Tilman Santarius · Hans Jakob Walnum
Carlo Aall *Editors*

Rethinking Climate and Energy Policies

New Perspectives on the Rebound Phenomenon

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Editors
Tilman Santarius
Institute for Ecological Economy Research
Technical University of Berlin
Berlin
Germany

Carlo Aall
Western Norway Research Institute
Sogndal
Norway

Hans Jakob Walnum
Western Norway Research Institute
Sogndal
Norway

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Preface

It has been a long 150 years since English economist William Stanley Jevons identified the potential rebound paradox created by technology advances that both improve resource efficiency and make uses of those technologies more economically. His impressive feat of systems thinking came to him already during the early stages of the fossil fuel age. He witnessed the onset of the current era through the emergence of the coal-fuelled Industrial Revolution. But his insight was mostly forgotten during the era of fossil fuel.

The interest is reawakening just at the onset of a new era ushered into being December 12, 2015 in Paris, where more than 190 countries joined together to commit to “aggregate[ing] emission pathways consistent with holding the increase in the global average temperature to well below 2 °C above preindustrial levels and [the need to pursue] efforts to limit the temperature increase to 1.5 °C.” This astonishing landmark means that this book is not only incredibly timely, but very necessary. It is about time indeed we lay out fully the issues that amplify, or moderate, the coupling of energy consumption and economic performance.

What does the Paris goal of staying well below 2 °C mean? Translating temperature into carbon speak is pretty straightforward. According to IPCC reports, holding the increase in the global average temperature to well below 2 °C above preindustrial levels means that there is only little carbon left to emit. In other words, it acknowledges the need to move out of the fossil fuel economy. To be specific starting from December 2015 until eternity, there are a maximum of 800 gigatonnes of carbon net emissions left, and possibly much less if we want to reach the goal with a high level of certainty. Currently we, the people living on this planet, emit more than 35 gigatonnes of carbon a year.

Now, to put this in perspective, if you were on vacation with just 800 Euros left in your pocket, and you knew you needed to spend 35 Euros a day to pay for food and board, how many more days could your vacation last until you have to return home? Obviously the analogy has its limitations. On the carbon front, in contrast to vacations, we want to phase out carbon softly to avoid disruption and chaos. If we are careful, we could wean ourselves over the next 35 years and make the transition manageable. We would need to get net emissions down to zero before 2050, all the while making sure that the journey does not compromise the rest of the biosphere as we are looking for alternative energies to power us. And more food and amenities, because I hear the world population is still expanding.

In this context, the design challenge before us is undoubtedly formidable. We need the best tools available to figure out, and walk, the path. Simplistic and naïve energy efficiency strategies are just not going to cut it. Only by understanding the dynamics of our interventions reasonably well can we can discover effective pathways that secure human wellbeing while allowing us to grow rapidly out of our fossil fuel dependence. This is the reason why this book edited by Tilman Santarius, Hans Jakob Walnum and Carlo Aall is essential.

If indeed we want to succeed with decoupling energy use and economic prosperity, and to live within the resource and carbon budget that our one planet provides, thoughtful and innovative ways forward are required. An essential step toward a sustainable world is for decision makers to recognize the possibilities of rebound effects in order to design public policies and initiatives that are truly effective. As this book reminds us very well, the challenge doesn't stop at climate and energy policy, but affects transportation, urban planning, the Internet, tourism, even labour-market policy and more. In fact, rethinking sustainability policies in order to make them impactful requires identifying—and eventually containing—rebound effect risks in virtually all fields of policy-making.

This book marks the long overdue beginning of a new chapter in the history of mankind. It provides insights we so dearly need if we truly want to succeed. Emancipating ourselves from fossil fuels while learning to prosper within the resource budget of our planet is worth the effort of every waking moment. Simply said, *Rethinking Climate and Energy Policies—New Perspectives on the Rebound Phenomenon* points the way.

Mathis Wackernagel, Ph.D.
CEO, Global Footprint Network

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Abstract

This volume suggests rethinking current climate, energy and sustainability policy-making by presenting new insights into the rebound phenomenon; i.e. driving forces, mechanisms and extent of rebound effects and possible ways to mitigate these effects. It pursues an innovative and novel approach to the political and scientific rebound discourse and, hence, supplements the current state of knowledge discussed in the field of energy economics and recent reports by the Intergovernmental Panel on Climate Change. Building on the realm of rebound publications from the past four decades, this volume contributes in three particular ways: Part I offers new aspects in rebound economics by presenting insights into issues that have so far not been satisfactorily researched, such as rebounds in countries of the Global South, rebounds at the producer side, as well as rebounds from sufficiency behaviour (as opposed to rebounds from technical efficiency improvements). Part II goes beyond the conventional economic rebound research and explores multidisciplinary perspectives on the phenomenon, in particular from psychology and sociology. Advancing such multidisciplinary perspectives delivers a more comprehensive understanding of rebound driving forces, mechanisms and policy options. Part III puts rebounds into praxis and presents several policy cases and sector-specific approaches, including labour markets, urban planning, tourism, information and communication technologies, and transport. The volume finally embeds the issue into a larger debate on decoupling, green growth and degrowth, and sketches out lessons learned for sustainable development strategies and policies at large. Employing such widespread and in-depth analysis, this volume makes an essential contribution to the discussion of the overall question: Can resource use, energy use and greenhouse gas emissions be substantially reduced without challenging economic growth?

Chapter 1
Introduction: Rebound Research in a Warming World

Tilman Santarius, Hans Jakob Walnum and Carlo Aall

In December 2015, at the UN conference on climate change in Paris (COP21), 195 governments accomplished a momentous agreement to diminish humanities' dangerous interference with the climate system, and to support actions and investments towards a low carbon, resilient and sustainable future. The parties agreed to stick to —and even strengthen—the goal agreed on in Copenhagen (COP15) in 2009; that is to "*holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels*" (UNFCCC 2015).

Throughout science, civil society and the media, the Paris Agreement is widely considered as again another strong political signal to cut greenhouse gas (GHG) emissions to sustainable levels and basically end fossil fuel use within the coming decades. However, 2015 came with a dramatic drop in the global prices on fossil fuels, whereas a number of commentators in the climate debate call for the opposite to happen. Global emissions of carbon dioxide related to energy use were flat in 2014, compared with the previous year according to the International Energy Agency (IEA), but are expected to increase again in 2015 due to falling oil prices.

As an explicit step to show action in the aftermath of the Paris climate conference, several countries have announced to increase their energy efficiency. Most notably, five days past the Paris talks, the US Department of Energy tabled a new energy efficiency policy, which it called "*the largest energy-saving standard in history*" (US DoE 2015). According to the US government, this policy intends to

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T. Santarius (✉)
Institute for Ecological Economy Research, Technical University of Berlin, Berlin, Germany
e-mail: santarius@tu-berlin.de

H.J. Walnum · C. Aall
Western Norway Research Institute, Sogndal, Norway
e-mail: hjw@vestforsk.no

C. Aall
e-mail: caa@vestforsk.no

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save the sheer amount of 885 million tons of carbon dioxide emissions until 2030 by way of making space heating and cooling devices more efficient. In the process, US businesses are expected to save 167 billion US dollars. Many other countries, from Ethiopia to Kazakhstan, are now also planning to invest in energy efficiency. And in the European Union, debate is heating to significantly increase the EU's 2030 energy efficiency target (e.g. to 40 %), as many consider the current 27 % target as too low on ambition for meeting the goal to limit global warming. So the idea in all these efforts is that a reduction in energy use per unit of consumption will reduce the total GHG emissions. The problem with this reasoning is that very little attention is given to the intermediate factor; namely, the level of energy consumption. Few—if any—countries have adopted a goal of reducing its absolute level of energy consumption, and few countries have integrated its climate and energy policies; in most countries, these are separate policy areas aiming at different overall goals—namely, that of securing the national energy demand compared to that of reducing national GHG emissions.

The authors of this volume appreciate any action to address the challenge to mitigate climate change, and to adapt to its unavoidable consequences. We assume that a significant portion of this effort will have to include energy use. However, we depart from the evidence that many efforts did already increase the energy efficiency of nations throughout past decades, but that all too often such honest endeavours have been partly or fully neutralized by newly increased energy demand (Sorrell 2015). Global data indeed suggests that over the long run, energy efficiency has steadily increased in most countries; i.e. energy use per unit of consumption or per dollar of gross domestic product has declined (IPCC 2014; IEA 2014). But at the same time, absolute energy consumption has increased in most nations or at best remained stable in very few countries—apart from certain phases of absolute reductions that could clearly be attributed to economic breakdowns (such as in the countries of Eastern Europe and the former Soviet Union during the 1990s, or globally during the financial crisis in 2008/2009).[1]

While this paradox can have many reasons, one of them has been found in the *systemic relationship between efficiency and expansion*; notably, that it is the efficiency improvement as such that enables, or even causes, an increase in demand. This phenomenon is termed the '*rebound effect*'. It raises doubts whether straightforward efficiency policies, such as the new US standard for heating and cooling devices, the tightening of the 2030 EU energy efficiency target, or others, can live up to their promises of producing substantial reductions in GHG emissions unless they are embedded in more comprehensive policy designs that address potential rebound effects at the same time. And with the Paris Agreement now even striving towards the aspiring goal of limiting climate change towards 1.5 °C warming, any size of global rebound effect will have to be considered in the calculation of policy effects and, as far as possible, be contained.

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[1] This fact appears all the more sobering when consumption-based data—instead of territorial statistics—are considered (see e.g., Bruckner et al. 2012; Peters et al. 2012).

