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The rebound effect through industrial ecology's eyes : the case of transport eco-innovation

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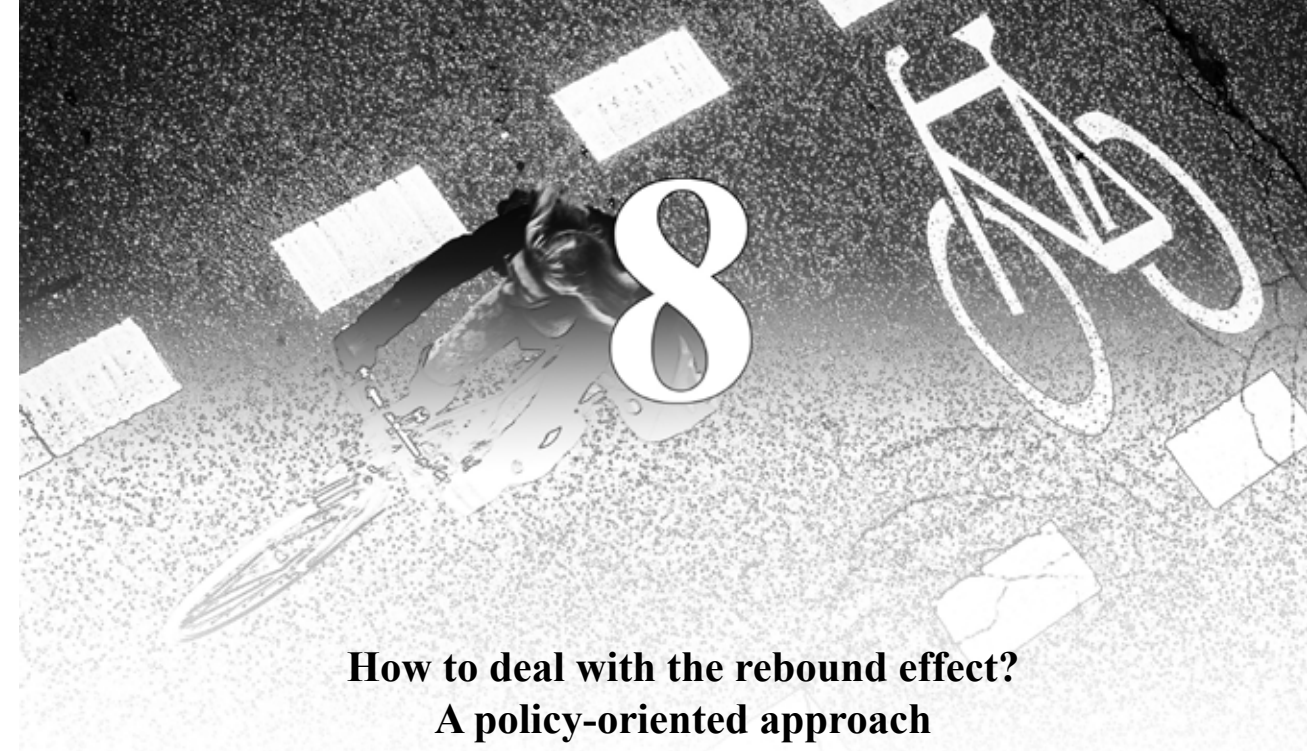


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**How to deal with the rebound effect?
A policy-oriented approach**

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

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Abstract

Policy makers and environmental agencies have echoed concerns brought forward by academics over 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 such inaction are not fully understood, and much is still unknown about the status of the rebound effect issue in the policy agenda and the 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 which 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 is key to avoid 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 emerge as most effective policies in setting a ceiling to emissions and addressing energy use across the economy.

Keywords: rebound effect, consumption, environmental policy, energy efficiency, Europe.

