of their success in the context of complex and adaptive systems. Overcoming the current systems-myopia would thus entail changing the foundations of the prevailing rational approach to public policy.

4.2. Rebound policy effectiveness: design and synergies

This paper identifies a number of policy pathways available to address the rebound effect and which offer governments multiple alternatives. By analysing the advantages and disadvantages of each action, it becomes clear that there is no single optimal instrument and that appropriate design and policy mixes are key. An important aspect of the policy design is to take into account additional rebound effects and consider ways to mitigate such effects. Another important aspect is the formulation of the policy, as empirical evidence and simulations show. For instance, the success of a carbon tax in curbing emissions depends largely on how the proceeds are spent. Moreover, cap and trade schemes may simply shift environmental pressures if their scope is insufficient, or may disincentivise efficiency improvements if the level of allowances disregard efficiency changes in the affected system. It is also important to consider socioeconomic factors to avoid essential welfare losses through regressive policies, for example, by reducing employment or bounding income from low income groups (Chitnis et al., 2014). For instance, rebound effects can be seen under certain circumstances as a way to mitigate social issues such as energy poverty (Ürge-Vorsatz and Tirado Herrero, 2012). An optimal configuration, however, often relies on a knowledge base that is currently limited, as empirical evidence or evaluation studies on the actual effects of policy mixes are missing, which shows the need for further research and implementation.

Adequate combinations of policy pathways are crucial for an effective rebound policy. By classifying pathways according to three essentially different strategies, synergies can be better identified. It is recognised to a degree that sustainable consumption strategies adddressing the efficiency, structure and overall levels of consumption are needed in combination (Jackson, 2014). Thus, ideal combinations should attempt to use all available strategies to avoid trade-offs and maximise their effectiveness. The potential combinations are manifold, and in the following we describe a number of possible options. One possibility is the combination of economic instruments such as taxes with targeted technology eco-innovation to mitigate the magnitude of economic rebound effects from cost differences. Additionally, the use of consumer behaviour actions such as consumption information and standardisation to shift consumption patterns, may strengthen the effects of carbon taxes. Another example would be the introduction of more encompassing definitions for the rebound effect so that economic instruments, such as cap-and-trade schemes, do not result in shifting environmental burdens. Whereas all policies have a role to play, economic instruments, such as carbon taxes and cap-and-trade systems, have the greatest potential to reduce rebound effects and avoid burden shifting. They promote technological change as well as changes in demand, thus avoiding tradeoffs that are associated with efficiency gains.

5. Conclusions and policy implications

Empirical evidence prompts policy makers to address the rebound effect if their intentions to achieve absolute energy and broader environmental decoupling are genuine. Policy responses so far, however, have been scarce and too little ambitious, although a panoply of policy pathways and combinations of these are available. The ongoing academic debate on the uncertainties behind rebound estimates has sometimes been used to justify inaction, but more complex reasons may underlie such positions. Some important reasons are the inability to reconcile policies aimed at constraining demand with the existing GDP-based economic growth paradigm, the better alignment of efficiency strategies with prevailing managerial discourses and the lack of a systems perspective in policy that would allow policy makers to better predict and verify the success of a rebound mitigation policy. Meaningful rebound mitigation and environmental strategies in general may thus require a shift towards systems-literate policy action (Levett, 2009) as well as transformative changes in the current socio-economic structures (Sorrell, 2010).

The analysis has identified a number of practical experiences for rebound mitigation through policy, mostly from Europe and other developed countries. As van den Bergh (2011) notes, however, rebound mitigation policies are particularly relevant in developing countries, for instance, because of the relative high costs of energy or the lack of saturation of consumption levels. Additionally, developing countries likely have a higher potential to introduce transformative changes due to the still developing or unstable socio-economic structures (Ayres and Simonis, 1994). For this reason, rebound mitigation strategies are likely to be more effective in these countries than in developed countries. However, aligning rebound mitigation policies in developing countries with the need to increase social welfare levels might be a challenge. These observations must be considered carefully in the context of global sustainability challenges and the increasing trend of industrial relocation to developing countries.

Lastly, most policy instruments are designed to tackle single environmental vectors, the most common being energy and GHG emissions (e.g., energy taxes and GHG cap and trade schemes). The rebound effect, however, ultimately relates changes in technical efficiency with changes in demand, with energy and GHG emissions being one environmental outcome of many possible outcomes. Thus, within the framework of the environmental rebound effect, that is, a change in demand that can be expressed through multiple environmental indicators, it is important to consider trade-offs between environmental pressures. Narrow definitions of the rebound effect can lead to a 'whack-a-mole'-type of game when addressing specific environmental issues through policy.

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Appendix A. Supporting information

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