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Industrial energy conservation, rebound effects and public policy



UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

DEVELOPMENT POLICY, STATISTICS AND RESEARCH BRANCH
WORKING PAPER 12/2011

Industrial energy conservation, rebound effects and public policy

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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna, 2011

Acknowledgements

This working paper was prepared by Professor Jeroen C.J.M. van den Bergh from ICREA and Universitat Autònoma de Barcelona as background material for the UNIDO Industrial Development Report 2011, under the supervision of Ludovico Alcorta, Director, Development Policy, Statistics and Research Branch, UNIDO.

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1. Introduction

This article will outline the problem of energy rebound and define its relevance for firm management and the design of public and governmental policies aimed at stimulating energy conservation and improvements in energy efficiency. Almost everyone appears to be in favour of energy conservation, especially when it is voluntary, as this is generally regarded as virtually costless, or as economists like to say: a free lunch. Most concrete proposals for reducing energy use are nevertheless very local and partial in nature. The rebound problem addressed in this part of the report suggests that one has to be sceptical or even pessimistic about cheap solutions or 'free lunches' regarding energy conservation. Rebound evaluation should be an essential part of sustainability thinking in the sense that system-wide effects must always be considered before judging any strategy or policy. Rather than just offering a pessimistic message about rebound, this article aims to provide an understanding of the rebound problem and offer suggestions for strategies and public policies in order to contain or reduce the rebound effect so as to maximize the efficiency of energy conservation.

Although this UNIDO report is concerned with industrial energy efficiency and conservation, an adequate treatment of the overall rebound effects and sensible policies requires that interactions between industry and consumers are taken into consideration. If not, the perspective will remain partial implying that certain rebound channels are overlooked and thus derived policy suggestions may turn out ineffective after all.

Rebound may be particularly relevant to industrial energy conservation in developing countries for a number of reasons. First, some of these countries show a high rate of growth, which means that they offer much potential for rapid accumulation of energy-using technologies and more energy-intensive consumption. The direction of development could in fact widely range from very energy-efficient to very inefficient - as opposed to industrialized countries, where this margin is likely to be narrower. Second, the cost of energy is relatively high for some poor countries, which may cause a relatively large financial gain to be associated with energy conservation and in turn, among others, a considerable re-spending effect, by both firms and consumers, among other things. The energy cost of production is relatively high due to low wages. Third, developing countries may "technologically leap-frog" in terms of energy efficient technologies as well as new energy using devices. Fourth, lower education and less availability of information in developing countries contribute to decision making by firms, households and governments that does not take all relevant economic and associated energy use effects into account. It should be noted, however, that private and public decision-makers in industrialized

countries are also largely unaware of the rebound effects of their decisions. One is even tempted to say that energy conservation is more driven by good intentions than by good insights.

2. Definitions and interpretations of energy and environmental rebound

"Energy rebound" denotes the phenomenon that greater energy efficiency, or plain energy conservation through changes in behaviour or choices (by firms or consumers), triggers additional energy use so that the net effect on total energy use over time becomes uncertain. Since we are concerned with definite solutions to serious environmental problems, like human-induced climate change, we need to assess the long-term and system-wide effects of any energy strategy to assess whether it makes sense from an energy conservation or environmental perspective. Improvements in energy efficiency may cause additional negative environmental effects when less energy use is characterized by more material use, more use of space/land, dangerous pollution (e.g., toxic materials), more transport and associated risks and noise, etc. This is sometimes referred to as shifting problems from one area to another, or "environmental rebound". A basic example is reducing air or water pollution but thus creating more solid waste, in line with the mass balance principle.

Rebound due to energy efficiency improvements (but not other types of energy conservation) may be understood in terms of technical engineering versus behavioural-economic phenomena. Here the initial energy savings are due to technical or engineering improvements in energy using equipment. This conservation then initiates or causes behavioural and economic responses - such as more intense use of more efficient equipment, re-spending saved money or diffusion of more efficient and therefore attractive technologies - which all together affects energy use.