1. Introduction

Sustainable consumption policies worldwide are largely shaped by the resource and environmental efficiency notion, that is, by pursuing to reduce the amount of environmental pressures per unit of product (e.g. Kilowatt-hour) or function (e.g. lighting) demanded. However, while energy and resource efficiency has been continuously increasing through history, mainly because of technological innovation (Ayres and Warr, 2005; Smil, 2003), absolute environmental pressures for many indicators have kept rising (e.g. primary energy consumption or raw material consumption) (Herring and Roy, 2007). Such paradox can be explained using the IPAT equation concept devised by Ehrlich and Holdren (1971), which describes the environmental impacts (I) as a product of population growth (P), affluence (A) and technology (T). Thus, improvements in technology have not been able to offset pressures from increases in population and consumption. In other words, while there has been a substantial relative decoupling, absolute decoupling has not been achieved for most pressures. Moreover, an important body of scientific literature goes even further by describing in some cases a negative relationship between technology and consumption, that is, the rationale that technology improvements 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 that of fuel efficiency improvements in passenger cars, which make driving cheaper, resulting in users driving more and buying bigger cars as well as spending the remaining savings on other products. As a result, fuel and energy savings are reduced or even completely offset. In the latter case, we speak of a backfire effect (Saunders, 2000). When dealing with broader environmental aspects instead of energy use alone (as generally defined by 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 relevancy of the energy or environmental rebound effect (from here on referred to as just “rebound effect”) has been acknowledged by many credible sources both from 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 on Sorrell (2007) and Jenkins et al. (2011). Likewise, various intergovernmental organisations and international agencies have also echoed concerns over the impact of the rebound effect on global sustainability. Some examples are the United Nations Environment Programme (UNEP) (2002), the International Energy Agency (IEA) (2012), the European Commission (EC) (2012b) or the European Environment Agency (EEA) (2013). However, such concerns have generally not been translated into any tangible policy action (IRGC, 2013; Maxwell et al., 2011). The reasons behind such inaction are not fully understood, and much is still unknown about the status of the rebound effect issue in the policy agenda as well as the range of policy pathways²¹ 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

21. 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).

agenda (Hempel, 1996). In any case, the overwhelming 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. It merits 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:

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

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

In this section, we try gaining insight into the current policy inaction to address the rebound effect issue. For this, we focus on the European Union (EU) legislation as a case study. 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 insights into the role of the scientific community. It is not the aim of this paper to systematically address the causes underlying policy inaction but 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 allows to search all kinds of EU legal acts, including treaties, international agreements, legislation or preparatory acts. Cross-citation analysis from the documents identified through the previous approach has also been carried out in order to survey other relevant documents in which the rebound effect is not explicitly mentioned, but alternative labels such as ‘take-back effect’.

From this survey, we observe that the rebound effect has increasingly found its way into the EU policy documents since almost two decades. The first mention of the rebound effect in a legal act can be traced back to 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 information and communication

technology (ICT) developments. The issue was then left out for a decade until it was mentioned 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 Supporting information S1 for a complete list), mainly working documents and opinions. Moreover, the rebound effect is also mentioned (though briefly) in the report ‘Global Europe 2050’ by the European Commission (EC) (2012b). As of the writing of this study, a total of 35 legal acts acknowledge the existence of the rebound effect, from which only 6 can be considered to prompt some form of policy action. 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. However, no binding act (regulation, directive or decision) provides an explicit mention to the rebound effect and thus no corrective policy action has been enforced so far.

While the rebound effect issue seems to be on the European policy agenda, how has it been introduced is still mostly unknown. A plausible hypothesis is that the issue was actively promoted by the scientific community, as it 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. In order 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 Figure 1; for a complete list, see Supporting information S1). 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 asked to address the rebound effect. We have found no reference to the rebound effect in those calls publicly available, which leads us to interpret that the outcomes of these studies in terms of recommendations regarding the rebound effect somehow induced policy responses, and not the other way around. By Directorate, Climate Action (DG CLIMA) and Taxation and Customs Union (DG TAXUD) lead the commissioning of research studies respectively with 14 studies (64% from total) and 3 studies (14% from total).

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 debates between academics, media and policymakers (US, 2014). Also in 2011 it was released the report of the project ‘Addressing the rebound effect’ (Maxwell et al., 2011), commissioned by DG Environment, which, from the experience of previous studies, summarises potential policy measures to deal with the rebound effect. This project can be interpreted as a turning point regarding the introduction of the rebound effect issue in the European policy agenda, being 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.

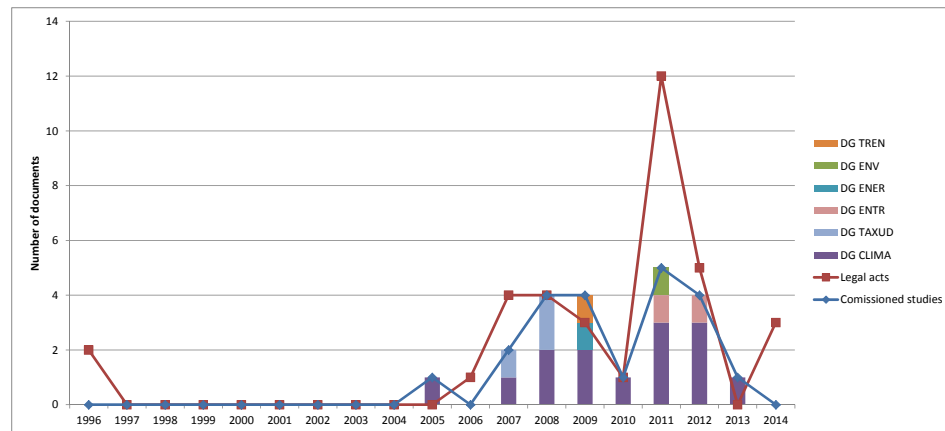


Figure 1. Number of European Union legal acts and cooperative research studies commissioned by the European Commission in which the rebound effect is mentioned. Source: European Commission (2014b).