This volume, which is dedicated to interrogate the nature and relevance of the rebound phenomenon for the purpose of contributing to improve climate as well as energy policy, is guided by several overarching questions: How can it be explained that energy efficiency improvements often do not translate into adequate absolute reductions of energy service demand? With what kind of scientific disciplines, theories, and empirical models can the rebound phenomenon, and its various different forms be investigated? What are specific conditions under which rebound effects tend to emerge in certain real-world sectoral- and policy-contexts? And finally, what kind of policies, measures and other solutions (individual, systemic) should be considered in order to contain rebound effects and take care that global energy and resource demand can be reduced to sustainable levels?

1.1 Reducing Energy and Resource Demand for Sustainability

The debate on the relationship between energy use and climate change, and the possible need to reduce energy use in order to avoid unacceptable global climate change, adheres to a continuous scientific discourse, initiated in the early 1970s by contributions from scholars like Georgescu-Roegen (1971), Daly (1973) and Mishan (1977). Embedded in this early discourse was a strong critique of economic growth as a superior goal for the development of nations and the formulation of physical limits of growth (Meadows et al. 1972). The 1987 Report by the World Commission on Environment and Development ‘Our Common Future’ renewed impetus to the discourses from the 1970s (WCED 1987). Energy use and consumption were key issues in the report, and the need to fundamentally change patterns of production and consumption in rich countries was very much emphasized.

Since the 1990s efforts were made to pick up on the critiques of economic growth and its implications under the heading of sustainable consumption (Schor 1991; Cross 2000; Princen et al. 2002). A basic element in the sustainable consumption debate was the issue of global justice and the idea that people in the rich north can ‘live better by consuming less’ (Jackson 2006) and the debate on the potential for decoupling environmental impacts from economic growth (Jackson 2009). In these debates, three perspectives on how society should achieve more sustainable consumption emerged (see Sachs and Santarius 2007): (1) **Efficiency**: increase efficiency in energy and resource use by making production processes as well as end-use products and services more efficient (e.g. improve fuel economy of cars), in most cases through technological innovations. (2) **Consistency**: change the resource base of production and consumption in order to make them less environmentally harmful (e.g. shift from fossil fuels to renewable energy carriers). (3) **Sufficiency**: reduce the volume of products and services (e.g. reduce kilometres driven, or resource inputs) and change structural patterns (and habits) of production and consumption (e.g. shift from private cars to public transportation).

The sustainable consumption discourse soon focussed on transforming production to become more efficient in terms of resource use rather than pressing for radical changes in consumption. This strategy, coined ‘eco-efficiency’ in 1992 by the World Business Council for Sustainable Development (Schmidheiny 1992), originates from a more general idea of how society could be transformed in order to solve environmental problems: the reform-oriented school of ecological modernization, which emerged in Europe during the early 1980s (Spaargaren et al. 2000; Mol 2001). A basic assumption of ecological modernization and eco-efficiency is the idea of environmental re-adaptation of economic growth and industrial development by means of increasing the marginal environmental efficiency of industrial production measured, e.g. in the form of energy per unit of production or per unit price. The final and total output received less attention; that is, whether applying a strategy of ecological modernization or eco-efficiency has actually reduced the total environmental pressure on society, or just literally moved the pressure to other regions or related economic activities, often referred to as either leaking or rebound effects (Hertwich 2005).

The debate on the relationship between consumption, energy use and climate change has recently been further developed under the heading of ‘degrowth’ (Latouche 2009; Schneider et al. 2010; D’Alisa et al. 2015). In these works, it is argued that degrowth should not be treated as a negative event affecting the present global economy—thus being met with strategies to boost the economy back onto the growth track. It should instead be treated as a strategy for economic restructuring in rich industrialized countries in order to achieve two goals: a more just distribution of economic welfare between rich and poor countries, and a substantial absolute reduction of environmental pressure.

Increasing the efficient use of energy and material resources is widely considered a key strategy for achieving such absolute reduction of environmental pressure, most notably human-induced climate change (Weizsäcker et al. 1998; UNEP 2011; OECD 2012; IEA 2014). Yet, while new technologies and environmental policies have indeed led to significant improvements in energy and resource efficiency per unit of consumption or output, progress in the total reduction of environmental impacts has been less than expected. What has rebound research so far delivered to explain this paradox?

1.2 A Brief History of Rebound Research

Already in 1865, William Stanley Jevons has precisely described the relationship between the increase in energy efficiency and the increase in demand in his famous book ‘The Coal Question’ (Jevons 1906). It appears that just as today, so too did at Jevons time obviously circulate the idea that efficiencies could save nations from an increasing shortage in the supply of energy carriers. For Jevons recites: “*It is very* *commonly urged, that the failing supply of coal will be met by new modes of using it efficiently and economically. The amount of useful work got out of coal may be made to increase manifold, while the amount of coal consumed is stationary or diminishing. We have thus, it is supposed, the means of completely neutralizing the evils of scarce and costly fuel.*" (Ibid, p. 102) But Jevons strongly opposed this view and instead postulated the core of the mechanism that today is termed a rebound effect: "*It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth.*" (Ibid, p. 103) Apparently, however, the (seeming) paradox described by Jevons has been forgotten for more than 100 years. Only since the 1980s, it has experienced a renaissance. The history of modern rebound research can roughly be divided into four distinctive, though partly overlapping phases:

Phase 1—Theoretical Exploration: Daniel Khazzoom published the first microeconomic explanation of the paradox (Khazzoom 1980, 1987)—although he did not yet mention Jevons nor called this a rebound effect. Around the same time, yet disconnected from Khazzoom, did Leonard Brookes formulate a number of hypotheses, which suggest a rebound effect at the macroeconomic level (Brookes 1978, 1990). Both publications sparked an intensive debate among energy economists, but it was not before Harry Saunders' publication in 1992 that the two strains of discussion—the Khazzoom and the Brooks discussion—had been merged as the 'Khazzoom-Brookes-Postulate' (Saunders 1992, 2000).

Phase 2—Empirical Foundation: The 1990s witnessed a large number of publications that theoretically and empirically investigated and substantiated Khazzoom's, Brookes' and Saunders' hypotheses (for an overview, see e.g. Alcott 2005). Dozens of microeconomic empirical investigations appeared. In addition, first macroeconomic rebound effects have been modelled (see Sorrell et al. 2009). In 1998, Greening and Greene presented the first meta-analysis of the rebound literature (Greening and Greene 1998; Greening et al. 2000). A special issue of Energy Policy was devoted to the issue in 2000, which contained a number of seminal articles (e.g. Berkhout et al. 2000; Birol and Keppler 2000; Brookes 2000; Saunders 2000; Schipper and Grubb 2000). Shortly thereafter, Binswanger (2001) and Jalas (2002) introduced the factor of time to rebound research and thus opened a new strand of debate. Another milestone is the multi-year research project at the UK Energy and Resource Centre under the direction of Steve Sorrell, which gave birth to several comprehensive reports (Sorrell 2007; Allan et al. 2007; Broadstock et al. 2007; Sorrell and Dimitropoulos 2007, 2008). Moreover, two edited volumes on the rebound effect have been published in the late 2000s (Polimeni et al. 2008; Sorrell and Herring 2009), on which this volume heavily draws and which it intends to update, advance and diversify.

Phase 3—Political Evaluation: As public critique on resource-intensive economic growth re-emerged with the financial and economic crisis in 2008/2009, this popularized the rebound issue in civil society and policy debates (e.g. Jackson 2009). Apart from the controversial popular book by Owen (2011), several Internet posts as well as occasional articles in daily and weekly newspapers have been published (e.g. Barret 2010; Burns 2011; Afsah 2012). To address policy-makers, further meta-studies were conducted and a number of policy-oriented reports as well as popular scientific articles appeared (e.g. Jenkins et al. 2011; Maxwell et al. 2011; Azevedo et al. 2012; Michaels 2012). Around the 'Rio+20' UN conference in 2012, the issue played a crucial role in the discussion of concepts such as green growth and green economy (Santarius 2012; International Resource Panel 2011, 2014). Besides, during this phase and until today, manifold further publications strengthened the empirical and theoretical foundations of the rebound effect.

Phase 4—Multidisciplinary Extension: In recent years, rebound research has shifted from solely to be discussed within energy economics towards an interdisciplinary field based on several disciplines and methodologies (Giampietro and Mayumi 2008; Schneider 2008; Girod and de Haan 2009; Peters et al. 2012a; Walnum et al. 2014; Otto et al. 2014; Santarius 2014, 2015a). Thus, a new chapter was opened in the history of rebound research, with the phenomenon being grasped through explanations that go beyond income and substitution effects. This implies that structures (physical infrastructures, economic and political systems, mental mechanisms) as well as other factors (e.g. habits, lifestyles, change of attitudes and norms) despite 'saved money' can generate rebound effects.

1.3 Terminology and State of Research

Energy economists usually distinguish at least three types of rebound effects: direct, indirect, and economy-wide rebound effects (Sorrell 2007). At the microeconomic, consumer-side level, for example, expected reductions in fuel consumption from making cars more fuel efficient may lead to cost savings, and these cost-savings can partly be used by car owners to drive more kilometres than before. This is called a 'direct rebound effect'. It might also be the case that car owners use the savings to spend them on other activities, e.g. on new household gadgets or long-distance flights. This is called an 'indirect rebound effect'. In certain cases, these effects can even lead to a net increase in energy use, which is dubbed 'backfire'. Rebound effects can be generated not only at the level of (end-use) consumers, but also in the process of production. Such effects could be considered as 'mesoeconomic rebound effects'. They can be generated through direct and indirect rebound effects from companies, but may also stem from energy price effects at industry branch or market level. Finally, making economies more energy efficient fosters overall economic output. This can generate additional demand for energy, thus multiplying micro- and mesoeconomic rebounds at consumer and industry level. Such efficiency-induced economic growth effects at the aggregate level have been researched as 'macroeconomic rebound effects'. All effects together sum up to the 'economy-wide rebound effect'.