Technical engineering improvements in energy efficiency are not the only possible starting point. Energy conservation can also result from changes in behaviour (less driving, lowering heating), which then can stimulate subsequent behavioural-economic changes that may partly or wholly undo the initial gains. The difference is that whereas with energy efficiency improvements the same functions or services can be fulfilled with less energy (exergy) inputs, in the case of energy conservation without efficiency improvements, the cost per unit of energy is not reduced and typically functions or services are altered (are reduced in size or number). Examples are fewer kilometres driven and a lower room temperature in the house. Energy efficiency improvements are therefore likely to generate rebound to a larger degree than other types of energy conservation.

Even though our concern should be with rebound on a global scale, it is clear that rebound is a phenomenon which occurs on multiple scales. When households or firms initiate energy conservation activities, these may cause additional energy use within their own sub-system, even without them being aware of it. One policy response could therefore be to make agents conscious or aware of rebound effects occurring within their own realm. In addition, rebound occurs at industrial park, urban, regional, national and international or global levels. Assessment of the rebound channels at each higher level becomes increasingly more difficult - both theoretically and empirically - because of more complex interactions and feedback mechanisms, and ever larger numbers of economic agents and activities. This motivates the uncertainty of rebound estimates, as will be discussed in more detail in Section 6. It also suggests that a system-level solution is needed to counter rebound.

Aside from rebound (effect), different terms have been employed to denote identical or similar notions or subsets of rebound effects: indirect or second-order effect, Khazzoom-Brookes effect, backfire and Jevons' paradox.¹ The latter two terms specifically denote 100 percent or more rebound, meaning that energy conservation ultimately gives rise to more energy use. Nevertheless, some authors use "Jevon's paradox" more generally, synonymously with "rebound" in general, i.e. without referring to a specific range of rebound effects. Other areas of research address similar issues referred to sometimes as "(carbon) leakage", notably in the context of climate mitigation policy, where the relocation of "dirty industries" (often to developing countries with less stringent environmental regulation) and associated changes in foreign trade flows cause initial, direct reductions in GHG emissions to be compensated by increases in GHG emissions elsewhere (Felder and Rutherford, 1993; Babiker 2001; Paltsev 2001; Kuik and Gerlagh, 2003). Eichner and Pethig (2009) refer to the "green paradox", meaning that policies aimed at curbing GHG emissions may aggravate rather than alleviate global warming.

The term rebound effect, although now quite widely accepted and precisely defined, is less popular among economists, who seem to prefer the more traditional notions of general equilibrium, economy-wide and macroeconomic effects. However, rebound really denotes a broader set of effects, as will become clear in the next section.

¹ Other, less common terms are take-back and snapback effects (Nadel, 1994).

3. Types of rebound pathways

As already indicated, rebound effects come in many different forms and therefore are not always easily recognized. The growing literature on rebound effects offers a range of classifications with different terminologies. A close to complete list of rebound mechanisms is as follows:

- More intensive use of energy-consuming equipment by current users because of higher energy efficiency and thus a lower effective energy cost; Sorrell et al. (2007a) calls this a direct rebound effect.
- Purchase of larger units or units with more functions/services and consequently more energy use (e.g., cars with air conditioning).
- Re-spending of financial savings on other energy-intensive goods and services (income effects).
- Creation of new demand (i.e. new users) due to a lower market price of energy if initial energy savings are considerable.
- Changes in the product lifecycle (virgin resource extraction, production/manufacturing, product use, waste treatment and reuse/recycling) affecting energy use in each phase and thus over the entire cycle; such effects may not be recognized because of split incentives (between firms or departments of firms).
- Substitution at the factor level (energy, capital, labour, materials) or product level (composition effects, notably the choice between energy-intensive versus -extensive goods).
- Improvements in the productivity of complementary production factors (capital, labour, materials) due to increased energy efficiency (Cashmir effect).
- Interactions between product, factor and financial markets due to changing prices/costs of energy.
- International trade and relocation effects.
- Capital investment and accumulation effects.
- Technological innovation and diffusion effects.
- Preference change in interaction with product or service innovation.
- Effects on energy embodied in new, more energy efficient technologies and products.
- Time effect of changes in the energy efficiency of technical equipment.