3. Policy pathways for rebound mitigation

This section addresses the policy options available to deal with the rebound effect. Section 3.1 exposes general strategies to mitigate rebound effects, and section 3.2 expands on this by describing how can these strategies be operationalised through specific policy pathways.

3.1 General strategies for rebound mitigation

The causes behind macro-level environmental pressures can be summarised into 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, the available rebound mitigation strategies can be described as: (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). Following, 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 unit²²) 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 energy intensity of all sectors using directly or indirectly such fuel. In such a case, the rebound effects stemming from other sectors (e.g. heating) would have a lower magnitude since the impact intensity of the liberated income will decrease and thus have a lower capacity to offset environmental gains.

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

However, being an efficiency-oriented measure, a potential issue is the creation of additional rebound effects through additional demand.

The strategy ‘consuming differently’ also targets decreasing the magnitude of rebound effects, but in this case by inducing changes in consumption patterns towards products with less environmental intensity (e.g. electricity obtained from renewable energies alone). By doing so, the indirect rebound effect from other technology changes is expected to decrease. Another advantage is that it can induce changes in the consumption determinants (e.g. income) in a way that the own rebound effect can be minimised or even reversed (negative rebound effect). For instance, the cost of electricity is likely to increase when shifted to renewable sources, thus binding income and consumption. However, a shortcoming of this strategy is that, since environmental efficiency is not improved through innovation, rebound mitigation is limited by the current technology stock and the possibilities to shift between consumption products.

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. It can be achieved either by voluntary means (voluntary frugal behaviour, see section 3.1) or by nonvoluntary 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, whether voluntary or not, seems a strategy more suited for the wealthy, as only they have enough financial security to renounce to non-essential welfare.

3.2 Policy pathways for rebound mitigation

The study of policy pathways for rebound mitigation has been scarce so far, and efforts have generally focused on market-based instruments, mainly carbon and energy pricing (Saunders, 2011). Some authors, however, have identified a number of 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 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) and Freire-González and Puig Ventosa (2015).

While highly insightful, previous studies present scope for improvement as some potential policy pathways and relevant discussion 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 deals with 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 on the potential of the pathway to effectively reduce rebound effects, including potential disadvantages such as the creation of additional rebound effects and, if possible, ways to overcome them.

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 Standardization	
			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		

3.1 Policy design

3.1.1 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 been often “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., 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 to 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 to achieve environmental goals from policy measures, either by allocating extra resources or by fostering different technologies with lower rebounds associated. However, empirical evidence supporting the effectiveness of this pathway is currently not available. Potential disadvantages of this pathway include the expenditure of additional public resources dedicated to the calculation of rebound effects and to the achievement of more ambitious objectives.

3.1.2 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 it (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 instance 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, there is a panoply of methods to estimate the rebound effect, some being relatively complex and untransparent, as is often the case with macroeconomic models (Sorrell, 2007). This aspect might 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. An example of such a tool is the one developed by the Department of Energy and Climate Change (2014) of the UK government, which estimates the direct rebound effect or “comfort taking” effect from energy saving policies through a publicly available spreadsheet. 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 rebound effect considering current uncertainties and debate both in scholarly and policy spheres, as well as the risk of overlooking complex macroeconomic rebound effects by developing tools that only capture narrow microeconomic effects.

3.1.3 Benchmarking tools

Rebound effect models sometimes require large amounts of data to calculate magnitude estimates. For instance, data on environmental profiles, economic costs or econometric estimates. Modelling exercises can thus become quite resource intensive. Given that any technological change or innovation can potentially lead to rebound effects, a challenge is thus to identify which of those innovations can lead to the most detrimental rebound effects (or most favourable negative rebound effects) without having to compile all necessary data to run a model. A way to screen through multiple innovations and benchmark them according to their relevance is to identify which parameters influence the most 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 placed 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 need 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.

3.2 Sustainable consumption and behaviour

3.2.1 Consumption information

Recent literature from social sciences consider the social and cultural dimension of consumption (Jackson, 2005), contrasting with the traditional economic theories of consumer behaviour, which attributed exclusive explanatory power to income levels and prices (Brekke and McNeill, 2003). From such a perspective, the existence of socio-psychological costs has been theorised, that is,

the theory that any consumption leads to costs 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 rise environmental awareness is to confront consumers with their individual consumption levels, especially for products with high environmental intensity such as heating or water consumption. For instance, through smart meters²³ and enhanced billings with additional information on consumption.

