HEINRICH BÖLL STIFTUNG
ECOLOGY

Wuppertal Institute for Climate, Environment and Energy

Green Growth Unravelled

How rebound effects baffle sustainability targets when the economy keeps growing

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Edited by the Heinrich Böll Foundation and the Wuppertal Institute for Climate, Environment and Energy, October 2012

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Published by: Heinrich Boell Foundation and Wuppertal Institute for Climate, Environment and Energy

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Acknowledgement:

The author should like to thank Christoph Görg, Hans Haake, Michael Kopatz, Manfred Linz, Reinhard Loske, Wolfgang Sachs and Uwe Schneidewind for their comments on the German draft of this paper and the valuable improvements that have resulted.

Moreover he wants to express his thanks to Christopher Hay for translating this study from German into English.

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Summary

The concept of 'green growth' is yet another promise to align ecology with economy in a win-win-situation. It rests on the idea of an 'efficiency revolution': manifold innovations of green and climate-friendly technologies, huge investments to restructure the industrial, building and transport sectors to sustainable modes, and a boost for using resources and energy more productively and efficiently. The suggestion is that national income can continue to grow while attaining sustainability targets at the same time. This study explores a fatal fallacy of the notion of green growth: while vast productivity increases do indeed incentivize a more efficient use of energy (and resources), they raise demand at the same time – which runs counter to the goal of saving energy. Such increased demand as a result of increased productivity is termed a rebound effect. Because rebound effects nullify a considerable proportion of the savings potential of efficiency technologies and measures, continuous economic growth will eventually thwart the much-needed steep reduction of absolute energy consumption.

Although the causal link between increased energy productivity and increased demand was identified back in 1865 and has been discussed in the economic sciences since 1980, rebound effects are still ignored in the majority of energy and climate studies and policies. Prominent research institutions such as the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA) assume in their scenarios and forecasts that most of the necessary reductions in greenhouse gas emissions can be achieved by means of efficiency improvements. This must be doubted, because rebound effects can constrain or in extreme cases even outweigh the savings potential of energy efficiency measures.

This paper explores the range of possible rebound effects, outlines their quantitative extent and describes the difficulties encountered by political efforts to contain them. It reveals that there is an urgent need for rebound effects to be taken into account in scientific scenarios and in policy-making.

Types and causes of rebound effects

As a first step, 13 possible rebound effects are identified, falling into four different categories. Financial rebound effects refer to cases in which an increase in energy efficiency results in an income gain and hence in new consumption. For example, the income effect may be triggered if petrol costs fall by 50% when a driver switches from a six-litre to a three-litre car. This releases money for increased energy use in other areas – whether for additional journeys or for other goods and services that also consume energy. Material rebound effects explain how the manufacture and use of more efficient technologies can be accompanied by greater use of energy, for example to produce efficient building insulation products or to develop new infrastructure and markets for energy-efficient products.

Psychological rebound effects explain how the shift to energy-efficient technologies can also boost the symbolic meaning of these goods and services. For example, a study from Japan shows that a year after purchasing what they considered to be an 'environmentally friendly' car, drivers who bought such cars were driving 1.6 times as far as they had done with their previous vehicle. Finally, cross-factor rebound effects illustrate how increasing the productivity of labour or capital can also increase the demand for energy, for example through mechanisation and automation that uses energy or if the use of energy-efficient technology also involves a time saving.

Quantitative extent

Calculation of the quantitative extent of rebound effects is still beset by considerable uncertainties. The majority of econometric studies consider only individual sector- and product-specific effects of financial and material

rebound effects on the consumer side. Conversely, the fact that there are still major gaps in quantitative rebound research indicates that existing model calculations probably reflect only a small proportion of the sum of rebound effects that actually occur.

A number of meta-studies now provide a summary and evaluation of the many individual empirical studies. It is from these that the present study derives the 'fifty-fifty' rule of thumb: in the long term and on average, combined rebound effects of at least 50% must be assumed. In other words, energy efficiency improvements in an economic system will on average yield half the theoretical savings potential of efficiency technologies and measures, and in some cases the saving that is achieved will be even less than this.

The limits of political containment

This study for the first time addresses the question of the extent to which environmental policy measures can contain or even prevent rebound effects. Efficiency standards for appliances or production processes harbour the greatest risk of evoking rebound effects. Real income gains and falls in market prices that arise from efficiency increases can theoretically be absorbed by ecotaxes. However, this would require a complex taxation scheme with sector- and product-specific tax rates, which would be difficult to implement. In theory rebound effects cannot arise if resource use is limited by caps (absolute upper limits). However, unless caps are introduced globally, rebound effects can still occur via international trade and increased imports.

Implications for sustainability policy

Because of the number and diversity of possible rebound effects and the appraisal that in the long term these combined rebound effects will consume at least half of the savings potential of efficiency measures, it will not be possible to achieve sustainability targets – such as an 80-90% reduction in the greenhouse gas emissions of industrialised countries by 2050 – through efficiency strategies alone. This is not because there is insufficient technical potential for savings, but because efficiency and productivity increases stimulate economic growth. To enable efficiency strategies to make an unrestricted positive contribution to sustainability and realise the savings potentials that are technically possible, further growth of national income would have to be halted. Whether and how national income can be kept stable or even fall is therefore one of the most important and most challenging questions of our time.

1. Growth and decoupling

It is now widely agreed across the political and social spectrum that in the foreseeable future modern industrialised societies will have to face the challenge of fairly radical change. Rising oil prices, dwindling resources, accelerating global warming and an historically unprecedented loss of species diversity will make a 'great transformation' essential – in particular to mitigate the environmental damage caused by the industrial metabolism and to set society on a course of socially and ecologically sustainable development.

However, there is far less agreement on the form this course will take and hence on how sustainable development will actually be achieved. One of the currently disputed issues is whether continuous economic growth is a risk or a requirement for sustainable development. In fact, the debate on sustainability, climate change and environmental policy is threatened by schism: On one side stand the heralds of the efficiency revolution and the technological optimists, who view continuing economic growth as desirable and even necessary. Ranged against them are the protagonists of sufficiency and cultural change, who plead as a minimum for growth paradigms in politics to be abandoned, sometimes even advocating stagnation or economic contraction.[1] Behind this polarised opinion spectrum lie conflicting assumptions, on the truth of which researchers have yet to deliver a final verdict.

In attempting to move closer to a scientifically sound resolution of these different points of view, it is essential to consider the arguments for and against decoupling 'economic growth'[2] from 'natural resource use'.[3] Ultimately the crucial question in the growth debate is: can natural resource use be decoupled in absolute terms from economic growth or not? The central argument for decoupling assumes that the consumption of non-renewable resources and emissions of harmful substances could be drastically reduced in absolute terms by means of efficiency and consistency strategies, even in a situation of continuing growth.[4] Critics, on the other hand, fear that adequate decoupling of growth from natural resource use is not possible. Or, more precisely, they fear that natural resource cannot be as drastically reduced as necessary to reach sustainability goals such as the reduction of material throughput by a factor of 10, or the reduction of greenhouse gas emissions by 80-90% in industrialised countries. They cite various reasons for this view, including the gradual shift of natural resource use from the industrialised countries to the global South[5] and the falling net energy balance that results from a shift to renewable sources of energy.[6] Yet the most weighty argument against sufficient decoupling of growth from natural resource use is the rebound effect, which is the subject of this study.