Note that economic growth and an associated increase in energy use are sometimes also cited. However, it seems more correct to say that many of the mechanisms named above contribute to economic growth, which is then not a separate, additional effect, but an aggregation of all effects.

Certain authors make a distinction between indirect effects, mainly income or re-spending effects, and economy-wide effects, covering price and quantity adjustment effects on all markets (intermediary and final goods/services). However, this distinction is not very convincing, as economy-wide effects really cover all possible effects, on inputs, productivity, incomes, expenditures, prices and quantities.

The energy embodied in products and services, i.e. all the direct and indirect energy needed to produce them, seems to be often forgotten, even though it may be relevant for technologies that diffuse widely. For instance, ICT (information & communication technologies), notably computers and internet, have often been suggested to reduce environmental pressure (the paperless office). However, their rebound effect may be significant, among others, because of considerable embodied energy effects (production of computer chips being very energy-intensive) and energy use involved in operating computers (van den Bergh et al., 2009). In addition, technological diffusion combined with preference changes are important, notably in relation to the diffusion of general purpose technologies (which affect or permeate the entire economy, like electric and combustion engines, the automobile, energy storage/batteries, ICT and the internet). Last but not least, from the perspective of industry relations, complex webs of firm interactions, long production chains and international logistics/transport may be very relevant to obtaining a full understanding of the rebound effect of industrial energy conservation. All in all, a complex picture of rebound pathways emerges.

The time effect of more energy efficient technology will influence rebound as well. If energy efficiency improvements are accompanied by (or cause) less time efficiency or cost more time in operating the technology (or travelling a certain distance, in the case of transport technology), generally a smaller rebound effect results. An increase in time efficiency, on the other hand, can generate a higher rebound effect (Binswanger, 2001; Sorell and Dimitropoulos, 2008). The latter seems to be the more common case.

Note that the above list contains 14 mechanisms. If 10 are operative and contribute only a 2 percent rebound on average, this would result in a 20 percent rebound.

One might argue that certain mechanisms are possibly too easily interpreted as rebound of energy conservation, namely because multiple factors are at stake. However, if energy conservation is an essential or necessary factor, it makes sense to regard the effect as rebound. Another argument is that rebound sometimes just rides on unmet demand that might have been fulfilled (later) in other ways, such as through regular income growth. This does not seem a convincing argument though, since the effect could be contained by a policy, as will be discussed later on.

4. Four fundamental reasons for the rebound phenomenon

To understand the nature of rebound effects and respond to them through management and public policy, one needs to understand their fundamental causes. For this purpose, I intend to elaborate on four views.

First, increased efficiency or conservation reduces limits that constrain the physical (energetic and material) dimensions of economies (Alcott, 2009). Limits relate to time, money, scarce resources, production factors, and space. By relieving such limits, the physical dimensions of the economy can grow so that it can capture more, or even maximize use of, energy/materials. In an analogous way, ecosystems focus on maximizing energy capture (Schneider and Kay, 1994).

A second view is based on recognizing the impact of improving the efficiency of general purpose technologies (Sorrell, 2009). This result in the diffusion of such technologies, which creates considerable economy-wide and dynamic effects, including the growth of existing sectors, the rise of new activities, processes and products, and associated emergence of demand and changes in consumer preferences. Technological history is full of examples, the steam engine being one: improvements in its efficiency gave rise to the diffusion of textiles, to transport and many other sectors. The same happened with electricity, chemicals and, currently, computers and mobile ICT equipment.

More generally, it seems that energy efficiency improvements in technology are associated with three important rebound channels that other types of energy conservation (changing behaviour) do not have: namely, direct rebound effects (more intense use because of a lower effective energy cost), diffusion of more efficient and therefore more attractive technologies, and general productivity effects. The latter covers increasing the productivity of other factors and relieving limits related to these, as explained under the first view. Note that all three rebound effects are stronger for general purposes than other technologies.