As of microeconomic direct rebound effects generated through income and substitution effects, there is broad agreement on the overall functioning of these effects. Controversy remains on the actual scale of direct rebounds in various sectors and countries, although several recent meta-analyses suggest somewhat reliable average trends (see Greening et al. 2000; Sorrell 2007; Maxwell et al. 2011; Jenkins et al. 2011; Madlener and Alcott 2011; Azevedo et al. 2012). However, indirect rebound effects have only been partly researched so far (see for instance, Druckmann et al. 2011; Chitnis et al. 2013, 2014; Azevedo and Thomas 2013; Lin and Liu 2015). This volume draws on more than three decades of microeconomic rebound research, outlines remaining open questions, and provides some fresh research on some aspects of microeconomic rebound research that have not yet been treated satisfactorily. At the same time, it exposes the rather narrow economic approach on consumer-side rebounds to theories from other disciplines, namely from environmental psychology.

As of ‘mesoeconomic rebound effects’, only few studies acknowledge the importance of production-side rebounds as a separate and identifiable factor and area of research. Greening et al. (2000) are the first to mention rebounds by “firms” and point out two distinct rebound mechanisms, namely ‘output effects’ and ‘factor substitution’, yet without further investigating these effects (likewise Sorrell 2007; Sorrell et al. 2009; Jenkins et al. 2011). The limited number of other publications that offer a theoretical perspective on production-side rebound effects (e.g. Michaels 2012; Borenstein 2013; Turner 2013) mention the same linkages that occur in the case of macroeconomic effects—namely, the fact that the interaction of labour, capital and energy as factors of production changes throughout the economy, which can lead to overall economic growth. Only few empirical studies start calculating producer-side rebounds at the aggregated level of industry sectors (Bentzen 2004; Safarzynska 2012; Saunders 2013), while a handful of studies are available on freight and air transportation (Santarius 2015b). This volume takes stock of the limited existing research and further develops the research agenda for producer-side rebound effects.

As of macroeconomic rebound effects, much controversy remains, such as on the scope of the output elasticity of energy (namely, how energy as a factor of production leverages overall economic growth), the degree of substitutability of all factors of production or the relationship between efficiency increases and product/service innovation (Sorrell 2007; Madlener and Alcott 2009; Turner 2013). It is difficult to prove or disprove how the dynamics between energy efficiency and growth work, based on macroeconomic growth models. The results of the models much depend on underlying assumptions (Santarius 2014). This suggests that investigating efficiency-induced economic growth effects should be carried out not only through the lens of economics but also through other scientific disciplines, which might help to better grasp the complex matter and shed new light on the relationship between energy efficiency and output growth. This volume intends to foster such a debate.

Although the rebound phenomenon has provoked many reports and dozens of peer-reviewed articles, it still appears greatly under-researched. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change, which mentions it in several chapters and reviews key findings of existing rebound research (e.g. IPCC 2014, pp. 98, 249, 390, 707, 1168), concludes that the research base is still far from delivering a robust understanding—let alone a reliable quantification of the various forms of rebound effects. Not merely empirical research is needed, but even more so sound theoretical explanations of how and under which conditions rebound effects emerge (see also Turner 2013; Santarius 2015a).

At the same time, strong controversy upon the phenomenon prevails. Some scientists claim that rebound effects are limited, due to demand saturation or negligible energy costs, and therefore are of minor importance (e.g. Lovins 1988, 2011; Schipper and Grubb 2000). Others conclude that rebound effects are at least of some importance, but do not indicate that energy efficiency polices are substantially ineffective (e.g. Sorrell 2007; Gillingham et al. 2013). Again others state that the rebound effect is very significant and challenges the belief that improving the efficiency of energy use is an effective policy for reducing energy demand and GHG emissions to sustainable levels (Saunders 2000, 2013; Ayres and Warr 2009). However, in part, these obviously contradictory conclusions may stem from applying different definitions of what is meant by rebound effects, applying different system boundaries in rebound analysis, and investigating the rebound phenomenon through different models, theories and disciplinary lenses. Throughout the chapters of this volume, and by summarizing common findings in the editor's conclusions, this volume hopes to provide more clarity on the nature and scope of the rebound phenomenon, as well as on the limits of rebound research.

1.4 Structure and Content of This Volume

This volume is structured into three parts. Part I is dedicated to rebound economics, part II advances multidisciplinary approaches to the phenomenon, and part III applies the rebound concept to a variety of sectors and policy cases.

Part I departs from the large existing body of economic rebound research, adds new qualitative and quantitative findings and poses still-open research needs. In Chap. 2, Reinhard Madlener and Karen Turner review the plethora of past publications and illuminate perspectives on how to look at economic dimensions of the rebound effect. This chapter attempts to synthesize existing rebound taxonomies, address the lack of clarity and understanding in how analysis can bridge the gap between micro- and macro-level effects and finally pays particular attention to what policy makers can do with rebound analysis and findings. Against this introductory background, the following chapters of part I present some fresh insights on aspects that have so far not been sufficiently researched in rebound economics. In Chap. 3, Johannes Buhl and José Acosta ask the question, to what extent sufficiency strategies are prone to rebound effects? The authors analyze re-spending effects along income elasticities from a national survey on income and expenditures in Germany. In doing so, they shed light on methodological shortcomings and rethink microeconomic demand functions. Chapter 4 takes the reader to India in order to contribute to the discussion about rebound effects in the Global South. On the basis of empirical evidence from private automotive transport in urban India, Debalina Chakravarty and Joyashree Roy question the common assumption that rebounds tend to be larger in the South than in the global North. Part I of this volume closes with Chap. 5 on 'meso-economic' rebound effects. Tilman Santarius reviews the scarcely available literature on company-caused rebounds, discusses potential sector-level- and market price-effects and finally analyzes potential new rebounds that may evolve from feedbacks between the micro- and the macro level.

Part II intends to go beyond conventional rebound economics and advance and diversify the multidisciplinary approach to the phenomenon. Chapters 6, 7, and 8 dive into micro-level, consumer-side rebounds from the perspective of environmental psychology; afterwards, Chap. 9 takes macro-level effects into account from the perspective of sociology. In Chap. 6, Anja Peters and Elisabeth Dütschke identify possible psychological drivers to explain rebound effects, including attitudes, personal and social norms and response efficacy, and then expose those to qualitative results from an empirical focus group study. Based on these insights, Tilman Santarius and Martin Soland develop a theoretical rebound model based on behavioural science theories and advance a typology of 'motivational rebound effects' in Chap. 7. Then in Chap. 8, Christine Suffolk and Wouter Poortinga round up this discussion by exposing psychological rebound explanations to empirical data from residential energy-efficiency improvements in Wales. Turning from micro- to macro-level effects, Chap. 9 begins by briefly reviewing pitfalls and shortcomings of macroeconomic rebound research. Tilman Santarius then tilts new ground by grasping macro-level rebounds through perspectives from sociology, namely by considering the impacts of efficiency improvements on social acceleration and the economy of time.

Part III is dedicated to discuss the implications of rebounds for various cases and fields of applied policy-making. These include such diverse areas as labour market policy (Chap. 10), urban planning (Chap. 11), adaptation and mitigation in the tourism sector (Chap. 12), ICT and cloud computing (Chap. 13), and freight transportation (Chap. 14). As will be seen, the chapters not only discuss the implications of efficiency-generated rebounds for policy-making. In a much broader perspective, they also apply the basic mechanisms behind rebound effects to consider blind spots, unexpected side effects and second-order feedback mechanisms that endanger the effectiveness of climate and energy policies to significantly cut energy use and greenhouse gases. This gives way to developments of more resilient policies and measures, which balance efficiency, consistency and sufficiency strategies and embed them into smarter and more comprehensive policy designs.

In Chap. 10, Johannes Buhl and José Acosta discuss implications of working time reduction to reduce consumption levels. Challenging the long-hoped hypothesis that more spare time would inevitably reduce resource consumption, they find out that time savings do trigger relevant rebound effects, but at the same time lead to increased voluntary social engagement and greater life satisfaction. Petter Naess in Chap. 11 projects the rebound phenomenon on matters of urban planning. Along data on the relationship between residential location and leisure travel in three Nordic cities, he identifies new forms of rebound effects in the form of resource-consuming side effects of otherwise resource-saving residential locations. Although the scope of these effects seems to remain modest, Naess' findings allow conclusions for both city planners and communal policy makers as well as individuals who aim to rethink their personal lifestyles.

Chapter 12 takes tourism to task. Carlo Aall, Michael Hall and Kyrre Groven transfer the concept of rebound from the energy to the climate field of research and policy making and demonstrate its application on aspects of both mitigation and adaptation for the case of skiing and winter tourism. This approach allows them to explain forms of mal-mitigation and mal-adaptation in this sector and to suggest a more solid policy agenda to avoid those. Hans Jakob Walnum and Anders Andrae look at rebound effects from cloud computing in Chap. 13. As cloud computing is said to deliver breakthrough efficiency improvements in the ICT sector, it serves as a prime example to discuss direct and indirect rebound effects from digital energy usage. However, Walnum and Andrae conclude the enabling effect of cloud computing, i.e. that it gives rise to new product and service innovations, will likely be larger than the rebound effect.