Smart meters and enhanced billings are found to reduce non-essential energy and water consumption in households. Concretely, Darby (2006) describes energy savings of about 5-15% due to the use of smart meters and up to 10% via enhanced billing, and Wright et al. (2000) reports energy savings up to 10% due to enhanced billing. Also, according to House (2010), smart water meters would have decreased water consumption an average of 17%. However, a potential downside of these measures is that economic savings can be allocated to other consumption with similar or even higher environmental intensities (e.g. air travel), thus decreasing only partially the associated rebound effects. Therefore, it is important to raise awareness on 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). 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). Also, the case of a power utility that encouraged customers to use the energy savings from low energy lamps to increase lighting consumption (Nørgård, 2000). Policies aimed at correcting perverse green advertising are thus needed in combination with consumption information actions to achieve the desired environmental savings.

3.2.2 Identity signalling

Following with modern theories of consumer behaviour, evidence shows that consumption does not exclusively aim at fulfilling functional needs, but also to reinforce conceptions of identity (Brekke and McNeill, 2003; Hurth, 2010). Products thus become a symbol to communicate or signal individual values to others (Levy, 1959). However, to function as a symbol, a product or, more precisely, the act of consuming it, needs to be visible by 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 more sustainable consumption patterns and in turn mitigate 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. A way to promote shifts towards more sustainable consumption is thus to increase the visibility of green products. This

²³ 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.

becomes especially crucial for those products the purchase or consumption of which is barely observable, for instance 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 to 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.

3.2.3 Standardization

Standardization 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 rebound effects related to re-spending. 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, standardization should be prioritized in those product categories with high environmental intensities, such as heating or transport, in order to offset the direct rebound effect.

Some relevant examples of technical standards in the context of energy use are those for energy transmittance for glass in buildings (EN 410 and ISO 9050) or thermal performance of solar collectors (ISO 9459). However, many options for technical standardization still remain unexplored. For instance, Biermayr and Schriefl (2005) propose to create 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. However, ecolabels are rarely based on life cycle data (only 23 in the world), which describes all 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 towards more sustainable products on a life cycle basis. In the context of rebound mitigation, footprint labels can reduce the so-called embodied rebound effects, 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, Gadema and Oglethorpe (2011) found, on a study on the effectiveness of carbon labelling of food, a stated preference rate of 72% from supermarket shoppers for carbon labels. Ozkan (2011) studied the effects of carbon footprint labelling on the consumption of milk, finding that about 32% of the sample stated preferences to pay up to 5% for the milk they typically purchase if a label showed notable carbon reductions. The same study also found that about 21% of the 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 might be transmission of a clear message to consumers or, as pointed out by Gadema and Oglethorpe (2011), confusion in interpreting and understanding labels can significantly hinder their effectiveness.

3.2.4 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 either by not using one’s purchasing power or by reducing it by means of working or earning less (*ibidem*). Such measures 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, but also 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 hard 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). Also, 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).

3.3 Technological innovation

3.3.1 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 shed light on which innovation

areas have higher potential to achieve absolute decoupling. Existing evidence on the drivers behind the rebound effect can help to determine which aspects are most important to prioritize between innovation areas. For instance, as Sorrell (2007) and Herring and Sorrell (2009) point out, 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. Also, innovations that entail large cost savings²⁴ 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. For instance, 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. However, this pathway 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.

3.4 Environmental economic policy instruments

3.4.1 Environmental taxation

Pricing mechanisms, when applied appropriately, have proven to be a successful way to shape 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, being energy and carbon taxes 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 were, however, not studied. Saunders (2011) used a macro-econometric approach to estimate the sector-specific energy

tax levels to offset historic direct rebound effects in the U.S. economy. The study found differing tax levels between economic sectors, ranging from around 10% to more than 300%. The study concluded that a uniform tax would have differing success among sectors with respect to rebound mitigation. Also, the results of a uniform tax would describe a decrease of about 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, though they raise a number of practical issues (Maxwell et al., 2011). The author also 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 (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 re-investment of the tax proceeds should, in any case, avoid inducing economic growth, and propose additional options such as investments 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, though how the tax proceeds are invested seems to be a crucial aspect. 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.

3.4.2 Bonus-malus schemes

Bonus-malus or feebates schemes 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 in the purchase of new cars in France, through which buyers of CO₂ intensive cars were charged a tax the proceeds of which are invested in subsidies for less carbon intensive cars, appeared environmentally beneficial in terms of the CO₂ emissions per km of new vehicles (D’Haultfœuille et al., 2014). By performing a decomposition analysis based on empirical data, D’Haultfœuille et al. (2014) concluded that the scheme did not achieve the desired goal by leading to an overall increase in absolute CO₂ 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

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

CO₂ emissions. Bonus-malus schemes can thus increase the efficacy of taxes but they add an extra layer of complexity in their design.