Alcott (2009) offers an interesting and detailed discussion of a third view on energy or environmental rebound effects based on the famous $I=P*A*T$ equation (Ehrlich and Holdren, 1971). This equation represents the environment impact (I) as being the product of three factors, namely population (P), affluence (A) and technological performance or efficiency (T). The latter factor captures increased efficiency, covering energy efficiency, which has the direct effect that it lowers I. However, P and A may change in response (indirect effects), which means the net effect on I is principally uncertain. Any 'right-hand' strategy or policy trying to reduce T (or P, A) will therefore run the risk of rebound: reductions in one factor can be followed by compensatory increases in others. Alcott instead proposes implementing 'left-hand' side or impact (I) caps, which are independent of P, A and T. Examples are physical caps or taxes on carbon-based energy harvesting and mining or on pollutive emissions, and limiting energy consumption per person (quotas, rationing) through personal carbon budgets, for example. We will consider the best choice in more detail in Section 7.

A fourth view relates to bounded rationality of individuals, households and firms. This expresses itself through agents showing myopia, habits, biases regarding responses to uncertainty, and "wrong/mistaken" goals. Much has been written on this already in relation to the energy gap, that is, the problem of profitable energy saving opportunities that are not or insufficiently being translated into concrete energy conservation actions. However, this problem may extend to rebound.

5. Empirical estimates of rebound

More research seems to have been devoted to energy rebound in relation to consumers/households than producers (industry/firms). The current report focuses the attention on energy conservation and efficiency improvements in industry. Nevertheless, much can be learned from both the mechanisms and magnitudes of rebound as assessed in studies oriented

towards consumers or households, since the basic energy saving strategies are similar, having to do with heating/cooling, transport, and use of electric equipment and other machinery (kinetic energy). Different types of studies (case studies, questionnaires, income/price-elasticity studies, statistical-econometric studies, general equilibrium modelling, etc.) offer distinct and possibly complementary angles.

A rigorous review by Sorrell (2007a) for the UK provides a summary of the main rebound estimates, the assumptions and conditions under which they hold and the shortcomings of the studies. The following empirical insights can be derived from it. Although there is much uncertainty about exact magnitudes, the available evidence shows that specific rebound effects or mechanisms vary widely between sectors and technologies. It is not possible to say whether direct rebound effects generally are larger or smaller than indirect effects. The direct rebound effect may be around 30 percent for many cases of household heating and cooling and lower for transport, although some studies report individual cases with much higher rebound rates. Indirect or economy-wide rebound effects may be around 10 percent, while they are often higher. Sorrell notes that various studies report indirect rebound effects greater than 50 percent. These findings mostly concern developed countries: for developing countries, the figures are likely to be higher, as argued in Section 1. A main reason is that rebound effects will typically be modest when the cost of energy is small compared to total costs or income. The latter suggests that rebound effects will differ between technologies and sectors in relation to energy/total cost ratios. In other words, sectors in which the production factor energy is relatively important are likely to show higher rebound effects in response to energy conservation efforts, *ceteris paribus*.

A caveat to all these results is that the empirical evidence is based on relatively few studies, few comparable studies and debatable models and data. Sorrell (2007a) and various other authors think that the empirical evidence is too weak to draw definite conclusions about the magnitude of rebound effects. For example, some studies find very high effects: e.g., Hanley et al. (2009) find that a general improvement in the energy efficiency of production sectors of the Scottish economy generates backfire; and Frondel et al. (2008) find fuel efficiency improvements to cause 57–67 percent rebound. In addition, several studies find relatively small rebound effects, in the range of 10–20 percent (Schipper and Grubb, 2000; Greening et al., 2000; Small and Van Dender, 2007). However, as will be discussed in the next section, these results need to be interpreted with care, as they are bound to be partial in many ways. The general question is why studies find such distinct rebound effects: is this because of unique local features or because of

methodological differences? Probably both factors play a role.