1.1 The forgotten paradox

Even though he did not use the term, the mechanism of the rebound effect was described in William Stanley Jevons' famous work '*The Coal Question'* (1865). Jevons relates how, paradoxically, efficiency improvements in the use of coal result not in savings of coal but in increased coal consumption, because technical progress boosts the demand for energy. The key aspect of the concept of 'rebound' that is used in the present study is not the extent of the effect but the causal link between increased efficiency and increased demand: *A rebound effect describes the increased demand that is caused or at least enabled by one or a number of productivity increases.* The definition acknowledges that not only increases in the productivity of resources or energy but

[1] This schism was pronounced by Loske, Reinhard (2010): Abschied vom Wachstumszwang. Konturen einer Politik der Mäßigung. Rangsdorf.
[2] Economic growth is defined in this paper as a quantitative increase in national income; it is an increase in real terms after allowing for inflation and not one in which the value of the increased quantity of money is eaten up by inflation.
[3] Natural resource use is defined here as the appropriation of resources and ecosystems both as sources of raw materials and as sinks for wastes and emissions. In this paper reference is mainly made to energy consumption and emissions, which clearly constitute only one aspect of natural resource use.
[4] Cf. e.g. Hawken et al. (2000).
[5] On the transfer of greenhouse gas emissions see e.g. Peters et al. (2010), Bruckner et al. (2010) or Santarius (2009).
[6] Cf. e.g. Heinberg (2009).

also increases in the productivity of labour and capital can result in increased demand. However, the present study confines itself on the output side to consideration of the increased demand for energy.

The paradox described by Jevons was by and large ignored by the scientific community for more than a century. As a result, the thinking and behaviour of politicians, businesses and consumers continues to be dominated by the idea that 'efficiency equals savings'. It is taken as given that more efficient use of energy and resources results in an absolute reduction in their use. Yet what sounds intuitively obvious in relation to a specific example quite clearly does not apply to societies' energy consumption in total. After all, it is evident that those societies that since industrialisation have made the greatest progress in productivity that mankind has ever known have continuously increased their consumption of energy and resources. An understanding of the causes and mechanisms of rebound effects not only explains this apparent paradox but also renders entirely logical and plausible the positive correlation between rising energy productivity and rising demand.

Not until 1980 did Daniel Khazzoom (1980) and Leonard Brookes (1990) revive Jevons' hypothesis and trigger renewed discussion of the concept of rebound. Since then, however, the rebound effect has only been considered among relatively few economists, who have looked at it mainly from two perspectives. On the one hand, environmental economists have debated it in the context of the connection between economic growth and demand for energy.[7] On the other, since the 1980s a modest but growing number of empirical studies have attempted to quantify the rebound effects of particular sectors or product groups using historical time series or econometric models.[8]

There has as yet been scarcely any scientifically based debate in disciplines outside economics. No sociological studies have been conducted, either on issues such as the relationship between rebound effects and individual behaviour or from the point of view of system theory.[9] Similarly, there has been insufficient discussion from the perspective of political science, for example of the policies and measures that might be used to curb rebound effects. In short, although the phenomenon was identified almost 150 years ago and rediscovered with the publication of the work of Khazzoum and Brookes in the 1980s, and although it has been the subject of growing public debate in recent years, there is still a great need for research even in economics, and most certainly in all other academic disciplines.

1.2 Focus of this study

Several meta-analytical surveys and literature reviews of the rebound effect have been published in the last few years. There is still, however, a lack of comprehensive analysis of how rebound effects arise. In the past the causes have usually been described in economic terms, citing the interaction of prices, incomes, (energy) demand and investment. Thus they all refer to income, price or substitution effects (see below), generally assuming rational, utility-maximising individuals. By contrast there have as yet been very few attempts to describe rebound effects in terms of psychological and social considerations. Obvious questions such as why people actually *want* to consume more when a saving has been made have yet to be answered by rebound research.

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[7] Among neoclassical economists the view predominates that energy consumption has a relatively limited effect on growth because energy costs make a limited contribution to GDP. Environmental economists, on the other hand, argue on the basis of the principles of thermodynamics that energy demand is the driving force behind economic growth. According to the latter view, decoupling is virtually impossible because an absolute reduction in energy demand – whether as a result of efficiency increases or by other means – would have a fundamental influence on economic growth. A summary of this discussion with further references can be found in Jenkins et al. (2011).

[8] On this point see Section 3.

[9] Cross-linkages with systems theory can be found in Giampietro and Mayumi, although with reference to systems theories in the field of natural sciences rather than social sciences. See Giampietro, Mario/ Mayumi, Kozo (2008).

This study will show how efficiency increases can result in greater demand even irrespective of income effects. It should be borne in mind that technological efficiency improvements not only reduce costs; they can also yield time savings or make environmentally oriented behaviour more socially acceptable. All these outcomes can change people's preferences. As a result, psychological and systemically induced rebound effects must be considered alongside the financial and material rebound effects described in economics.[10]

In addition, the realm of empirical studies has concentrated on econometric analysis of consumption-related rebound effects, while investigations of production-related and macroeconomic rebound effects are rare. Still the debate lacks sound theoretical explanations of how macroeconomic rebounds arise. By introducing the concept of 'cross-factor rebound effects' this study wants to help elucidate the mechanisms of economy-wide rebound effects and add additional systemic causes to the causes that arise on the production and consumption sides.

More thorough understanding of the hidden mechanisms at work when rebound effects occur (Section 2) and the possible quantitative extent of rebound effects (Section 3) is essential before even a tentative attempt can be made to decide whether these effects can be contained by political means. Can environmental policies and measures curb or even prevent rebounds and hence enable growth to be sufficiently decoupled from natural resource use? Critical examination of current environmental policy instruments leaves little hope of success in this area (Section 4). This scepticism inevitably raises the question of how efficiency strategies can be successfully embedded in future sustainability policies and what conditions must be met if they are to play a fully constructive role in the 'great transformation' to more sustainable patterns of production and consumption (Section 5).

[10] Psychological and material rebound effects have already been mentioned by Paech, Niko (2011).

2. Reasons for rebounds

Three types of rebound effects are frequently identified in the literature. First, the direct rebound effect, which is manifested in increased demand for the same product or service. For example, the switch from a six-litre to a three-litre car may result in additional journeys being made in the three-litre car. Second, the indirect rebound effect, expressed in increased demand for different products or services. For example, the change from a six-litre to a three-litre car may result in consumers taking more holidays by air. And third, the structural or macroeconomic rebound effect. For example, because many consumers drive three-litre cars, overall demand for petrol is lower, causing relative prices to fall and creating an incentive for increased demand for energy-using products in other sectors.