3.4.3 Cap and trade schemes

Cap and trade schemes share certain aspects 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, and then the market sets the price for the pressure and ultimately, the products (Durning, 2009). Although similar in theory, a panoply of practical issues can make an instrument more feasible than the other (Hovi and Holtmark, 2006). Cap and trade schemes are more attractive than taxes because they focus on the desired end (e.g. 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”, since would “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, for instance the EU Emissions Trading System (EU ETS) (Ellerman and Buchner, 2007). However, the limited scope of this scheme has been the subject of discussion. For instance, some authors propose its extension to road transport, which is currently not included (Flachsland et al., 2011). Such extension could be a technically feasible and effective way to reduce economy-wide GHG emissions (EC, 2014a). On the statement that these schemes are immune to rebound effects, this would hold true only if (1) the cap and trade scheme encompasses all the economic sectors, (2) only direct emissions are considered and (3) other environmental pressures are disregarded. Otherwise, the rebound effect could show in other economic sectors through indirect effects, in upstream processes of the supply chain (e.g. situated in other countries) or expressed through other environmental pressures. Therefore, the design of the cap and trade scheme would largely determine whether indeed rebound effects would be completely offset. Moreover, their impact on other indicators such as total output or employment remains largely unknown (Jorgenson, 1984; Sorrell and Dimitropoulos, 2007).

3.4.4 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 subsidies in the purchasing 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.

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 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 total cost of ownership (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 rewarding 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 is high unless the revenues for such programmes come from the taxing of environmental harmful activities. Therefore, the overall benefit would depend upon whether the new rebound effects are larger or smaller than the decrease in magnitude of the existing ones.

3.6 New Business Models

3.6.1 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 material and energy decoupling of the economy (Goedkoop et al., 1999). Some relevant examples are car sharing schemes (CSS) or laundry services, among many other (Mont, 2004).

The environmental performance of PSS in the context of rebound effects has been not explored. However, being a generally efficiency-oriented measure, 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 CO₂ eq.) from CSS in Europe for the period 2000-2010. 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) and 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 routinized behaviour (Tischner et al., 2010). According to one estimate, around 80% of every day consumption choices stems from routinized behaviour (Tischner, 2012). 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

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 to the rebound effects in science and in policy circles but unsuccessful in making policy makers 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 react to such warnings and that rarely urge for any tangible policy action. The rebound effect issue is thus far from being a consolidated, priority issue in the European policy agenda, and no legally-binding legal act has been enforced so far. Even though 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 of 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" (2014), a comprehensive collection of Commonwealth legislation, yields no results either.

The reasons for such inaction are likely to be manifold and of diverse nature and scope. Ongoing academic debates about the definition and uncertainties of the 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 deal with the rebound effect through policy under such circumstances. The ulterior motives can thus be other, for instance, the difficulty to combine policies aimed at constraining demand with the current widespread GDP-based economic growth paradigm (Sorrell, 2010). Indeed, predominant efficiency-oriented policies (those aimed at improving the 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", since "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 a certain "efficiencyism" 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 other; (2) "maximization 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 to obtain 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 deal with the rebound effect, which offer governments multiple alternatives. By analysing the advantages and disadvantages from each action, it became clear that there is no single optimal instrument, and that appropriate design and policy mixes are key. An important aspect in the policy design is to take into account additional rebound effects and think of 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. It is also important to consider socioeconomic aspects in order to avoid essential welfare losses, for example, by reducing employment or bounding income from low income groups. However, an optimal configuration relies often on a knowledge base that is currently limited, 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 identified more easily. It is recognised to a degree that sustainable consumption strategies dealing with the efficiency, structure and overall levels of consumption are needed in combination (Jackson, 2014). Thus, ideal combinations should try to make use of all strategies in order to avoid trade-offs and maximise their effectiveness. The potential combinations are manifold, and in the following we describe a number

of possible options. For instance, the combination of economic instruments such as taxes with targeted technology eco-innovation to mitigate the magnitude of economic rebound effects from cost differences. Also, the use of consumer behaviour actions such as consumption information and standardization 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, are the ones that have the greatest potential to reduce rebound effects and avoid burden shifting. They promote technology changes as well as changes in demand, thus avoiding tradeoffs which are associated with efficiency gains.

5. Conclusions and policy implications

Overwhelming empirical evidence prompts policy makers to deal with the rebound effect if intentions to achieve absolute energy and broader environmental decoupling are genuine. However, policy responses so far have been scarce and too little ambitious, even though 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 position. 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 to better predict and verify the success of a rebound mitigation policy. Meaningful rebound mitigation and environmental strategies in general might 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. However, as van den Bergh (2011) points out, 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 have a likely higher potential to introduce transformative changes due to the still developing or unstable socio-economic structures (Ayres and Simonis, 1994). Because of this, rebound mitigation strategies are likely to be more effective in these countries rather 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, being the most common energy and GHG emissions (e.g. energy taxes and GHG cap and trade schemes). However, the rebound effect ultimately relates technical efficiency changes with changes in demand, being

energy or GHG emissions an environmental outcome of many possible. 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 game when addressing specific environmental issues through policy.