Table 1 illustrates four aggregate categories of energy-consuming activity indicators that allow a qualitative estimation of rebound effects of energy conservation. From the rebound mechanisms listed in Section 3, we can derive that important features to assess the potential rebound effect are the energy/total cost ratio, direct rebound effect (more intensive use of current equipment), productivity effect (or effect on other production factors), and technological diffusion effect. One can conclude from the table that most rebounds are likely to be associated with the activities of industrial processing and transport/logistics.

Table 1 Qualitative assessment of indicators of potential rebound for different energy consuming activities

Type of industrial energy consuming activity	Proportion of energy use	Energy conservation with or without efficiency improvement	Energy efficiency improvement		
		Energy/total cost ratio	More intensive use of existing equipment (direct rebound effect)	Productivity effect (effect on other production factors)	Technological diffusion effect (esp. general purpose technology)
Industrial lighting	Small	Small	Medium	Small	No
Refrigeration	Medium	Small	Small	Small	No
Air conditioning	Medium	Medium	Small	Small	Small
Space heating	Medium	Large	Small	Small	No
Water heating	Medium	Small	Small	Small	No
Industrial processing	Large	Large	Medium	Large	Medium
Transport and logistics	Large	Large	Large	Medium	Medium

Note: Activities like energy (electricity, oil, gas) generation, transformation and transport, and electric motors may also be included.

6. Uncertainty about empirical estimates: A lower bound to rebound?

There is not much disagreement that rebound is possible and likely. But there is debate over its magnitude. Various studies summarize the debate (e.g., [http://www.eoearth.org/article/Rebound effect](http://www.eoearth.org/article/Rebound_effect)). The relevance of policy to contain or reduce rebound effects is clear, irrespective of the precise magnitude of rebound. Nevertheless, it is interesting to know whether rebound is small (0–20 percent), significant (20–50 percent) or worryingly large (more than 50 percent) or even

counterproductive (more than 100 percent, or "backfire"). Current empirical research cannot settle this entirely, even though methodologically correct studies have estimated backfire for particular cases (e.g., Hanley et al., 2009).

Various authors argue that there are many reasons to believe, firstly, that an accurate estimation of rebound is very hard, and secondly, that many empirical studies of rebound have produced estimates that very likely underestimate the real effect, since upward biases are more noteworthy than downward ones (Polimeni, 2008; Sorrell, 2007a, 2009). To support this view, partial analysis, unclear system boundaries, uncertain and unobservable cause-effect chains, limited time horizons, neglect of international dimensions (trans-boundary effects, trade, relocation), and long-term dynamics (changing, endogenous preferences, technological change and diffusion, new products, capital accumulation and economic growth) are relevant. Many empirical studies of energy conservation and rebound depend heavily on price elasticity estimates. However, these reflect very partial and temporal indicators of behavioural responses to energy cost changes. Of all the rebound mechanisms identified in Section 3, several are difficult to assess empirically. More generally, the exact causality is difficult to trace or prove - decision makers themselves may not even be aware of it.

Polimeni et al. (2008) emphasize that system boundaries are not fixed, but rather continuously change as part of the almost inevitable, evolutionary drive of the system to capture more energy, to expand and to create new pathways of energy through the innovation and creation of new technologies, products, services and even preferences and sectors. Herring (2008) refers in this context to "transformation effects". Any reduction of energy use somewhere in the system will mean more available energy that will somehow be captured - similar to what is widely documented to happen with natural, ecological systems. To fully understand this point, one needs to delve into the difficult thermodynamics of living systems (Schneider and Kay, 1994). A similar approach is followed by Ruzzenenti and Basosi (2008), who argue that a good example is provided by the rise in the overall complexity of production characterized by more roundabout processes and outsourcing, in turn giving rise to an increase in freight transport and associated energy use.

Some authors have claimed a rebound at the macro or global level of more than 100 percent, also known as the Jevon's paradox (after Jevon's 1865 analysis of consumption and prices of coal) or "backfire" effect. A fierce position on this was taken in a recent book by Polimeni et al. (2008). However, it does not really offer a systems analysis, but rather ad hoc examples. As a result, correlation may be confused with causality, in particular income growth and

technological diffusion may be attributed too much to improvements in energy efficiency, rather than be recognized as autonomous phenomena.