The level of a rebound effect is generally defined as the percentage of an efficiency-boosting measure or technology that is offset by a rise in demand. To calculate this it is necessary to distinguish between on the one hand the technically and theoretically feasible efficiency potential (that which might be envisaged by the engineer) and on the other that which can actually be achieved in practice. For example, the development of new engines makes it theoretically possible for cars to use on average only three litres of petrol per 100 kilometres, instead of six litres as previously. For calculation of the rebound effect, however, the important figure is how much petrol the three-litre car actually uses over its lifetime. For example, a rebound effect of 50% would mean that when drivers switch from a six-litre to a three-litre car, half of the total technical efficiency increase is offset by an increase in demand.

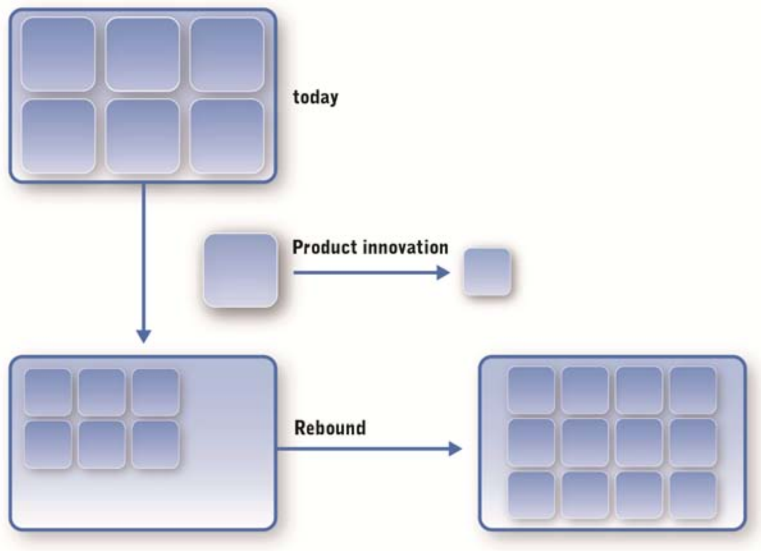

Figure 1: Schematic representation of the rebound effect[11]

An extreme form of the rebound effect is the backfire phenomenon. Backfire is another name for what Saunders termed the Khazzoum-Brookes postulate.[12] It is a rebound effect of more than 100%. In 1865 Jevons had already described that as a result of rebound effects the outcomes of efficiency increases are not only partially offset but are more than offset, so that after the efficiency increase energy consumption is actually higher than it was before.

But how do direct, indirect and macroeconomic rebound effects occur? Why do consumers use more energy after buying a more efficient product? Why does demand at the macro level shift towards energy-using prod-

[11] Source of the illustration: diagram produced by the Wuppertal Institute.
[12] Saunders (1992).

ucts and sectors when energy efficiency improves economy-wide? There are numerous reasons why a rebound effect may occur. They can be classified as financial, material, psychological and cross-factor rebound effects (see Box 1).[13]

Box 1: Classification of 13 possible rebound effects

Financial rebound effects	**Material rebound effects**
Income effect	Embodied energy effect
Reinvestment effect	New markets effect
Market price effect	Consumption accumulation effect
Psychological rebound effects	**Cross-factor rebound effects**
Moral hazard effect	Cross-factor effect
Moral leaking effect	Material cross-factor effect
Moral licensing effect	Multiple cross-factor effects
	Consumption efficiency effect

2.1 Financial rebound effects

Financial rebound effects are elicited by cost savings as a result of efficiency measures. For example, switching to more efficient cars means that drivers need to spend less on petrol. What do they do with the money that is released? And how do petrol and energy prices change if cars consuming only three litres of petrol per 100 kilometres ('three-litre cars') become the norm, as they soon may? Three financial rebound effects can be identified.

Energy efficiency measures that are amortised in economic terms result in a real income gain for the consumer. A rebound effect may then be caused by an income effect. For example, even if a three-litre car is initially more expensive to buy than a traditional six-litre one, the investment is likely to be recouped over time. The money freed up may be used to fund more of the same sort of consumption (direct rebound effect) – in other words, the owner of the three-litre car may simply drive more kilometres. Or the money may be put towards the consumption of other goods and services that themselves consume energy and resources (indirect rebound effect). The level of the rebound effect then depends on the quantity of natural resources used by these alternative goods and services. An example is the correlation between space heat requirement and living space in Germany. As a result of building insulation measures and more efficient boilers, the amount of heating energy consumed per square metre of living space fell by 9% between 1995 and 2005. However, total energy consumption for the heating of private homes rose by 2.8% during the same period. The efficiency saving was offset by an increase of around 13% in the demand for living space. Overall, the space heat requirement per person has remained constant since 1970. Decoupling has not taken place (see Figure 2).[14]

[13] Jenkins et al. (2011) and Paech (2011) have already made a start at systematising rebound effects. In addition, van den Bergh provides a list of 14 rebound effects, although without exploring them in more detail; see van den Bergh (2011).
[14] Ebert et al. (2010).