From the digital era back into the analogue world, Chap. 14 is devoted to identify possible rebound effects in road freight transportation that stem from technology changes as well as climate change mitigation policies. On this basis, Hans Jakob Walnum and Carlo Aall try to grasp how policies must be designed to achieve major GHG emissions reduction in that sector. With Chap. 15, part III sums up this volume's policy-oriented discussions by asking what implications the rebound phenomenon has for the quest of decoupling energy demand from economic growth. To profoundly illuminate the polarized debate between 'green growth' and 'degrowth', Jørgen Nørgård and Jin Xue systematically analyse the interrelationship between technological efficiency improvements, demographic developments and affluence levels of consumption. They discuss various policy options, including work sharing, reversed obsolescence and a progressive population policy, to sketch out viable pathways that may achieve a just reduction of global economic scale and a long-term sustainable economy.

In the conclusions (Chap. 16) to this volume, we will once again embed the rebound debate into the larger perspective of climate, energy and sustainability politics. We will summarize key findings, point out observations when comparing this book's various rebound approaches, argue that a new 'phase 5' of rebound research should carry the discourse one step further, but also highlight some weaknesses and general limits to rebound analysis.

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Part I
New Aspects in Economic Rebound Research

Chapter 2
After 35 Years of Rebound Research in Economics: Where Do We Stand?

Reinhard Madlener and Karen Turner

Abstract The phenomenon of rebound effects has sparked considerable academic, policy and press debate over the effectiveness of energy efficiency policy. In recent years, a plethora of theoretical and empirical rebound studies have been published, fueling the discussion but also raising further issues and unanswered questions. At the same time, it seems that there is a lack of understanding of how to treat and measure central aspects such as potential energy savings expected and the energy services impacted by an efficiency increase. Moreover, there is a lack of clarity and understanding in how we move from micro- to macrolevels of analysis and reporting. In terms of policy understanding, the crux of the problem is that there is no such thing as a simple formula for all aspects of rebound. The aim of this chapter is to clarify the correct perspective on how to look at economic dimensions of rebound, with particular attention to what policy-makers can do with rebound analysis and findings. Further, we attempt to synthesize existing rebound taxonomies and to provide, in a concise manner, the economic rebound mechanisms at work. We then approach the rebound theme from both micro- and macroperspectives, before bringing the two angles together. Overall, we argue that both policy-makers and researchers need to be aware that rebound is an issue that ought to be tackled at multiple levels and that there are policy trade-offs, especially between economic growth and ecological sustainability. This may be resolved at least to a certain extent by welfare considerations.

Keywords Energy economics · Economic rebound mechanisms · Rebound taxonomy · Economy-wide rebound

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R. Madlener (✉)
Institute for Future Energy Consumer Needs and Behavior (FCN),
School of Business and Economics/E.ON Energy Research Center,
RWTH Aachen University, Aachen, Germany
e-mail: RMadlener@eonerc.rwth-aachen.de

K. Turner
Centre for Energy Policy, International Public Policy Institute,
University of Strathclyde, Glasgow, Scotland, UK
e-mail: karen.turner@strath.ac.uk

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Increasing energy efficiency by implementation of new technology is still seen by many as a kind of ‘silver bullet’ for energy and climate policy in terms of its cost-effectiveness and many other benefits stemming from technological innovation. An intensive debate was triggered by Brookes and Khazzoom in the early 1980s on the remaining energy efficiency potentials in the presence of rebound. Rebound is triggered by the reduced cost of delivering or receiving an energy service when increased efficiency reduces physical energy input required. However, beyond this basic ‘trigger’, there has been debate in terms of how different types (and mechanisms) of the ‘rebound effect’ should be named, measured and reported. This debate has been partly between engineers and economists but also among economists and other social scientists. Over the last 35 years or so, critical minds have continually warned that rebound effects undermine the potential benefits to be reaped in terms of resource savings and make efficiency policies less attractive cost-wise (i.e. in terms of the physical energy savings delivered per monetary unit invested).

However, at the same time, it is important to note that rebound is driven by processes that also deliver economic benefits such as increased incomes, improved competitiveness, better quality of services etc. Thus, others have then joined the discussion by arguing that the energy-saving perspective is just one out of many that will be taken into account by policy-makers working in a context of multiple objectives. In this context, hence, there is a need for analyses to consider a careful balancing of the manifold and often delicate policy trade-offs involved. These tradeoffs, as well as the heterogeneity of energy efficiency and rebound impacts throughout the economy, require a better and sound understanding of the complex mechanisms at work. Besides, in more recent research in economics (e.g. Gillingham et al. 2016; Borenstein 2015; Turner 2013) rebound is considered less in terms of being exclusively a negative factor to be minimized (as ecologists would argue). Rather, many economists would argue that rebound minimization may or may not be the welfare-optimal outcome (due to opportunity costs of forfeiting the utility of energy services and related indirect benefits).

What is the right perspective to look at rebound?

Some of the existing rebound research has been very narrowly focused, for example by estimating direct rebounds—the intensified use of a durable good that has become more energy efficient, thus lowering the marginal cost of using the energy service in question. Other rebound studies have been extremely broad in focus, trying to attribute many or all increases in the energy use of society to rebound effects. That is, not just those stemming from technical efficiency improvements (thereby lowering the cost of providing an energy service), but extending, for example in Druckman et al. (2011), to those that stem from lifestyle changes (and simply involve a change in the level of use of an energy service with no change in cost). Van den Bergh (2011) also extends the concept of rebound to conservation activity, where the price of the resource (rather than the service delivered) will trigger an economic response. This raises questions in terms of what different authors mean when they refer to rebound, questions regarding the ‘trigger’ for rebound (and any economic benefits sharing that trigger), as well as what we regard as the potential or anticipated energy ‘engineering’ savings that any economic rebound response is measured against. This raises issues as to whether malfunctioning of new and energy-efficient hardware or a poor match between the technological capabilities of the hardware and the ability of the user to learn how to exploit these, is actually part of the rebound effect measured. Moreover, consideration of the trade-off between energy-use minimization and economic benefits raises questions such as whether energy *sufficiency* (i.e. voluntarily consuming less energy than one can afford) can be considered a viable option to combat rebound.

What can policy-makers do?

There has been a tendency in the rebound literature to regard rebound as ‘bad’ that policy-makers should attempt to minimize it in order to maximize reductions in energy use if energy efficiency policies are to be regarded as effective. Rebound has also been presented as something of an additive process, with the effect multiplying as consideration of the impacts on energy use extends beyond that of the user whose efficiency is the target of policy. A central objective of this chapter is to highlight contributions to date, and encourage greater focus in the future on the range of reasons why the rebound ‘problem’ is not so simple in its nature or implications as many believe, make believe, or hope for. At the most fundamental level, we raise issues regarding how policy expectations regarding ‘potential energy savings’ may be framed and determined in practice relative to how they are considered in different academic studies. That is, do policy-makers start from the perspective of a pure engineering saving so that zero rebound implies no response to energy efficiency improvements beyond the pure energy savings expected from engineering calculations? Transparency is required in rebound research regarding the perspective taken, on just what type of responses are analyzed, the nature of trade-offs involved, as well as the extent to which rebound mechanisms can be considered purely in economic terms.

We attempt to focus attention on developments in rebound research that can be of immediate practical use to policy-makers. For example, we highlight consideration of embodied energy ‘multipliers’ to assess the impacts of switching expenditures between more and less energy-intensive goods and services, and how impacts may vary at local, regional, national and (where there is concern over issues of pollution leakage/displacement or ‘carbon footprints’) global levels.

2.1 The Rebound Architecture

2.1.1 Another Taxonomy of Rebound Effects?

A common categorization of energy efficiency rebound is the one in direct, indirect and economy-wide rebound effects (cf. Turner 2013, Sect. 2). The complex nature of rebound, however, raises the need for introducing more layers, for instance in terms of source of efficiency improvement and whether this is on household (consumption) or the industry (production) side of the economy (of course the emerging notion of the "energy prosumer" blurs the division line between producer and consumer). However, we also have to consider the type of energy use concerned, as well as what share of the difference between potential/expected and actual energy savings is due to rebound and what is due to technical performance or human learning problems, or changes in lifestyles/preferences, that prevent the full efficiency improvement being realized. This lack of consensus and clarity in the rebound taxonomy—after 35 years of intensive rebound research and a burgeoning literature—is an issue on the micro-, meso-, and macrolevels, but relates especially to the indirect and economy-wide effects.

An important field of controversy concerns the issue of what is, or should be, called "rebound" and what is due to other effects. In this respect, studies that measure rebound need to be able to separate all other effects on energy use from those that are caused by energy service cost reductions due to an increase in technical energy efficiency. Another discussion is on what should be counted as an "energy service" in order to assign energy rebound effects.