Another factor contributing to uncertainty about total rebound effects is the precise role of energy in production, notably the degree of substitutability of energy by other production factors, the energy (exergy) embodied in such other factors - labour, capital, materials and land, and the effect of improvements in the productivity of capital, labour and materials due to energy efficiency improvements (Ayres and Warr, 2009). This is relevant for our context here, since if it is true that energy is largely complementary to other factors as well as a more important factor in production than recognized by most current economic models and studies, the improvements in its efficiency would increase the productivity of other factors, thus contributing to rebound more than is recognized by the majority of available economic models.

Other uncertainties or, at the very least, difficulties in assessment of rebound effects relate to capital costs and embodied energy of more energy efficient equipment. With regard to the first issue, improved technology generally is more expensive (in terms of investment/capital cost and sometimes also in terms of operation costs or input of other factors), in which case the direct (intensified use) and re-spending effects will be smaller. Embodied energy contributes to increase the rebound effect. However, its assessment requires taking into account all indirect use of energy throughout the economy, ideally using a perfect I/O table. In summary, although biases in estimating rebound can go either way, it is most likely that rebound is underestimated.

7. Policy responses to reduce or minimize rebound effects

Even though the magnitude of rebound is uncertain, the high likelihood that rebound often will be positive is sufficient reason for trying to reduce or even minimize it. The starting point for the analysis here is the set of fundamental reasons for rebound as discussed in Section 4. An important principle should be to make sure that limits are not relieved, neither physical, temporal, nor financial limits - at the individual and systems level. To realize this, policies should either integrate the stimulation of energy conservation/efficiency and minimization of rebound, or implement complementary rebound policies. For example, industrial, national or global standards or ceilings can pose an overall limit to pollutive emissions; price regulation means that financial or budgetary limits are made effective. This section will address the question of which advantages and disadvantages from the perspective of rebound are associated with the various instruments.

To take a robust starting point for policy analysis, let us consider a common typology of instruments to stimulate energy conservation: (i) information provision and "moral suasion" (fostering "voluntary action"), (ii) direct or physical regulations (standards for technology or buildings), (iii) price regulation (taxes, levies), and (iv) tradable permits (i.e. an overall ceiling combined with a price mechanism). There are two shortcomings associated with instruments (i) and (ii). First, they do not raise the costs of energy use per unit, so that in any case the direct and re-spending rebound effect will be considerable. Second, there is no ceiling, so that productivity effects, new preferences, technological diffusion and, ultimately, income growth can give rise to more consumption of energy services. A recent example of instrument (ii) is the abolishment of incandescent light bulbs set in motion by the EU - which can be judged as a good intentions, but as a possibly ineffective policy against the background just outlined. In addition, a practical problem of technical (emission or quality) standards is that each technology, product and service needs its particular piece of information, otherwise rebound will also involve shifts to products and technologies which fall outside the regulatory framework. With regard to instrument (iii), the first problem does not exist, but the second does. Only with instrument (iv) can both shortcomings or problems be avoided. This is summarized in Table 2.

Table 2 Impact of policy instruments on rebound

Instrument type	Rebound effects	
	Cost per unit of energy use: E.g., more intense use of equipment, and re-spending effect and shifting to other energy consuming products and services	Hard limits to overall energy use (or GHG emissions): Productivity effects, new preferences and diffusion of technology effects
(i) Information provision and "moral suasion"	No	No
(ii) Command-and-control (direct / physical regulation or technological / emission standards)	No	No
(iii) Market-based instruments or price regulation (taxes, levies)	Yes	No
(iv) Tradable permits (i.e. an overall ceiling combined with a price mechanism)	Yes	Yes