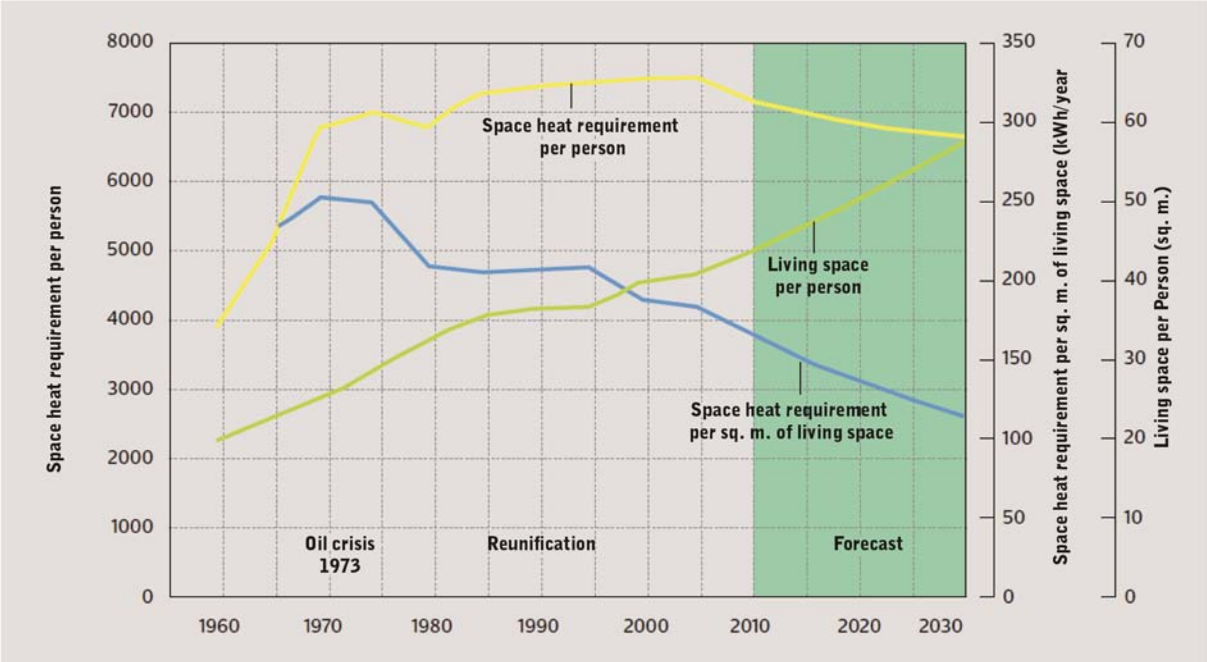

Figure 2: Living space and space heat requirement in Germany[15]

If cost-reducing efficiency measures in the production process result in a real income gain on the production side, a reinvestment effect equivalent to the income effect may occur. Businesses may spend the increased profits either on expanding production of the same item (direct rebound as expansion) or on investment in new products and services (indirect rebound as diversification of the product range). The business may also raise the wages of its workers, which can in turn produce the income effect described above. Frequently, too, anticipated cost savings on the consumer side result in money being spent on redesigning the traditional product, perhaps to make it more attractive. For example, increases in the efficiency of engine technology have seldom been used to put more energy-efficient cars on the market; instead more powerful, faster and heavier cars are produced that use the same amount of petrol per kilometre driven. The fuel consumption figures of the classic 1955 VW Beetle, which uses 7.5 litres of petrol per 100 kilometres, and the modern 2005 Beetle, which uses 7.1 litres over the same distance, are almost identical. But while the earlier model weighed 730 kg, had a 30 hp engine and reached a top speed of 110km/h, the 2005 Beetle weighed in at around 1,200 kg, had a 75 hp engine and was capable of 160km/h. Here the rebound effect, measured in tonne-kilometres per litre of petrol, is clear.

The above-mentioned rebound effects at actor level (consumers, producers) can in aggregate produce additional effects at the societal level. For example, the widespread introduction of three-litre cars will reduce the demand for petrol by society at large, so that petrol prices will fall or at least rise more slowly than they would have done if engine efficiency had not improved. The general fall in price may now trigger a rise in demand from other sectors. The lower price of petrol is likely to result in increased demand for other petrol-using products, which are now cheaper to operate. This can therefore be termed a market price effect. Local authorities may now spend more money on petrol-powered leaf blowers to replace conventional brooms. The widespread introduction of efficient wood pellet stoves in some parts of southern Germany and Austria may result in a relative fall in local wood prices, enabling wood-processing industries (furniture, wood for export) to become more competitive and to increase their demand for wood.

[15] Source of the illustration: BMWI (2011). Illustration there taken from Ebert et al. (2010).

2.2 Material rebound effects

Investment in efficiency measures can increase the demand for energy or materials for the production of the associated goods. These energy and material costs are termed 'grey energy' because they are 'embodied' in the product. The associated increased demand can be called the embodied energy effect. For example, an uninsulated house uses more heating energy on a day-to-day basis than one with energy insulation, but manufacturing the insulation uses energy that is not needed when an uninsulated house is built. The additional energy needed to produce the insulation can be compared with the heating energy saved over the useful life of the house. Various studies put energy payback times for building insulation products at between one and 15 years, depending on the specific insulation measure, the type of building and the climate zone. If it is assumed that buildings have a life of around 100 years, this corresponds to a material rebound effect of 1-15%.[16] For many energy-saving products life cycle analyses are now available that show the level of the embodied energy effect and describe the service life and type of use that render investment in more efficient products worthwhile.

It will not be possible to introduce new efficiency technologies and change the makeup of the economy – moving it away from fossil sources of energy and resources and towards renewable ones – solely by converting existing production facilities. Instead, new capacity and infrastructure will need to be developed on a large scale. In other words, entirely new markets are required. It is therefore appropriate to speak of a new markets effect.[17] For instance, depending on how the electricity needed by electric cars is generated, the large-scale introduction of electric cars may indeed lead to efficiency gains per kilometre driven. But to understand the implications of the rebound effect for society at large it is important to consider not only the life cycle analysis of the production, use and disposal of electric cars but also the construction of the new material infrastructure made necessary by the use of electric cars – from the industries involved in producing new engines and batteries to the charging or 'quickdrop' stations where drivers can swap flat batteries for newly charged ones. Even the salaries that the battery engineers or the operators of the new charging stations use to pay for their own energy needs can produce rebound effects – for example, if their income is now higher than it used to be or if more people are now in work overall. In sum, the new markets effect encompasses all the material rebound effects that are not included in the life cycle analysis of individual products.

Similar to the new markets effect is a material rebound effect identifiable at consumer level that can be termed the consumption accumulation effect. Its starting point is the fact that consumption of more efficient, more environmentally friendly products often does not replace but instead supplements conventional products. For example, when a highly efficient A+++ refrigerator is purchased, the old, more energy-intensive one may be put to new use in the basement or holiday home. Or parents who buy an electric car may decide not to scrap their conventional one but instead give it to their children. In terms of the life cycle analysis of the more efficient product or the resource use of an individual consumer, resource consumption does indeed fall, but for society as a whole the accumulation of new and old consumer goods produces a material rebound effect.

2.3 Psychological rebound effects

In the course of becoming more environmentally friendly, products and services frequently change not only their technical properties but also their symbolic meaning. People may conclude that as a result of efficiency improvements the use of something widely considered harmful is now considered environmentally friendly, and this can result in increased demand. In social psychology this is termed the moral hazard effect. To the

[16] For more details, with analysis of various empirical studies, see Sorell (2007), esp. p. 48.

[17] The new markets effect was first described by Niko Paech, see Paech (2011).

surprise of the researchers involved, an empirical survey in Japan showed that a year after purchasing what they considered to be an 'environmentally friendly' car (e.g. a Toyota Prius with a hybrid engine), drivers who bought such cars had driven at least 1.6 times as far as they had done with their previous vehicle.[18] The moral hazard effect thus provides a further explanation for the direct rebound effect: consumers actually use more of the same thing *because* the product has become more efficient.

Increased demand for a now energy-efficient product is not necessarily the result of an active, rationally intended action; it can also be the consequence of unintended behaviour. For example, after installing a more energy-efficient boiler, consumers may feel relieved that they no longer have to be quite so particular about keeping windows permanently closed throughout the winter. In the same way, buying energy-efficient compact fluorescent lamps could mean that lights are sometimes left on in unused rooms – especially as the cost to the consumer of leaving the light on also falls. Buying the more efficient product in effect salves people's conscience, which is why one might coin the term moral leaking effect: because in environmental, economic and sometimes also social terms they 'no longer matter that much', energy-saving actions (closing windows, turning lights off) are no longer given such high priority in the hierarchy of motives and may even be abandoned altogether. The moral leaking effect thus provides another explanation for the direct rebound effect.