Figure 2.1 summarizes the taxonomy of rebound. It shows that two very central distinctions are those between direct and indirect rebound effects on the one hand side, and between private household and firm rebound on the other hand. From the microlevel, which can be thought of either as the individual or firm/household level (cf. Fig. 2.2), the level of analysis can be widened by moving to the sectoral (meso)

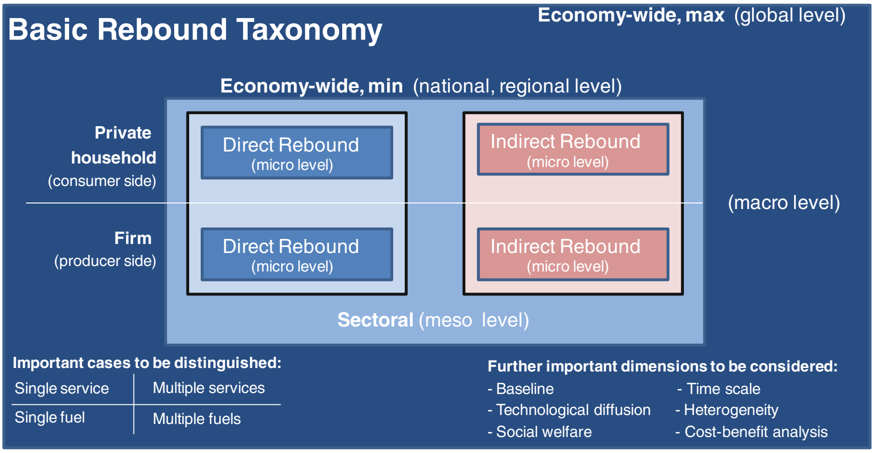

Fig. 2.1 Basic rebound taxonomy. The rebound literature is full of taxonomies, and taxonomy discussions, so that the reader is sometimes overwhelmed (at best) and often confused (at worst) by the many different versions. The present one is intended to be useful by being relatively simple and yet comprehensive

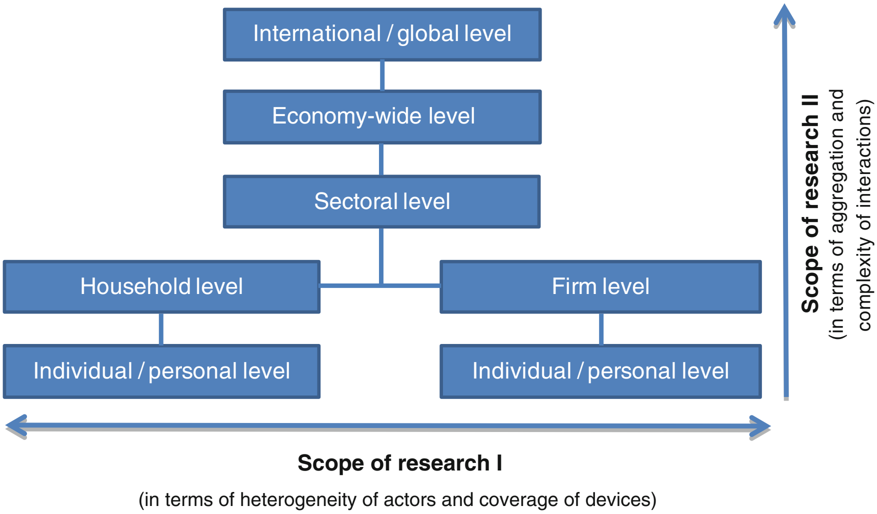

Fig. 2.2 Levels of rebound effects. Rebound can be analysed at different levels and by means of different methodologies/approaches. Dynamics and interdependencies remain hard to tackle, as do new kinds of energy services on which data may not yet be available

level of analysis, and on to a more macroeconomic, i.e. regional (province/state, urban/rural), national or global perspective. Further, the analyst needs to be clear about whether to study a single or multiple fuel energy rebound and whether a single service or multiple services are involved. The latter has to do with fuels such as electricity, which can be used for providing a multitude of energy services. Finally, the choice of an appropriate baseline, the time frame and dynamics of rebound, heterogeneity of consumers and firms, and social welfare considerations are important additional dimensions to deal with.

2.1.2 Rebound Mechanisms

Besides definitions of rebound and terminology, the mechanisms at work also need to be clearly identified. So far the probably most comprehensive collection of rebound mechanisms ("types of rebound pathways") is provided by van den Bergh (2011). The 14 mechanisms identified comprise the following: (1) direct rebound (price effect); (2) adoption of larger units or such with more functions/services; (3) respending (income effect); (4) extra demand for energy-intensive goods (composition effects); (5) changes in the processes of one phase of the product chain or life-cycle on a later phase/later phases; (6) change in factor input mix; (7) increase in total factor productivity and production output; (8) energy efficiency induced relative price changes rippling through the economy (general equilibrium or macroeconomic effect); (9) international trade and relocation effects; (10) capital investment and accumulation effects; (11) technological innovation and diffusion effects; (12) changes in preferences; (13) indirect energy use effects due to investment in new technology (embodied energy effect) and (14) time savings (time rebound effect). It becomes clear that some mechanisms overlap with the definitions of certain types of rebound (e.g. direct, indirect, economy-wide and macroeconomic rebound). Additional mechanisms that can lead to rebound effects are identified in later chapters of this volume (most notably, in part II).

Note that a useful analysis is likely to involve more than simply attempting to aggregate over the different rebound effects that can be investigated along these rebound pathways or mechanisms to arrive at a single overall rebound effect. Rather, they all take a different perspective of how induced technical energy efficiency improvements ripple through the economy and, thus, need to be understood individually. Further below we will discuss that some rebound categories impact each other (i.e. if the direct rebound is large, indirect rebound from re-spending can, under specific circumstances, be expected to be small) and that some rebound effects have a negative sign, thus compensating positive rebound effects elsewhere in the system.

Figure 2.2 makes the two dimensions more explicit that complicate matters in rebound research. One dimension is the scope of research in terms of the aggregate investigated (from the household and firm that are both composed of individual actors or decision-makers all the way from sectoral-, economy-wide- to the international and global level of analysis). This impacts the complexity of interactions that need to be tackled. The other dimension has to do with the heterogeneity of actors considered, the heterogeneity of devices and energy services involved, and the multi-tasking increasingly enabled by software agents and automation.

In terms of type of research and analysis, we move up from very micro, partial equilibrium analysis (at the household and firm level) through micro-/meso-level but still partial (sectoral level) analysis to the analysis of inter-sectoral effects. Such inter-sectoral impacts (supply chain interdependencies; see below) can most easily be addressed by studying multiplier effects—even where prices are assumed to be fixed. When prices are flexible, changes in demand and impacts on revenues matter, rather than just the required capacity, while macroimpacts may be limited. On this basis, one may decide to potentially link meso-level and economy-wide rebound analysis. Note that at the level of inter-sectoral analysis, we have a combination of still partial effects (prices may still be fixed) but working with meso-level or economy-wide input-output (I-O) analysis, e.g. for the computation of multiplier effects or, alternatively, general equilibrium impacts (to capture inter-sectoral effects while also allowing for the price changes involved). Finally, for international/global analysis of rebound, I-O multiplier analysis is still relevant in terms of partial analytics, although economy-wide analysis (e.g. by means of computable general equilibrium, CGE, modelling) could extend up to the inter-country global level where changes in relative prices and terms of trade are likely to be important.

2.2 The Micro Perspective

2.2.1 Enhanced Microeconomic Foundations

There have recently been some key contributions in the area of micro-level rebound analysis. First, Borenstein (2015) shows that non-marginal cost pricing, as it is often used in a utility industry context, may have a large impact on rebound effects due to income effects. Moreover, he discusses some implications of substitution and income effects when sub-optimal behaviour on the one hand leads to an "energy efficiency gap" (i.e. seemingly rational but nonetheless ignored opportunities for monetary savings by improving energy efficiency), and on the other hand reduces substitution-effect rebound.

Chan and Gillingham (2015) focus on the direct rebound effect and aim at guiding both modellers—on the usability of the canonical relationships between different elasticities relevant to the rebound effect (e.g. efficiency elasticities and price elasticities of energy demand)—and policy-makers—on how to take welfare considerations into account when dealing with rebound effects. In contrast to many studies in which the analysis is simply based on demand functions (and a grossly simplified world with only one fuel and a single energy service), and not on the underlying consumer preferences, they deal with the implications of studying situations with multiple fuels and multiple energy services. In doing so, they show that empirical estimates may be severely upward or downward biased depending on whether the energy services considered are gross substitutes or gross complements. They conclude that commonly used elasticity identities are especially problematic for investigations of household electricity consumption, but likely less of a problem for investigating petrol use for car driving. In terms of welfare analysis, the authors find that efficiency improvements are more likely to enhance welfare when the surplus gained from energy services is high, when service-based external costs are low, and when the rebound effects are modest. Interestingly, and less intuitively, the authors further demonstrate that when pollution-induced external costs are high for other goods and services, then the welfare effects depend again on whether the energy services in question are gross complements or gross substitutes to each other.

2.2.2 New Empirical Evidence on Direct and Indirect Rebound

In recent years, a number of empirical studies have been published on both the direct and the indirect energy rebound. Only a few studies, typically only investigating direct rebound effects, have so far focused on rebound heterogeneity (e.g., Madlener and Hauertmann 2011—residential space heating; Frondel et al. 2012; Wadud et al. 2010—automobile travel; Saunders 2013—manufacturing industry).

By and large, these studies come to the conclusion that rebound varies considerably among the different energy-using groups investigated. For private households, these may be income-rich versus -poor groups of society, owners versus tenants etc. In manufacturing, it is a well-known fact that industries differ a lot from each other, and in automobile travel demand these studies even find large differences, for instance, in the direct rebound estimates between the US and Europe (Germany), the former interestingly being much smaller than the latter.

2.2.3 Further Research Needs

Aside from the benefit to "pause and reflect" (Turner 2013) before undertaking more rebound research, especially empirical work using the same limited approaches over and over again (e.g. the use of simple estimates of the elasticity of energy demand with respect to energy price as proxies for direct rebound effects), there are research needs in terms of scope, theoretical advancement and methodology.

In light of a rapidly changing world, with many new kinds of energy services being provided in an increasingly digitalized and automated economy and society, there seems to be an urgent need to undertake more research on such new services, provided the data are available.

Moreover, there is definitely a need for more sound empirical evidence on under-researched energy services but also on particular types of countries and regions. For China, for instance, an impressive number of new, by and large empirical studies have emerged over the last years (e.g. Lin and Tian 2016; Lin and Liu 2015; Lin and Du 2015; Wang et al. 2012, 2014). However, there is a dearth of work particularly on energy efficiency and rebound in developing/low-income countries, where rebound in itself could be positive in terms of investment in, and uptake of, even quite basic energy service systems.