If instrument (iv), that is, tradable permits are introduced, preference and technologies can change in any direction in response to energy conservation. However, if this means an increase

in the potential demand for energy services (or CO₂ emissions), then scarcity will increase and the price of permits and therefore of energy will go up to the extent that demand for energy services will remain within the limits set by the ceiling because of the fixed supply, that is, the ceiling of total energy use (CO₂ emissions). No other instrument can realize this. Some studies have compared CO₂ taxes with tradable permits and have decided in favour of taxes. Subtle comparisons show that the two instruments share many features and that hybrid systems can do the job as well, perhaps even better (Parry and Pizer, 2007). However, none has taken the rebound effect into account as an evaluation criterion. If this is done, then tradable permits stand out as a superior instrument of an energy conservation annex climate or CO₂ mitigation policy. However, an alternative solution is offered by Sorrell (2007a): "Carbon/energy pricing needs to increase over time at a rate sufficient to accommodate both income growth and rebound effects, simply to prevent carbon emissions from increasing. It needs to increase more rapidly if emissions are to be reduced." The disadvantage of such a policy arrangement is that governments need to continuously collect information about relevant changes in the economy and adapt the policy in response, which is bound to meet a great deal of political and social resistance. In contrast, a once-and-for-all installed tradable permit system, if implemented well, can do the job more easily, with an endogenous price that responds automatically to market (technological and preference) changes.

To make this conclusion absolutely clear, let us look at instruments other than price regulation and tradable permits. Voluntary action stimulated by information provision and moral suasion has the disadvantage that it may seem like a cheap solution (that is why it receives so much political support – from the left to the right). However, it allows for a maximum of rebound and leakage due to the lack of any additional physical and price constraint on behaviour. Subsidizing energy efficiency improvements or conservation will even further stimulate rebound as spending power increases. Generally, one should be careful with direct and indirect (hidden) subsidies if there is no good reason for these (like positive externalities, such as mainly are found in R&D or innovation processes). Due to rebound stimulus in this case, there is extra reason to be careful with subsidies (van Beers and van den Bergh, 2009).

Section 4 concluded that energy efficiency improvements in technology are associated with two important rebound channels that other types of energy conservation (changing behaviour) do not have: namely direct rebound effects and diffusion of more efficient technologies. This suggests that energy conservation policy ought to focus its attention on the latter type of energy conservation strategy, i.e. changing behaviour. Along with this, policy could try to motivate

decisions, particularly regarding spending, to be directed at (relatively) energy intensive goods and services. This holds equally true for consumers and firms/industry. The obvious instrument is one that can accurately notify buyers about the energy intensity of goods and services. Again, price corrections to account for energy (or better yet CO₂ and other externality causing substances) stand out as the superior instrument, whether in the form of taxes or tradable permits that capture energy-related external costs.

Of course the previous conclusion does not imply one should avoid improvements in technical efficiency. Yet one needs to realize that many of these will have negative net effects, especially when they concern core or general purpose (GP) technologies which tend to permeate the economy once a threshold efficiency of operation is realized, and thus indirectly contribute to the growth of energy services. Pragmatically, policy should distinguish clearly between GP technologies and technologies that can realize a net conservation benefit. Sorrel (2007a) emphasizes the case of insulation, but not many examples exist. The problem may be that when technologies do not have a general purpose character, innovation (R&D) costs may be relatively high, as each specific technology with a limited area of application will require its own R&D and learning path. So it seems there is no ideal solution, i.e. one without disadvantages.

Policymakers must finally realize that a potential paradox ensues from the discussion of Section 3, namely that rebound is large where energy use and, consequently, potential savings are large, and that rebound is small where energy use is modest and respective potential savings are small. The foregoing notes imply a serious warning against being overly optimistic about what can be realized with energy conservation if measures are not regulated well by taxes or permits that are easier to trade. However, even adequate regulation cannot guarantee avoiding rebound. The ultimate contribution of energy conservation might be more disappointing than many are willing to accept. Taking rebound seriously means making energy conservation strategies more effective. It will also affect the evaluation (e.g., with cost-benefit analysis) of energy conservation programmes or comparisons with alternative strategies, like stimulation of, or investment in, renewable energy.

8. Conclusions

Despite the good intentions of governments, firms and individuals stimulating or undertaking energy conservation, such efforts offer no guarantee for effectiveness in terms of reduced

energy use and associated GHG emissions. One message of this article is therefore: don't be fooled by good intentions.