By contrast, the moral licensing effect is a form of indirect rebound effect: because an environmentally friendly product has been purchased, demand for other environmentally damaging products increases. Some empirical studies have already shown that buying 'ethical' products (organic foods, Fair Trade products etc.) can result in consumers feeling justified in making unethical purchases in other areas.[19] One can readily imagine that this can also lead to a psychological rebound effect in relation to energy consumption. Hence people who have bought an economical car may take more holidays by air, or replacing all one's conventional light bulbs with compact fluorescent lamps may justify the purchase of a new plasma TV or multimedia projector.

2.4 Cross-factor rebound effects

So far we have considered the effects of energy efficiency increases on demand for energy. Let us now consider how increases in the productivity of other factors can also boost the demand for energy. As a first step we shall look briefly at how increases in the productivity of labour impact on the demand for labour.

While politically promoted energy efficiency strategies are based on the assumption that efficiency increases can save energy overall, labour productivity increases have long been justified on exactly opposite grounds.[20] It would be tantamount to political suicide for governments to permit or even promote an increase in labour productivity that led to a rapid decline in the number of jobs.

By conventional estimates labour productivity has increased at least 10-fold during the 20th century. But weekly hours for an average full-time job have only dropped from about 60 to 40 hours. Accounting for other changes in the conditions of work, such as the length of working life, increasing vacation times, as well as the increased occupational rate of women in particular, gives a similar result: the input of paid labour from the population has only dropped by one third in hundred years in spite of the stunning increase of labour productivity.[21] Fears that robots would eliminate the jobs of assembly line workers or that computers would put all secretaries out of work have proved true – if at all – only for individual sectors and even then only in some limited areas. On the contrary, it is frequently and rightly argued that increasing the productivity of labour

[18] Ohta/Fujii (2011).
[19] See e.g. Mazar/Zhong (2010); also Zhong et al. (2009).
[20] In the 19th century the theory behind this was debated in detail – see Alcott (2008). The view clearly prevailed that increasing the productivity of labour creates an increasing volume of work in the economy as a whole.
[21] Sanne 2000, p. 489.

ultimately creates jobs or at least protects them – in other words, that a socially and politically very welcome rebound effect ensures that increases in the productivity of labour result in a greater demand for labour. Madlener and Alcott point out that historically time that is freed up has seldom been filled with doing nothing. If it were, we should all be working much less than in earlier times when labour productivity per hour was much lower than it is today. It seems that there was and is close to a 100% rebound effect or, if population growth is taken into account, even backfire.[22]

Now, how does an increase in the productivity of labour affect demand for resources and energy? Some time before Jevons discovered the rebound effect of energy efficiency improvements in 1865, other economists had already noticed a rebound effect in the link between increases in the productivity of labour and demand for natural resources. For example, John Stuart Mill made the point that: *'increased effectiveness of labour (…) always implies a greater produce from the same labour, and not merely the same produce from less labour'*.[23] In 2009 Turner et al. quantified the correlation between labour productivity and demand for energy with an econometric equilibrium analysis for England and Scotland. They calculated that a 5% increase in the productivity of labour increases the demand for energy both short- and long-term. While they found out that national income rises faster than demand for energy, so that relative decoupling occurs, the crucial finding is that an increase in labour productivity has a cross-factor rebound effect on demand for energy, causing it to rise.[24] The same effect can be assumed to exist for increases in the productivity of capital: they too boost economic growth, which – *ceteris paribus* – is likely to result in increased demand for energy.

It should also be noted that increases in the productivity of labour are sometimes the direct result – or prerequisite – of increased demand for energy. Whenever human labour is replaced by mechanisation and motorisation, a material cross-factor rebound effect occurs. Whether the electrical food processor amplifies the muscle power of the chef or of the transport- and IT-intensive just-in-time delivery boosts the productivity of logisticians, increased demand for energy often causes or results from increased productivity of labour. For decades, increases in the productivity of labour have been achieved at the price of a (relative) fall in the productivity of energy. This problem is exacerbated – especially in high-wage countries – by fiscal policies that combine high taxes on labour with low taxes on energy.

For the reverse correlation the opposite is frequently true: an increase in energy efficiency is frequently accompanied by an increase in the productivity of labour and capital, even if this increase was not the primary aim. The overall increase in the productivity of the economy then boosts growth, with further implications for the demand for energy.[25] These relationships, which can be termed multiple cross-factor rebound effects, have been vividly described by Saunders in relation to the steel industry.[26] Spurred on by the steep rise in energy prices as a result of the oil crises of the 1970s, the steel industry in the USA cut its energy costs per tonne of steel by 45% by the end of the twentieth century, partly by introducing electric arc furnaces. This new production process enables steel scrap to be recycled and avoids the need for hugely energy-hungry blast furnaces. Because blast furnaces are also very capital-intensive, the productivity of capital in the steel industry also rose sharply. At the same time, the productivity of labour in the American steel industry more than tripled between 1983 and 1998, increasing from 10.1 man-hours per tonne of steel to 3.2 man-hours. In sum, the increases in the productivity of all factors of production and the resulting fall in the relative price of steel have led to an absolute increase in demand that might well have offset or even outweighed the gains in energy efficiency in

[22] Madlener/Alcott (2011), p. 27.
[23] Mill (1848), p. 133.
[24] Turner et al. (2009).
[25] This view is shared by Sorell (2007).
[26] See Saunders (2000).

the production process.[27] Saunders conjectures that, in general, technological developments that increase the productivity of labour and capital as well as the efficiency of energy are highly likely to generate backfire.

Just as on the production side, rebound effects on the consumer side can also be the result of other types of efficiency gain, in particular saved time.[28] An example of this is the correlation between travel, journey time and energy consumption. Across different cultures, countries and epochs it can be empirically demonstrated that people relatively consistently spend between 0.75 and 1.5 hours per day travelling – irrespective of whether they walk from village to village or commute between two towns some distance apart.[29] Because – surprisingly – the time spent travelling correlates in the long term neither with the level of mechanisation nor with the cost of travel, saved travel time converts into longer journeys. But travelling further involves greater consumption of energy. In other words, time efficiency gains in relation to travel generate rebound effects in terms of energy consumption. Another example arises in connection with the use of the Internet. Anyone who remembers how slow Internet surfing was in the 1990s with an old PC and a 56k modem via an analogue land-line will be able to confirm that ever-faster Internet connections and more powerful computers mean that significantly more clicks per minute are now possible. However, every use of the Internet needs energy – not only at the individual user's end but in particular at the server and for data transport. It can be assumed that gains in the time efficiency of surfing result in greater Internet use involving a larger volume of data and hence an increased energy consumption in the IT sector. Both examples suggest that it is appropriate to speak of a consumption efficiency effect: increasing efficiency of consumption can trigger an increased demand for energy.