The theoretical contributions of Borenstein (2015) and Chan and Gillingham (2015)—mentioned above—identify new challenges for applied research of energy efficiency rebound (beyond the relatively straightforward estimation of energy price elasticities). The former sheds new light on the size of rebound effects when (1) goods are not priced at marginal cost; (2) when consumers are optimizing their utility in an imperfect manner and (3) the role of technological progress. On the other hand, the latter study makes an attempt to cast rebound analysis in a more generalized modelling framework that formally enables to incorporate welfare optimization considerations. Furthermore, both studies emphasize that elasticity identities—e.g. that efficiency elasticities can be treated as equal to price elasticities of energy demand—must not be used lightheartedly given that the complement and substitute relationships govern their validity.

From a methodological point of view, econometric rebound estimates are limited in many ways, not just because they are typically based on standard assumptions, so that they comply with microeconomic theory or are simply easier to handle, but also because the functional form impacts the results. For example, if global concavity is forced on a translog model, a fairly flexible functional form that has been frequently used in energy demand studies, then this automatically leads to backfire, i.e. rebound greater than 100 % (cf. Saunders 2008, 2013).

Hunt and Ryan (2011) use a utility-theory-based model with multiple energy services and multiple input fuels, thus also starting off from the underlying preferences rather than just demand functions. They find that due to the unavailability of expenditure data on each energy service, empirically estimating rebound effects in such a framework is very difficult.

2.3 The Macroperspective

2.3.1 Differences in Economy-Wide and Macroeconomic Methods and Focus

Generally, economic rebound occurs where a portion of the potential (engineering) energy savings from uptake of efficiency-enhancing technologies are offset by a variety of economic responses triggered by the initial change in the price of energy services faced by a more efficient user. This user's response to the initial energy service price impact gives us direct rebound. However, as argued in the growing literature on rebound effects, this is only a part of the story—and potentially just a small part. A variety of indirect and economy-wide rebound effects also come into play as prices and incomes adjust throughout the economy and as expenditure and production decisions change. The net effect of these various mechanisms gives us economy-wide rebound. For example, cost-effective energy efficiency improvements by producers (e.g. steel manufacturing) lower the marginal cost of energy services, thus encouraging increased use of those services, as well as lowering output prices. This boosts economic productivity and competiveness (both in the sector where efficiency improves and downstream, e.g. in white goods manufacture), thereby triggering economic expansion and, consequently, energy use throughout the economy. This is the type of productivity-led expansion considered by Jevons (1865) in what has come to be widely considered as the first thesis on the rebound effect. It is also what Greening et al. (2000) implicitly identify as the source of 'secondary' rebound when firms increase the efficiency with which they use energy. In his consideration of more efficient use of coal in the context of productivity-led expansion during the industrial revolution, Jevons (1865) also highlights what has come to be known as the backfire argument that is developed by Brookes (1990, 2000), Saunders (1992, 2000) and others.[1]

Consideration of economy-wide rebound is also relevant in the context of efficiency improvements in household energy use. If households improve the efficiency

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[1] More recent survey contributions focusing on the issue of backfire are provided by Alcott (2005), Dimitropoulos (2007), Sorrell (2009), Madlener and Alcott (2009) and Azevedo (2014).

with which they use energy—for example, by installing a condensing boiler that uses less gas to produce a given amount of hot water—this frees up income to spend on other goods and services (e.g. going on holiday or buying a new TV). This changed and additional consumption of services may involve direct energy use by the household, but also indirect use of the energy that is 'embodied' in all goods and services from different stages of their supply chain, both within their home economy and abroad. However, this is demand—rather than productivity-led expansion and shifts in domestic consumption patterns may also change the demand for locally produced and imported goods relative to exports. Thus, depending particularly on labour and capital market responses, there may be negative impacts on economic activity, prices and energy consumption in a range of different industries, markets and regions (Lecca et al. 2014).

While such arguments are intuitive and have (to varying extents) been explored in a number of studies over the last ten years, the evidence on the size of economy-wide rebound effects remains limited, contradictory and controversial. One crucial issue is that rebound from increased efficiency in household energy use has been the subject of most microeconomic studies of direct rebound. However, investigations of economy-wide rebound (particularly those using CGE models) have tended to focus more on impacts of industrial energy efficiency. This has led to some confusion (and conflation) in relating analyses and results from direct rebound studies to investigations of economy-wide rebound that are essentially analyzing different things.

However, there are issues of comparability even among economy-wide rebound studies that share a focus on industrial energy efficiency. In the major review of rebound evidence reported in the UK Energy Research Centre (UKERC) study edited by Sorrell (2007), economy-wide rebound findings from studies using CGE modelling studies ranged from 37 to >100 %. The UKERC review established common ground across the studies in terms of cases of backfire generally being limited to cases where energy efficiency improves in highly energy-intensive and traded electricity production. However, a key conclusion was that economy-wide rebound is dependent on the nature and location of the energy efficiency improvement and the economic conditions prevailing in the economy under study.

The findings of more recent CGE studies reiterate this conclusion. For example, Broberg et al. (2015) report that rebound and other micro- and economy-wide impacts of increased industrial energy efficiency in Sweden are dependent on a range of factors, particularly costs of introducing efficiency improvements, energy intensity of the sector where efficiency improves, and how the labour market functions. The key implication is that it is generally not possible to directly relate the findings of individual CGE studies, or to compare between CGE studies simulating 'what if' scenarios and macroeconometric studies analyzing historical trends or forecasting future ones.

This latter point is key in distinguishing between economy-wide studies, which consider rebound in the context of a full range of impacts across the economy, including those on key macroeconomic variables such as GDP. Macroeconomic rebound is often considered through macroeconometric studies that take an *ex post* perspective on aggregated effects on energy demand as the energy intensity of the economy is observed to have changed over time. Economy-wide rebound studies, in contrast, tend to focus on *ex ante* ‘what if’ scenario analyses involving simulation of how the impacts of an energy efficiency in one or more sectors of the economy ripple out through various markets and mechanisms.

That the problem of comparability across different macroeconomic and economy-wide rebound studies continues is further evidenced in IEA (2014). The studies reviewed there involve a range of different methods and models applied to different types of energy efficiency improvements in a range of countries and geographical regions, with some using CGE simulation models to consider a range of ‘what if’ type scenarios, while others (e.g. Barker et al. 2007, 2009) use econometric methods to project future rebound effects of different policy packages. Moreover, while some studies focus on impacts of pure efficiency improvements, others focus instead (or as well) on the expansionary impacts of investment decisions preceding the implementation of actual efficiency improvements.

2.3.2 Economy-Wide Sectoral Level Impacts Versus Macroeconomic Effects and the Questioning of a Single Rebound Measure

It is important to distinguish between the provision of CGE and other macroeconometric modelling techniques for another reason. A key issue demonstrated in multi-sector CGE modelling studies of energy efficiency improvements is that, even where high-level general equilibrium impacts on macroeconomic variables such as GDP are limited, there can be important inter-sectoral effects.

For example, Anson and Turner (2009) find that a 5 % improvement in efficiency in energy use in the Scottish passenger and freight transportation industry has what may be considered limited impacts on key macroeconomic variables, generating long-run changes in Scottish GDP and employment of around 0.02 %. However, this is accompanied by important impacts in the domestic fuel supply industry, including a short-run decrease in revenues and return on capital that triggers what Turner (2009) terms as a ‘disinvestment’ effect. To halt a process of shedding capital stock/mothballing of production capacity, the local price of refined fuel—which initially falls due to decreased demand from passenger and freight transporters—has to rise again to restore the return on capital and achieve a new equilibrium in the sector (at a reduced level of activity) and the economy as a whole. This, in turn, impacts on fuel and other energy demands and rebound effects at sectoral and economy-wide levels over time.

More generally, building on the sectoral detail of input-output and social accounting matrix databases, CGE modelling studies consider economy-wide rebound through the lense of up- and downstream supply chain interactions and impacts channelled through changing quantities, prices and returns in markets for different goods and services as well as for capital and labour. This offers the advantage of being able to identify and consider both increases and decreases in different types of energy use in different areas of the economy when energy efficiency increases in any one (or more) sector/s. In this respect, multi-sector CGE models do respond, to some extent, to the need to incorporate an extent of meso-level detail beyond a purely 'top down' macroeconomic approach. However, studies must be transparent in terms of their assumptions and specifications in key areas of CGE model specification that influence price, capacity and output decisions particularly in energy supply and demand. For example, Turner (2009, 2013) explains that where the return on capital in energy supply sectors is assumed to be fixed or exogenously determined, any downward pressure on long-run rebound through the aforementioned disinvestment effect will not be captured.

However, there is a more fundamental problem in the form of a lack of agreement and clarity in the literature regarding how 'rebound' should be measured. Moreover, this is amplified when we move to the economy-wide or macro-context where a wide range of potential and complex mechanisms come into play. One issue is that rebound research generally has tended to neglect the issue of energy supply responses to changing demand, prices and profitability. Moreover, as noted above in the context of Borenstein's (2015) work at a microeconomic level, economy-wide studies have neglected the issue of non-marginal cost pricing in energy supply industries. Turner (2013) notes that energy market effects may impact what have become accepted theoretical underpinnings for a single rebound measure at the macroeconomic level. In particular, lower prices in energy markets may confound the zero rebound condition identified by Saunders (2000) while higher prices cast uncertainty on his 100 % rebound condition. This raises the question of whether these reference conditions for macro-level/economy-wide rebound should be reconsidered in light of energy market effects or does the notion of a single measure become less useful as a multitude of determining factors are identified?