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Supporting information S1: Complete list of legal acts and commissioned studies

See next page

Table S1-1. Commissioned studies by the European Commission referring to the rebound effect.

Legal act's name	Author
Opinion of the Economic and Social Committee on: - the 'Communication from the Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions on the Information Society: from Corfu to Dublin - The new emerging priorities', and - the 'Communication from the Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions on the Implications of the Information Society for European Union policies - Preparing the next steps	European Economic and Social Committee
Commission staff working document accompanying document to the Communication from the Commission "Action Plan for Energy Efficiency: Realising the Potential". Impact assessment. SEC(2006)1174	Commission of the European Communities
Impact Assessment of a Proposal for a Directive of the European Parliament and of the Council modifying Directive 98/70/EC relating to the quality of petrol and diesel fuels	Commission of the European Communities
Commission staff working document accompanying document to the Communication from the Commission to the Council and the European Parliament Results of the review of the Community Strategy to reduce CO2 emissions from passenger cars and light-commercial vehicles	European Commission
Commission staff working document accompanying document to the Proposal for a Directive of the European Parliament and of the Council amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil that may be placed on the market and introducing a mechanism to monitor and reduce greenhouse gas emissions from the use of road transport fuels and amending Council Directive 99/32/EC to remove the elements setting the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC	European Commission
Accompanying document to the Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions - A European Strategic Energy Technology Plan (Set-Plan) - Capacities Map	Commission of the European Communities
Commission Staff Working Document accompanying the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "Public procurement for a better environment". Impact assessment	Secretary-General of the European Commission
Commission staff working document accompanying the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the Sustainable Consumption and Production and Sustainable Industrial Policy Action Plan	European Commission
Accompanying document to the proposal for a recast of the energy performance of buildings directive (2002/91/EC)	Commission of the European Communities
Energy efficiency: delivering the 20% target	Commission of the European Communities
Commission staff working document accompanying the Commission Recommendation on mobilising Information and Communications Technologies (ICT) to facilitate the transition to an energy-efficient, low-carbon economy	Commission of the European Communities
Opinion of the European Economic and Social Committee on Enhancing energy efficiency policies and programmes by end users (Own-initiative opinion)	European Economic and Social Committee
Opinion of the European Economic and Social Committee on the restructuring and evolution of the household appliance industry (white goods in Europe) and its impact on employment, climate change and consumers	European Economic and Social Committee
DG ENER - Impact Assessment on Energy Efficiency Action Plan	Impact Assessment Board, European Commission
Impact assessment accompanying document to the White Paper Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system	European Commission
Annexes to the impact assessment accompanying the document Directive of the European Parliament and of the Council on energy efficiency and amending and subsequently repealing Directives 2004/8/EC and 2006/32/EC	European Commission
Industrial Policy: Reinforcing Competitiveness	European Commission
Lighting the Future Accelerating the deployment of innovative lighting technologies	European Commission

Type of legal act	Year of publication	Link
Opinion	1996	http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:51996AC1401&from=EN
Commission Staff Working Document	2006	http://ec.europa.eu/smart-regulation/impact/ia_carried_out/docs/ia_2006/sec_2006_1174_en.pdf
Commission Staff Working Document	2007	http://ec.europa.eu/environment/air/transport/pdf/ia_sec_2007_55_en.pdf
Commission Staff Working Document	2007	http://ec.europa.eu/smart-regulation/impact/ia_carried_out/docs/ia_2007/sec_2007_0060_en.pdf
Commission Staff Working Document	2007	http://ec.europa.eu/smart-regulation/impact/ia_carried_out/docs/ia_2007/sec_2007_0055_en.pdf
Commission Staff Working Document	2007	http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52007SC1511&from=EN
Commission Staff Working Document	2008	http://register.consilium.europa.eu/doc/srv?!=EN&f=ST%2012041%202008%20ADD%201
Commission Staff Working Document	2008	http://ec.europa.eu/smart-regulation/impact/ia_carried_out/docs/ia_2008/sec_2008_2110_en.pdf
Commission Staff Working Document	2008	http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52008SC2864&qid=1408719006967&from=EN
Communication	2008	http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52008DC0772&from=EN
Commission Staff Working Document	2009	http://ec.europa.eu/smart-regulation/impact/ia_carried_out/docs/ia_2009/sec_2009_1315_en.pdf
Opinion	2009	http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52009IE1459&from=EN
Opinion	2009	http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52008IE1675&qid=1408719006967&from=EN
Opinion	2010	http://ec.europa.eu/smart-regulation/impact/ia_carried_out/docs/ia_2011/sec_2011_0281_en.pdf
Commission Staff Working Document	2011	http://ec.europa.eu/smart-regulation/impact/ia_carried_out/docs/ia_2011/sec_2011_0358_en.pdf
Commission Staff Working Document	2011	http://ec.europa.eu/energy/efficiency/eed/doc/2011_directive/sec_2011_0779_ia_annexes.pdf
Communication	2011	http://ec.europa.eu/DocsRoom/documents/112/attachments/1/translations/en/renditions/pdf
Green paper	2011	http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0889&rid=10