[27] What Saunders initially sets out in theoretical terms in his article from the year 2000 he also seems to confirm empirically with an econometric calculation of historical energy consumption in 30 industrial sectors in the USA in an article of 2010; see Saunders (2010).
[28] Rebound effects that result from the saving of time are also described by Binswanger (2001).
[29] Knoflacher (2007).

3. Quantities and uncertainties

Over the past 30 years a considerable number of empirical studies have attempted to calculate the quantitative extent of rebound effects using econometric models or historical data series. For a number of reasons, the ability of such studies to provide information about the economy-wide, total rebound effect is generally limited. By far the majority of studies model only product- or sector-specific rebounds as they affect the end consumer – for example, in connection with transport, housing or the use of electrical appliances. Some studies consider only direct rebound effects, while others at least look at direct and indirect ones. Only a few models explore production-side rebound effects[30], and only very few studies consider the extent of macroeconomic rebound effects.[31] Furthermore, the econometric models have focused only on financial rebound effects. Because psychological and other rebound effects have so far been ignored, the studies of individual sector-specific rebound effects – studies that in any case are of limited information value – cover only a small selection of all possible rebounds even within the sector that they do consider. That apart, by far the majority of studies relate to industrialised countries, with developing and emerging countries remaining largely ignored.

The challenge of future quantitative rebound research will therefore lie not only in combining the various econometric approaches to direct and indirect rebound effects at consumer level with complex approaches to the modelling of rebound effects on the production side. In order to take account of psychological rebound effects it will also be necessary to consider empirical studies from the field of environmental and behavioural psychology. It will further be necessary to introduce cross-factor rebound effects to macroeconomic equilibrium models. Without a synthesis of all strands of such interdisciplinary empirical research, some of which has yet to be embarked upon, it will not be possible to make a comprehensive estimate of the total sum of all rebound effects associated with an efficiency increase.

Conversely, the fact that there are still major gaps in quantitative rebound research indicates that existing model calculations probably capture only a small proportion of the rebound effects that actually occur. This makes it virtually certain that the figures quoted below are at the lower limit of what can in reality be expected.

3.1 The 'fifty-fifty' rule of thumb

Five meta-studies provide an overview and evaluation of the numerous empirical studies.[32] In matters of detail there are sometimes significant contradictions between the studies. A cautious estimate of direct rebound effects of 10-30% for end consumers in the transport, domestic & electrical appliances and buildings sectors in the industrialised countries can be extrapolated, although there are deviations both upwards and downwards. To this must be added indirect and macroeconomic rebound effects (e.g. the market price effect) of a magnitude of 5-50%, with peaks of over 90% and backfire in some sectors; the wide range of figures obtained is itself an indicator of the uncertainties that prevail.

For guidance one can therefore state as a rule of thumb that on average and in the long term it must be assumed that macroeconomic rebound effects of at least 50% occur. In other words, efficiency measures will on average realise at most half of their inherent savings potential, and in several cases the saving will be even less.[33]

It should again be pointed out that the model calculations cover only financial rebound effects and take no account of available material, psychological and cross-factor ones – even if these effects are not necessarily

[30] See for example Saunders (2010).
[31] Holm/Englund (2009); Giampietro/Mayumi (2008); Barker et al. (2007).
[32] Maxwell et al. (2011); Madlener/Alcott (2011); Jenkins et al. (2011); Sorell (2007); Greening/Greene (1998).
[33] See e.g. Sorell (2007), p. 91.

additive but sometimes cancel each other out. An estimate of all rebound effects in aggregate can only be arrived at using historical time series. In a wide-ranging study, Holm and Englund found that in the USA and six EU countries energy efficiency increased by around 30% between 1970 and 1991, while energy consumption rose by 20% in the same period.[34] Over 21 years and in several countries, therefore, on average 66% of efficiency increases were eaten up by an increase in demand. Note, on the one hand, that the increased demand is unlikely to be attributable to rebound effects alone; other growth effects will also have played a part. Yet on the other hand, the study also ignores any transfer effects as a result of world trade, by means of which energy consumption is shifted successively from industrialised countries to emerging and developing ones; if Holm and Englund's analysis had included energy consumption in the countries of origin of the imports in their study, the increase in demand might well have turned out to be even higher.[35]

The German Advisory Council on the Environment (SRU) likewise concludes: '*Overall, the available research findings indicate that the long-term macroeconomic rebound effect is regularly in excess of 50% and can sometimes exceed 100% – in other words, it can offset half or even all of the savings achieved*.'[36] In emerging and developing countries the rebound effects are likely to be higher, because far more catch-up consumption and infrastructure investment is both possible and desired there.[37]

[34] Holm/Englund (2009).
[35] See Section 4.3 below.
[36] SRU (2011), p. 353.
[37] On the rebound effect in developing countries see for example for India: Roy (2000); for the Sudan: Zein-Elabdin (1997); also the attempt at a global analysis by Barker et al. (2009).

4. Limits of containment

Can rebound effects be contained or even prevented by environmental policy measures? There has as yet been no real debate on this issue.[38] This omission urgently needs to be rectified, and what follows is an initial contribution to the debate.

4.1 Efficiency standards

Of all efficiency-boosting policies, command-and-control measures such as mandated efficiency standards for products or production processes run the highest risk of triggering rebound effects. As described in Section 2, 'win-win' opportunities – in which the additional costs of an efficiency increase are quickly recouped and not only environmental costs but also labour and/or capital costs fall – are particularly likely to generate large financial and cross-factor rebound effects and frequently backfire.[39] They invariably fail to achieve the full savings potential that is technically possible. Recommendations such as that of the IPCC[40] or McKinsey[41] that substantial savings of greenhouse gas emissions can be achieved at zero or even negative cost will not achieve the envisaged result because the scenarios on which they are based take no account of rebound effects. In future the introduction of a cost-neutral efficiency standard should be preceded by an assessment of the risk of backfire. If efficiency standards are likely to trigger extensive rebound or even backfire, alternative measures should be considered.

Command-and-control measures that increase costs for producers or consumers can also be accompanied by rebound effects. The above-mentioned example of the manufacture of ever heavier and more powerful cars while fuel consumption remains constant[42] shows that efficiency standards for certain highly sought-after product groups are unlikely to produce large savings. This almost certainly applies too to televisions, the size and features of which are predicted to increase and expand further,[43] as well as to various consumer electronics devices (laptops, smartphones, games consoles, etc.), for which sales figures and usage are likely to increase sharply in the next few years. For product groups of this type the effect of even cost-intensive efficiency standards will be largely offset by growth.

As a general recommendation, therefore, command-and-control measures such as efficiency standards should be combined with market-based instruments (taxes, emission trading) so that rebound effects are partially contained.