Indeed, one specific example of where a single rebound measure beyond the direct level may cause confusion arises in the context of Guerra and Sancho's (2010) argument regarding definition of rebound in a general equilibrium context. The crux of the Guerra/Sancho argument is the treatment of any downward quantity (but not price-driven) adjustment in (direct or indirect) energy use in the supply chains serving any energy commodity directly impacted by an efficiency improvement (e.g. different fuel uses in both gas extraction and supply serving a gas-fired electricity station servicing households that have increased the efficiency with which they use electricity). They argue that this should be considered as part of the potential energy saving (PES) in the denominator of the conventional rebound (R) calculation (where $R = [1 - \text{AES/PES}] \times 100$, with AES being actual energy savings). Turner (2013) disputes this, arguing that, since indirect savings in energy supply chain activity will not be known *ex ante* (unless policy analysts have access to appropriate fixed price input-output models), practical considerations and the understanding of policy-makers should overrule the strict general equilibrium conditions that Guerra and Sancho (2010) propose. The Turner argument is that the PES in the denominator of the economic rebound calculation should be restricted to projected engineering savings (that is, proportionate to the extent of the efficiency improvement), with all other changes in energy use (positive and negative) that occur as a result of economic responses included only in the actual energy savings in the numerator. In this respect, Turner's economy-wide argument coincides with the microeconomic one of Borenstein (2015) in arguing that substitution between more and less energy-intensive goods and services will put downward pressure on rebound, and may even lead to net negative rebound effects.

Whatever the stance one takes on this particular argument, the central lesson would seem to be that there is a need not only for the identification of solid theoretical foundations for the range of mechanisms governing indirect and economy-wide rebound effects. On the one hand, there is a need for the development of a common and transparent methodology for how impacts on different energy uses are brought together in a single rebound measure. On the other hand, it may also be argued that the definition and measurement of a single 'rebound' measure is in danger of becoming a distraction from actually understanding and explaining how energy efficiency improvements work and impact on a full range of activities and agents in the wider economy in different case study and policy contexts. From this perspective, it may be more important to clearly report and explain a full range of both upward and downward impacts on energy use in different sectors of the economy when energy efficiency improves in any one sector. Moreover, this must be set in the context of both economic benefits (e.g. increased income in low-income households) and costs (e.g. contractions in activity and employment in fuel-refining activity) that accompany these changes.

This latter argument corresponds with that of the IEA (2014), where energy efficiency and rebound are considered in the context of a 'multiple benefits' framework. This involves consideration of impacts on a range of indicators including energy prices, supply security and poverty, along with GHG emissions (the 'energy trilemma'), alongside a range of macroeconomic indicators such as GDP, employment and public budgets, as well as 'health and well-being'. A key role of multi-sector economy-wide modelling in this wider policy context would then be scenario analysis to consider how benefits in different sectors may be maximized while 'costs' of physical resource use (which must be clarified beyond simple arguments of energy saving) are minimized. This viewpoint is shared by Gillingham et al. (2016), who argue that rebound has come to be perceived as an 'evil' with an implicit focus on energy minimization rather than welfare maximization. Gillingham et al.'s argument reiterates that in the introduction to this chapter regarding the need to balance multiple and often delicate policy trade-offs. In this context, the key question is not one of focusing on mitigating rebound, rather it is one of whether rebound can be reduced (thereby maximizing energy savings or emissions reductions) without sacrificing the macroeconomic, welfare-enhancing benefits that share the same trigger. This may be possible if increased energy efficiency in a particular sector (e.g. public transport) leads to a change in the relative price with a more energy-intensive competitor (e.g. private transport). In the public versus private transport example, the central issue is the extent to which households are prepared, or can be persuaded, to respond to the increased competitiveness of public transport by substituting away from private options in their (increased) consumption bundle. As this increases, it may be possible to reduce economy-wide rebound (which includes petrol/diesel use by households) through a change in the composition rather than the level of economic activity. In this context and more generally, analysis should ideally extend to identifying and understanding the distributional implications across different industries and households. Where there is a binding constraint underlying the need to reduce energy use (e.g. climate change commitments), taking a welfare-maximizing perspective implies that this should be treated in a similar way to any other macrolevel constraints (on government budget, balance of payments etc.).

2.3.3 Research Needs

There is a clear need to clarify the role of economy-wide and macroeconomic analyses and modelling in energy efficiency policy analysis. Put simply, what are the questions that policy-makers need answered? Macroeconomic rebound analysis is appropriate if questions related to how the energy intensity of a growing economy has changed in the wake of technological progress (though causality may be difficult to infer from correlation). On the other hand, if policy-makers are more interested in what may happen to energy use in different areas of the economy in response to different energy efficiency initiatives, economy-wide scenario analysis is more appropriate. Given that the motivation for this chapter is to consider the state of understanding of rebound effects at different levels, we have focused more on the analysis of mechanisms driving economy-wide rebound. However, particularly as we move to the level where economy-wide rebound is considered in the context of a range of macroeconomic indicators (IEA 2014), it is not clear that the questions that have engaged the research community align with the concerns and analytical needs of policy-makers.

Therefore, a starting point in setting out research needs at the macrolevel is less about debating over the ‘right’ way to define macroeconomic or economy-wide rebound, or whether CGE models do a ‘better’ job than, for example, macroeconometric models. Rather, our focus should be on considering how economic rebound mechanisms impact different outcomes that policy-makers are concerned about and how best to develop and report analytical frameworks for policy-relevant analyses.

In informing this process, a key research need is to establish the type of microfoundations we need in CGE or other ‘whole system’ models, as well as in meso-modelling frameworks. In modelling, just how efficiency improvements actually occur in different sectors of the economy—including any technology uptake or investment decisions involved—we must consider whether this can be configured in the micro-specification of an economy-wide model or whether soft/hard linking between micro, meso, economy-wide or macromodels is required.

The next challenge, then, is to establish the key specifications required to consider how economy-wide impacts may spread through interactions between different agents through different markets in the context of macroeconomic closures and constraints. That is, to improve key specifications in terms of, for example: how labour and capital markets function and respond to the changes in economic behaviour triggered by energy efficiency improvements at the microeconomic level; how government may look to spend additional revenues or balance budgets; how we model dynamic adjustment processes etc.

Lessons learned from existing economy-wide rebound research suggests that there is a serious need for serious research on how we model different elements of energy supply. This is both in terms of pricing and capacity decisions (set in a context where imperfectly competitive market structures tend to prevail in practice) but also understanding key issues such as energy use (and related emissions) embedded in energy and non-energy supply chains.

In this context, there is also a need to consider how different elements of models and sub-models may provide useful tools for policy analysts. For example, in the previous subsection we have considered the debate over how negative and positive impacts on energy use embedded in energy and non-energy supply chains should be treated in rebound calculations. This argument is concerned with what are commonly termed 'negative multiplier' effects in reallocation of spending between different types of goods and services when income is freed up from spending on energy when efficiency improves. Many policy analysts are familiar with the concept of input-output-based multipliers that, computed from published input-output accounts, report the level of output, employment, emissions, energy use etc. required throughout the economy for one monetary unit of final demand spending on the output of (or commodity produced by) any given sector or industry. From this perspective, calculating and reporting 'output-embodied energy' (and related GHG) multipliers from input-output databases that underlie CGE models provides a useful tool for policy analysts. This facilitates basic assessment of whether economy-wide energy use impacts of any switch in spending between two or more commodity outputs are likely to be positive and negative. Where there is an interest in pollution leakage or global 'footprint' impacts of spending decisions, recent availability of inter-country input-output databases such as WIOD[2] allow multiplier analyses to extend their focus beyond domestic supply chain impacts. At the other end of the spatial scale, the availability of regional input-output accounts permit multiplier methodologies to be deployed as a tool for policy analysis were energy efficiency initiatives are implemented at a sub-national level.

More generally, there is a need to develop the type of modelling frameworks that give policy-makers the answers they require to make informed decisions. CGE models sit between more top-down purely macroeconomic approaches and more bottom-up, data-rich meso approaches. Rather than continue debates over macroeconometric versus CGE (particularly in the current absence of research activity at the meso-level), there is a real need to focus on the type of questions policy-makers need answered and select models/suites of models on this basis.

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[2] http://www.wiod.org/new_site/home.htm.

2.4 Putting the Two Perspectives Together

2.4.1 The Micro Level as the Starting Point Triggering Rebound and Other Economic Processes

The study of human behaviour, also in economics, naturally starts at the level of the individual (person or household). The overall economy is understood as a system composed of individuals, and individual decisions, that in the aggregate lead to an entity called "the economy". How the individual and groups of agents then interact in the wider economy gives us the next level for investigation.

2.4.2 Limitations to Microlevel Analytics, Need for Multi-level Analysis, and Link to Other Research Disciplines

Due to the many impacts rippling through an economy following an energy efficiency improvement in any one sector, the micro-level analysis needs to be complemented by meso- and macrolevel analysis. Likewise, standard economic analysis needs to be complemented by analysis rooted in other research disciplines, such as psychology, sociology and engineering.

2.4.3 Need for Partial Equilibrium Analytics and Relevance of a Meso-level (Sectoral) Analysis

The meso level has been neglected in rebound research to date. While micro-level research continues to provide insights on how individuals respond to energy efficiency changes, and multi-sector economy-wide CGE analyses capture key interactions between sectors, there is a 'missing level' to rebound analytics. Economy-wide models such as CGE build on microfoundations but generally this involves aggregation to representative household and industry level groupings that then interact through markets within a context of a set of macroeconomic 'closures'. However, there may be missing insights in terms of the dynamic and complex interactions between individual technologies and different groups of actors (with heterogeneous characteristics) at the level of different system elements. This may occur at the sectoral level and give rise to key regime/group behaviours that are important in terms of the response of different societies to energy policies. Moreover, as argued by Santarius (2015; see also Chap. 5 in this volume), meso-level analysis may uncover a layer of rebound effects arising from sectoral level interactions that would not be uncovered by micro- or macro-focused analyses. This again raises the issue of economy-wide versus macroeconomic rebound analyses: in Sect. 2.1, we have highlighted the use of CGE to consider important inter-sectoral effects even where macroeconomic impacts (e.g. on GDP) are limited. To what extent would meso-level analyses add value in analyzing the type of effects identified there?