Fourteen possible rebound channels or mechanisms have been defined here and it was argued that rebound or indirect compensatory effects of energy and environmental strategies and policies are no exception, but rather the rule. Moreover, they have been insufficiently taken into account in studies on energy efficiency so far, that is, of the very large empirical literature on energy conservation and efficiency, a relatively small number of studies have corrected for rebound. Indeed, most studies arguing that certain energy conservation strategies are beneficial to the environment are based in partial analysis and thus tend to arrive at overly optimistic conclusions regarding the environmental effectiveness of such strategies. All in all, we have to be careful when judging studies that claim that energy efficiency is easy and truly pays off. A note on rebound is always in order.

The most practical advice arising that can be implemented at short notice may be that whenever concrete energy conservation activities or efficiency improvements are proposed, an energy rebound assessment is needed, just like any large investment project requires an environmental impact assessment. Or perhaps one should require an environmental rebound instead of an energy rebound assessment, as our ultimate concern is with environmental, notably climate change impacts, also in view of the distinction between more and less environmentally harmful energy generation (e.g., coal versus wind).

In addition, policy evaluation for energy conservation or better climate policy aimed at mitigation of CO₂ (or more generally greenhouse gas) emissions should include the impact on the rebound effect as an evaluation criterion. If this is done, then - as discussed in the previous section - tradable permits stand out as a superior instrument of energy conservation annex climate or CO₂ mitigation policy.

As was argued in the introduction, there are various reasons to believe that energy rebound can be a serious problem in developing countries, the main reason being that consumption of energy services by both industries and households is much less saturated than it is in developed countries. Energy efficiency has a double role in developing countries, namely to contribute to development and to reduce pollutive emissions. Although these goals may seem to be in conflict, they are not. If rebound is minimized, development can be realized at a minimal (additional) environmental cost.

Unfortunately, few rebound studies are available for developing countries. Most empirical evidence on rebound is for industrialized countries, which means that transfer of associated insights to developing country contexts is required, correcting for fundamental differences in production and consumption. Evidently, there is a clear need for research specifically focussed on the rebound of industrial energy efficiency improvements in developing countries before any definite conclusions can be drawn. Nevertheless, a precautionary approach would mean that we seriously consider the possibility of relatively high rebound effects in comparison with developed countries. It should also be noted that while many existing empirical studies show positive to very high rebound, several even over 100 percent (backfire), all studies are incomplete and partial in system, space and temporal senses, meaning that they tend to underestimate the total rebound effect.

The literature on energy rebound makes clarifies that energy conservation (policy) is no substitute for environmental regulation, just as environmental innovation (policy) is no substitute for environmental regulation. Politically, this may not be a very welcome message. But it needs to be stressed that both energy conservation and environmental innovation can only be effective after a good policy has been put in place to secure environmental regulation (pricing environmental externalities). As argued here, also considering rebound requires setting a ceiling for undesirable emissions, like of GHGs, notably CO₂. The ideal instrument which follows from the two conditions is a system of tradable permits. This should apply to the whole (world) economy. Any incomplete coverage of policy, as is presently the case (Kyoto does not cover the entire world and the ETS is limited to Europe and a subset of production sectors) will only allow for avoidable rebound.

We further have to recognize that private firms, consumers and politicians alike will always search for an easy way out. This means they will try to focus on solutions that seem effective and cheap. Unfortunately, the easier and cheaper the solution seems, the more likely rebound tends to occur. This is one more reason to install a good regulatory policy that encompasses rebound.

It is likely that rebound problems also hold for co-generation (combined heat and power - CHP), and carbon capture and storage (CCS). A general conclusion is that renewable energy and related stimulation policy become more attractive when rebound is taken into account. In fact, the preferred order of strategies in view of environmental aims is: renewable energy, energy conservation without efficiency improvements, energy efficiency improvements. This suggests that it is opportune to redirect part of our intellectual and financial efforts away from energy efficiency to renewable energy. In particular, industries/firms might be stimulated to invest in local renewable energy rather than in energy conservation.

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