4.2 Ecotaxes

Weizsäcker et al. propose a specific kind of Ecological Tax Reform, in which tax rates rise in line with efficiency increases.[44] This way, cost savings achieved through efficiency can be siphoned off by taxes and – in Weizsäcker's words – incentives to continuously increase efficiency are maintained. The proposal does indeed provide a means of counteracting financial rebound effects. However, the attempt to contain rebound effects through ecotaxes encounters at least three challenges.

[38] In a very cursory manner van den Bergh (2011) discusses the extent to which environmental policy instruments can limit rebound. Some authors make general suggestions to policy-makers on the decoupling of growth from natural resource use, but without focusing specifically on containing rebound effects. See for example Jackson (2009) and Loske (2010).
[39] This view is shared by Sorell (2007), page xi.
[40] IPCC (2007).
[41] McKinsey & Company (2010).
[42] See Section 2.1 above.
[43] See also SRU (2011), p. 353, and Oehme et al. (2009).
[44] Weizsäcker et al. (2010).

Firstly, ecotaxes can only curb income and market price effects; psychological, material and to some extent cross-factor rebound effects are unaffected by cost increases. It is therefore unclear to what extent the total sum of all rebound effects can be curbed by ecotaxes.

Secondly, concrete implementation of an Ecological Tax Reform specifically designed to counter rebound effects comes up against significant political and social problems. There is bound to be a trade-off between the effect of setting a price on efficiency gains in this way and the social costs of the tax. As Saunders has shown, the more inelastic the substitution elasticity between the natural resource factor and other factors (labour, capital), the higher the tax rates that must be introduced to actually achieve anything. With regard to rebound effects the reverse holds true: the more elastic the substitution capacity, the more readily will a low tax rate bring about a change in behaviour or investment – but extensive rebound effects are then likely to occur.[45] In short, high elasticity leads to high rebounds at low cost as a result of ecotaxes, while low elasticity leads to low rebounds but high costs. When considering the introduction of ecotaxes specifically intended to contain rebound effects, it should therefore be borne in mind that they may encounter social acceptance problems possibly far in excess of the political acceptance problems that previous energy/fuel taxes and Ecological Tax Reforms have faced.[46]

Thirdly, therefore, if the different substitution elasticities of different sectors and product groups are to be taken into account, ecotax rates would have to be rigorously differentiated according to sector and product. A general ecotax rate based on the macroeconomic, aggregated efficiency increase achieved cannot ensure that rebound effects are adequately contained. Yet experience of the tortuous process of introducing previous ecotax systems indicates that a complex ecotax design with numerous different sector- and product-specific tax rates is unlikely to be feasible in the real world of politics.

These challenges should not be construed as an argument against the introduction or refinement of ecotaxes and Ecological Tax Reforms, even in the form of simple, all-encompassing rates of tax on the use of resources, energy or CO_2. From the point of view of environmental policy, making natural resources or energy more expensive always makes sense and is in addition a suitable instrument for containing certain rebound effects to some extent.

4.3 Absolute caps

If natural resource use is restricted by means of absolute upper limits or caps, there can in theory be no rebound effects. For example, the introduction of a worldwide emissions trading scheme that caps the overall greenhouse gas emissions of all countries renders emissions increases as a result of rebound effects impossible; there can also be no increase in emissions as a result of indirect rebound effects, because the emissions arising from the consumption of alternative goods and services would likewise be limited by the global cap. There is also discussion of various caps on other pollutants and for specific environmental media, which in principle could likewise be used to contain rebound effects.[47] In practice, however, the introduction of absolute upper limits encounters two problems.

Firstly, it will rarely be possible to set caps on a worldwide basis. For example, the introduction of a worldwide cap on greenhouse gas emissions is a remote prospect. Negotiations under the United Nations Framework Convention on Climate Change (UNFCCC) remain hamstrung by the question of what contribution it is fair to expect from industrialised, emerging and developing countries. Until this question of 'climate justice' is re-

[45] See Saunders (2000), p. 443ff.

[46] On the problems associated with the political acceptance of ecotaxes and possible solutions see for example Beuermann/Santarius (2006).

[47] See e.g. Barnes (2006).

solved, an absolute emissions limit for all countries is unattainable. Yet when caps apply only to individual countries, the displacement of emissions to other countries can reduce the effectiveness of these caps. For example, Germany is one of the few industrialised countries to have succeeded in reducing its national emissions since the Kyoto Protocol came into force. Between 1995 and 2005 CO_2 emissions on German territory fell from 10.5 to 9.7 tonnes per person. However, during the same period around 1.1 tonnes of CO_2 per person was transferred abroad through higher imports of products whose manufacture gives rise to CO_2 emissions in the countries of origin. As a result, consumption-related per-capita emissions have risen even in Germany;[48] in absolute terms there has been no decoupling of economic growth from emissions. Despite absolute national caps, rebound effects can therefore still arise if domestic products are replaced by imports.

Secondly, even within a country it will rarely be possible to set national caps for an environmental medium. For example, the EU's emission trading system merely caps emissions of emissions-intensive businesses, with the result that it covers around 50% of EU emissions. Even if the EU were a 'closed economy' from which transfer to other countries could not take place, indirect rebound effects could still occur if the demand from sectors covered by the emission trading system were transferred to other sectors. For example, fewer emissions-intensive goods might be consumed, but the sum of the lower-emissions goods consumed in larger quantities in their place could lead to a further increase in emissions.

As already stated above in connection with ecotaxes, neither problem is to be construed as an argument against the introduction of absolute caps on natural resource use, even if the limits apply only to individual sectors or countries. In fact, of all environmental policy instruments, absolute caps are the most suitable for impeding rebound effects. For example, the introduction of an absolute electricity consumption target for Germany, as the German Advisory Council on the Environment has proposed,[49] would be a major step forward and would also help to mitigate rebound effects. Nevertheless, note that neither ecotaxes nor absolute caps can fully prevent rebounds effects.

4.4 Sustainability communication

The fact that there are many different reasons for rebounds suggests that efforts to reduce them should not focus solely on command-and-control and market-based instruments but should be extended to include sustainability communication measures of all types that aim to influence the knowledge and values of consumers and producers. Such measures include environmental education, sustainability advertising campaigns and eco-label schemes, as well as environmental management systems, environmental audits and green marketing, to name but a few. Psychological rebound effects in particular, if it is possible to tackle them at all, can be addressed only through instruments of sustainability communication.

However, although much has been done to raise environmental *awareness*, efforts to change actual environmental *behaviour* have so far met with little success. In addition, the extent to which sustainability communication measures achieve their intended environmental effect remains unclear. They should form part of the policy mix and be used with other instruments to educate people about the diverse causes of rebounds and the complex linkages involved. And it would be worth exploring how they could be refined for the specific purpose of addressing rebound effects. However, in the present circumstances there is little reason to hope that sustainability communication could noticeably reduce the macroeconomic rebound effect.