Legal act's name	Author
Opinion of the European Economic and Social Committee on 'The impact of the crisis on the ability of European firms to undertake pro-climate investments' (exploratory opinion)	European Economic and Social Committee
Executive summary of the impact assessment Accompanying the document Proposal for a regulation of the European Parliament and of the Council on Union Guidelines for the development of the Trans-European Transport Network	European Commission
Commission staff working document accompanying the Regulation establishing the Connecting Europe Facility	European Commission
Member State Competitiveness Performance and Policies	European Commission
Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Roadmap to a resource efficient Europe	European Commission
Opinion of the European Economic and Social Committee on the 'Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions — Energy Efficiency Plan 2011	European Economic and Social Committee
Summary of the impact assessment accompanying document to the communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions European Energy Efficiency Plan 2011	European Commission
Progress report of the Energy Efficiency Action Plan 2006 accompanying document to the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Energy Efficiency Plan 2011	European Commission
Impact assessment accompanying the document Proposal for a Decision of the European Parliament and of the Council on a General Union Environment Action Programme to 2020 "Living well, within the limits of our planet"	European Commission
DG MOVE- Impact Assessment on a proposal for a Directive of the European Parliament and Council amending Directive 96/53/EC on certain road vehicles circulating within the Community, the maximum authorised dimensions in national and international traffic and the maximum authorised weights in international traffic	Impact Assessment Board, European Commission
Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A Blueprint to Safeguard Europe's Water Resources.	European Commission
Communication Report on the Review of the water scarcity & droughts policy in the EU	European Commission
Impact assessment Accompanying the documents Proposal for a regulation of the European Parliament and of the Council amending Regulation (EC) No 443/2009 to define the modalities for reaching the 2020 target to reduce CO2 emissions from new passenger cars and Proposal for a regulation of the European Parliament and of the Council amending Regulation (EU) No 510/2011 to define the modalities for reaching the 2020 target to reduce CO2 emissions from new light commercial vehicles	European Commission
Impact assessment accompanying the document Strategy for Reducing Heavy-Duty Vehicles Fuel Consumption and CO2 Emissions	European Commission
Commission staff working document accompanying the document Commission Delegated Regulation amending Commission Delegated Regulations (EU) No 1059/2010, 1060/2010, 1061/2010, 1062/2010, 626/2011, 392/2012, 874/2012, 665/2013, 811/2013 and 812/2013 with regard to labelling of energy-related products on the Internet	European Commission

Type of legal act	Year of publication	Link
Opinion	2011	http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011AE1601&from=EN
Commission Staff Working Document	2011	http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011SC1213&rid=12
Commission Staff Working Document	2011	http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011SC1262&rid=14
Commission Staff Working Document	2011	http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011SC1187&from=EN
Communication	2011	http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0571&from=EN
Opinion	2011	http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011AE1180&from=EN
Commission Staff Working Document	2011	http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011SC0280&qid=1408719006967&from=EN
Commission Staff Working Document	2011	http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011SC0275&qid=1408719006967&from=EN
Commission Staff Working Document	2012	http://ec.europa.eu/smart-regulation/impact/ia_carried_out/docs/ia_2012/swd_2012_0398_en.pdf
Opinion	2012	http://ec.europa.eu/smart-regulation/impact/ia_carried_out/docs/ia_2013/sec_2013_0200_en.pdf
Communication	2012	http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52012DC0673&from=EN
Commission Staff Working Document	2012	http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52012SC0380&from=EN
Commission Staff Working Document	2012	http://eur-lex.europa.eu/resource.html?uri=cellar:70f46993-3c49-4b61-ba2f-77319c424cbd.0001.02/DOC_1&format=PDF
Commission Staff Working Document	2014	http://ec.europa.eu/smart-regulation/impact/ia_carried_out/docs/ia_2014/swd_2014_0160_en.pdf
Commission Staff Working Document	2014	http://ec.europa.eu/smart-regulation/impact/ia_carried_out/docs/ia_2014/swd_2014_0057_en.pdf

Table S1-2. Legal acts from European institutions referring to the rebound effect.