[48] Bruckner et al. (2010); similar figures in Peters et al (2010).
[49] SRU (2011), p. 353; see also Linz/Scherhorn (2011).

5. Sustainability or growth

In view of the large number and variety of possible rebound effects and the estimate put forward here that in aggregate these rebound effects will permanently negate at least half the savings potential of efficiency measures, it is clear that it will not be possible to achieve targets such as the reduction of greenhouse gases by approx. 80-90% in the industrialised countries by 2050[50] by means of technology and innovation alone. Several studies have explored whether and how it is feasible for Germany and Europe to be fully powered by renewable energy and to reduce greenhouse gases by up to 90% by 2050.[51] They assume that national income will continue to grow, but none of the studies considers any rebound effects.[52] The studies assume exploitation of all the technical potential for emissions reduction in order to reach the 90% emissions reduction target and hence leave no room for manoeuvre. In the light of rebound effects and the 'fifty-fifty' rule of thumb, achievement of this target through efficiency and consistency strategies is presently not feasible.

Ultimately this failure is not the result of insufficient technical savings potential but of a drawback inherent in efficiency and productivity increases of any sort – namely, the fact that they stimulate economic growth. In particular, growth is stimulated by 'win-win' solutions in which consumers, businesses and governments cut costs. Ultimately any productivity increase triggers a spurt in growth. This growth causes the output of all goods and services to rise, thereby boosting demand for energy and resources for the manufacture of these goods. The sum of all rebound effects resulting from this growth spurt depends on the relationship between energy demand and output – in other words, on how energy- and material-intensive the additionally produced goods are. Yet even 'green' products, such as renewable energy, cannot be had for zero environmental cost. Doubt must therefore be cast on whether 'green growth' can effect a sufficient decoupling of natural resource use from economic growth. It might instead be that an effective 'greening of economy' needs to be accompanied by economic contraction in non-sustainable sectors.

5.1 The fallacy of green growth

Ecologically minded proponents of further economic growth argue that large-scale expansion of renewable energy, building insulation, sustainable transport infrastructure etc. can only be achieved under conditions of rising national income. Their claim is that green growth does not represent an additional environmental burden, because it is based only on the higher costs incurred in investing in sustainable infrastructure and modes of production and in using environmentally friendly products.

Yet it must be made clear that even in the theoretical case of an economy growing only by 'green' means there would still be rebound effects. For example, if the use of fossil energy is reduced by insulating buildings, the natural resource factor is replaced by the capital factor. As explained above, this process is particularly likely to lead to extensive rebound effects if the substitution elasticity between natural resources and capital (or labour) is high. But with the progressive transition to a post-fossil economy, this elasticity will increase, because it will become ever easier to replace the natural resource factor with labour or capital.

A simplified example will serve to illustrate the link between green growth and increasing rebound effects. Consider the very different quantities of resources, labour and capital needed to build on the one hand the first cars with internal combustion engines and on the other the hybrid cars of today. First-generation engine technology required few parts – parts that were in the main made of iron and steel – and involved relatively simple design plans that were devised by a manageable number of researchers and engineers. By contrast, the propul-

[50] IPCC (2007); or WBGU (2009).
[51] In addition to studies by e.g. Shell, BMU/UBA, Greenpeace see in particular WWF (2010).
[52] This is also the verdict of the SRU (2009), and of Linz/Scherhorn (2011).

sion technology of a hybrid car is complex, incorporates countless different raw materials from all over the world, the mining and transport of which involves numerous companies, and is developed by armies of scientists and engineers, all of whom draw salaries and are themselves consumers. In short: while hybrid cars use less energy per tonne-kilometre, their manufacture involves multiple macroeconomic and worldwide rebound effects.

It is short-sighted to argue that further growth – of even the ‘greenest’ sort – would result in investment and consumption, and consequently also resource use and emissions, being reduced to such an extent that sustainability targets could be achieved. An increase in national income, even if it results from more expensive ‘green’ products, will ultimately always produce an increase in consumption. After all, what do the higher costs of the ‘green’ products indicate? They indicate that more human capital (knowledge) has gone into their development, or that more labour time is needed for their manufacture, or that more work is involved in mining specially needed raw materials. In each case more economic transactions are undertaken, which, other things being equal, involve more businesses or people in adding value to these products and hence generate multiple rebound effects both here and in other countries as a result of world trade. The anticipated green ‘efficiency revolution’ might effect an absolute decoupling of resource and energy use from national income, but the extent of this decoupling will not do to realize the much-needed steep reduction of absolute energy and resource consumption. In short, rebound effects counteract *sufficient* decoupling of economic growth from natural resource use.

5.2 Towards a sufficiency society

There is no escaping the fact that real economic growth results in increased demand. If the goal of sustainability is taken seriously, it would seem that the only remaining option is to put an end to the vicious circle of the growth spiral. A growth society seeking to undergo the ‘great transformation’ to a sustainability society is faced with the mammoth task of effectively limiting its economic growth. Only when national income stops constantly rising can efficiency and consistency strategies realise their technically possible – that is, their full – savings potential and reduce resource consumption to a viable level. Whether and how national income can be kept stable (‘steady state economy’) or even shrink is one of today’s most important and challenging research questions.

It is possible that ecotaxes, besides promoting a general change of course, could make an additional contribution to achieving a post-growth economy. If the aim is to ensure that the revenue from an Ecological Tax Reform does not produce any new rebound effects, this revenue should be used only to reduce the national debt.[53] It is likely that the outcome would then not be green growth but rather an ecological and social contraction of the economy into a healthy state. If the tax revenue is in effect removed from the economic cycle, national income may remain stable or fall, but both the environmental debt to the biosphere and the economic debt to future generations could be reduced.

There is no doubt that ending the growth spiral requires enormous economic, political, institutional and individual will for reform. Economic teaching must first develop a ‘macroeconomy of moderation’, because the academic mainstream has so far completely ignored the question of whether and how market economies can flourish without growth. Politics must not only find a way of managing without adding to the national debt and of reducing old debt but must also reform all those social welfare institutions that have in the past relied on continuous growth.

[53] Binswanger describes national debt as ‘everlasting debt’ of the central banks, because since the removal of the gold standard central banks have been able to take on debt in almost unlimited amounts. No one requires this debt to be repaid and it is used to create money and drive real economic growth until the system collapses. See Binswanger (2006).

Moreover, politicians and the public must engage in a debate on 'societal sufficiency'. Only when the realisation dawns that there can and should come a point at which enough – or perhaps already too much – economic growth has been achieved in a given society will it be possible to consider the economic limits to growth. And only when these limits are one day adhered to will efficiency and consistency strategies be able to make an entirely constructive contribution to sustainability. In the meantime, the years that are likely to pass before this mammoth task is completed will provide new evidence for the thesis of this study: that rebound effects will continue to thwart sufficient reduction of absolute natural resource use as long as the economy keeps growing.

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