Project's name	Commissioned by
Interactions of the EU ETS with Green And White Certificate Schemes	DG CLIMA
Study on reduced VAT applied to goods and services in the Member States of the European Union	DG TAXUD
Possible regulatory approaches to reducing CO2 emissions from cars	DG CLIMA
Assessment and improvement of methodologies used for Greenhouse Gas projections	DG CLIMA

Publication year	Report's link
2005	http://ec.europa.eu/clima/policies/package/docs/ec_green_final_report051117_en.pdf
2007	http://ec.europa.eu/taxation_customs/resources/documents/taxation/gen_info/economic_analysis/tax_papers/taxation_paper_13_en.pdf
2007	http://ec.europa.eu/clima/policies/transport/vehicles/docs/technical_notes_ia_en.pdf
2008	http://ec.europa.eu/clima/policies/g-gas/monitoring/docs/ghg_projections_en.pdf

Project's name	Commissioned by
Reduced VAT for environmentally friendly products	DG TAXUD
A study on the costs and benefits associated with the use of tax incentives to promote the manufacturing of more and better energy-efficient appliances and equipment and the consumer purchasing these products	DG TAXUD
Model-based Analysis of the 2008 EU Policy Package on Climate Change and Renewables	DG CLIMA
Quantification of the effects on greenhouse gas emissions of policies and measures	DG CLIMA
Technical support for European action to reducing Greenhouse Gas Emissions from international maritime transport	DG CLIMA
Study on the Energy Savings Potentials in EU Member States, Candidate Countries and EEA Countries	DG ENER
TRANSvisions	DG TREN
Analysis of impact of efficiency standards on EU GHG emission	DG CLIMA
Addressing the rebound effect	DG ENV
Methodology for Ecodesign of Energy-related Products	DG ENTR
Support for the revision of Regulation (EC) No 443/2009 on CO2 emissions from cars	DG CLIMA
Impacts of Electric Vehicles	DG CLIMA
Public consultation on the role of agriculture and forestry in achieving the EU's climate change commitments	DG CLIMA
Evaluation of the Ecodesign Directive (2009/125/EC)	DG ENTR
Behavioural Climate Change Mitigation Options	DG CLIMA
Technical report accompanying the analysis of options to move beyond 20% GHG emission reduction in the EU by 2020: Member State results	DG CLIMA
Next phase of the European Climate Change Programme: Analysis of member states actions to implement the effort sharing decision and options for further community-wide measures	DG CLIMA
Consideration of alternative approaches to regulating CO2 emissions from light duty road vehicles for the period after 2020	DG CLIMA

Publication year	Report's link
2008	http://ec.europa.eu/taxation_customs/resources/documents/taxation/gen_info/economic_analysis/economic_studies/study_on_reduced_vat_for_environmental_friendly_products_en.pdf
2008	http://ec.europa.eu/taxation_customs/resources/documents/taxation/gen_info/economic_analysis/economic_studies/study_costs_benefits_bio_en.pdf
2008	http://ec.europa.eu/clima/policies/package/docs/analysis_en.pdf
2009	http://ec.europa.eu/clima/policies/g-gas/monitoring/docs/ghgpam_method_121209_en.pdf
2009	http://ec.europa.eu/clima/policies/transport/shipping/docs/ghg_ships_report_en.pdf
2009	http://ec.europa.eu/energy/efficiency/studies/doc/2009_03_15_esd_efficiency_potentials_final_report.pdf
2009	http://ec.europa.eu/danmark/documents/alle_emner/transport/090617_transportpolitik_rapport_task1_en.pdf
2010	http://ec.europa.eu/clima/policies/effort/docs/impact_ggas_en.pdf
2011	http://ec.europa.eu/environment/eussd/pdf/rebound_effect_report.pdf
2011	http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/methodology/files/meerp_methodology_project_report_en.pdf
2011	http://ec.europa.eu/clima/policies/transport/vehicles/cars/docs/study_car_2011_en.pdf
2011	http://ec.europa.eu/clima/policies/transport/vehicles/docs/d5_en.pdf
2011	http://ec.europa.eu/clima/consultations/docs/0003/final_report_en.pdf
2012	http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/review/files/ecodesign_evaluation_report_part1_en.pdf
2012	http://ec.europa.eu/clima/policies/roadmap/docs/main_report_en.pdf
2012	http://ec.europa.eu/clima/policies/package/docs/technical_report_analysis_2012_en.pdf
2012	http://ec.europa.eu/clima/policies/effort/docs/esd_case_studies_transport_en.pdf
2013	http://ec.europa.eu/clima/policies/transport/vehicles/docs/alternatives_en.pdf