2.4.4 Limitations to General Equilibrium Analytics in 'Whole System' Analysis

In general equilibrium analytics, there is an important trade-off between conformity with general equilibrium theory and the impact assumptions of the functional forms have on the outcome. For example, a common assumption in the aggregation across sectors is that consumer utilities follow a Cobb-Douglas functional form. This, however, albeit being very convenient, assumes that demand for sectoral outputs are independent from each other and can be aggregated easily (cf. Saunders 2013, p. 1325). Likewise, assuming perfect elasticity of labour, materials and energy supply is consistent with the extreme of perfect market clearing in neo-classical general equilibrium theory, but may lead to systematic distortions of unknown sign and magnitude). Hence, the question arises how to best deal with such "hidden effects" arising from assumptions considered necessary based on theoretical grounds.

Of course, it should be emphasized that CGE modellers are increasingly challenging the restrictions of historical comparative static neo-classical general equilibrium theory to incorporate considerations of imperfect competition (particularly in labour markets where unemployment and wage setting are important realities) and to consider dynamic adjustment processes. However, particularly in recognition of energy supply issues raised in more recent rebound contributions, the question remains as to how general equilibrium models can be improved in such a way that they better fit the theory. Or should the theories be modified (enhanced) in order to provide a more realistic picture of what is actually happening in an economy? In this respect, and again emphasizing the importance of how energy supply is treated, there is a real need to consider how issues such as engineering insights on issues such as physical constraints and technological innovations may inform and be informed by the insights of economic models at all levels. More generally, is there a need to consider suites of soft- or hard-linked economic, engineering, sociological etc. models that may offer more integrated insights on a wide range of energy-economic system issues?

2.5 Conclusions, Policy Recommendations, and Outlook

In this chapter we have discussed some of the achievements and some of the remaining issues and problems in rebound research. We argued that despite the considerable attention rebound phenomena have seen in recent years, there are quite a few open questions. Probably, the most challenging item on the list is how to move from micro to macrolevels of analysis, and how to provide simple messages regarding what policy-makers can do with the evidence that is provided by rebound researchers. We conclude that rebound should be taken as a complex phenomenon that in principle needs to be tackled at multiple scales, and be analyzed from different perspectives. A holistic picture and comprehensive analysis of rebound effects calls for interdisciplinary and integrated research, but bears the danger of becoming fuzzy. Moreover, all methodologies available have their limitations and, even worse, may lead to different results. Hence, decision-makers should be cautious with regard to false interpretations of insights, or unjustified comparisons across studies, sectors and regions.

At the microlevel, we conclude that while there is a need for further and sound (unbiased) empirical estimates also of new energy services, relying on direct rebound for policy guidance is clearly insufficient and one-dimensional. Further, despite the insights on important interactions and interdependencies between sectors of multi-sector CGE models, there is a real need for meso-level analyses to provide insights on complex behaviours between different types of actors. We also argue that extending consideration of multiplier effects beyond the industry level focus of input-output and CGE models to micro- and meso-level analyses can provide very practical, useful and complementary insights to policy-makers. Finally, we have identified more generally a need for much better policy guidance and ‘usability’ in view of the multi-facetted implications of rebound and the trade-offs involved. This is especially so between economic expansion and resource efficiency, but also regarding a systematic (and ideally comprehensive) inclusion of welfare analysis in rebound research. Policy-makers need to learn (and be educated) on how to “work with rebound”, and to better understand the various rebound mechanisms at work at different levels, in order to be able to mitigate the ‘bads’ associated with rebound while maximizing the merits.

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Chapter 3
Indirect Effects from Resource Sufficiency Behaviour in Germany

Johannes Buhl and José Acosta

Abstract The notion of rebound effects commonly suggests that an efficiency strategy is found to be insufficient to address an absolute reduction of raw material consumption. Advocates of eco-sufficiency claim that renouncing affluent consumption could limit resource consumption appropriately. Still, the literature on sufficiency fails to empirically corroborate their strategy. In this respect, the question is, to what extent sufficiency is prone to rebound effects. This chapter strives to empirically investigate indirect rebound effects arising from sufficiency behaviour. It shows estimates of income elasticities from national surveys on income and expenditures in Germany. Re-spending of savings is analyzed for abatement actions in the fields of housing, mobility and food. The chapter discusses findings concerning rebound effects from sufficiency with respect to policy implications and methodological issues.

Keywords Rebound effect · Income effect · Resource use · Consumption

Academics and politics commonly assume that a sufficient reduction of resource consumption is needed for an absolute decoupling of resource use from economic growth. But despite of an increase in resource efficiency over the past decades, resource use is still rising. Critics of eco-efficiency consider the strategy to be

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J. Buhl (✉) · J. Acosta
Wuppertal Institute for Climate, Environment, Energy,
Doeppersberg 19, 42103 Wuppertal, Germany
e-mail: johannes.buhl@wupperinst.org

J. Buhl
Faculty for Social Sciences, Economics and Business Administration,
University of Bamberg, Bamberg, Germany

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inappropriate to address an absolute reduction of resource use.[1] On the other hand, they support the idea of eco-sufficiency. Only eco-sufficiency is capable to transform production and consumption in a sustainable way without generating rebound effects (Santarius 2012). “Absolute decoupling of prosperity (wealth, satisfaction, happiness) from economic growth, and economic growth from resource use (use of nature) will only be possible, if [. . .] our consumption and production patterns move towards sufficiency” (Irrek 2012, p. 284).

We question, however, whether eco-sufficiency is truly a strategy that is immune to rebound effects or just as prone to rebound effects as eco-efficiency. In order to discuss our research question, we first introduce the strategy of resource sufficiency and then, in Sect. 3.1, we identify resource sufficiency behaviour. We subsequently present methods and data to show how to calculate rebound effects arising from resource sufficiency behaviour. Sections 3.3 and 3.4 show the methodology and data and Sects. 3.5 and 3.6 discuss the findings and conclusions.

3.1 Literature on Rebound Effects from Eco-Sufficiency

Whereas Alcott (2008) stated that the existence of sufficiency rebound is “a certainty” (p. 777), Figge et al. (2014) highlighted that limiting resource consumption by renouncing affluent consumption behaviour may theoretically go either way. Either the decreasing demand lowers the prices, or suppliers decide to raise the prices as a result of lower demand. Both studies introduce rebound effects from sufficiency as a result of consumers newly entering the market after an overall price decrease. Druckman et al. (2011) think of sufficiency rebound effects differently, as a result of individual “abatement actions” in daily life affecting individual consumption behaviour correspondingly.[2] Later Chitnis et al. (2014) explicitly refer to rebound effects due to abatement actions as sufficiency rebound effects. They analyze rebound effects coming with a reduction of the indoor temperature, avoiding food waste and not travelling short distances by car. In this respect, Berg

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[1] By definition, efficiency is a relative concept. The strategy of eco-efficiency is supposed to reduce resource use while increasing the (economic) return of the transformation activities in the economy. Thus an increase in efficiency does not state an absolute reduction of the input. Just as well, a gain in efficiency describes an increasing return while the input of natural resources remains constant or has been reduced.

[2] “[The sufficiency strategy] is not the same as consumption efficiency, by which is meant behaviour that achieves a given level of utility with less (energy) input: e.g., boiling only the amount of water needed for the cup of coffee, switching off unneeded lights, or carpooling. [**...**] Sufficiency, in contrast, means doing without the cup of coffee, getting by with dimmer lighting, and not taking the car” (Alcott 2008, p. 771).

It is not the idea of sufficiency behaviour that differs between Alcott (2008) and Druckman et al. (2011), but how rebound effects may emerge from sufficiency behaviour, i.e. (other) consumers entering markets due to lowered prices versus. (the same) consumers re-spending income gains due to abatement actions.

et al. (2014, p. 26) “are specifically interested in abatement actions that may lead to significant savings in resource and energy consumption and do not require (major) capital investments […]. From a microeconomic point of view, such actions are cost-effective measures to significantly reduce energy and resource use. From a socio-cultural perspective, the actions aim directly at changing social practices in the long run.” Abatement actions are low cost and do not come with capital costs as rebound effects from technological efficiency gains are likely to. At the same time, they wonder “to what extent are those resource and energy savings compensated by re-spending of the saved money”, i.e. indirect rebound effects. The estimates of indirect rebound effects from sufficiency by Druckman et al. (2011) and Chitnis et al. (2014) do not differ much from estimates of indirect rebound effects from efficiency. We follow this line of research and the corresponding understanding of sufficiency rebound effects as an effect stemming from abatement actions.

Generally, only a few studies focus on rebound effects as “the unintended consequences of actions by households to reduce their energy consumption” (Sorrell 2010, p. 8) and thus, take rebound effects from sufficiency behaviour into consideration. The studies presented basically derive energy, carbon or GHG emission intensities of consumption usually from Input-Output Analysis or Life Cycle Assessments (or a mix of both) and combine it with the estimation of income elasticities derived from econometric analysis of microdata on income and expenditures. Not surprisingly, they differ substantially in terms of data used, estimators used or the behavioural changes they examined.[3]

Lenzen and Dey (2002) analyze a shift in diets to recommended dietary intake (RDI). The authors show backfire effects when they allow for re-spending the savings from an adjusted diet. Net effects show an increase of energy use of 4 % in the highest income quintile and 7 % in the lowest income quintile stating rebound effects between 112 and 123 %. Alfredsson (2004) analyzes similar shifts in diets. She analyzes greened diets according to nutritional recommendations that come with less meat and dairy products. She allows for re-spending monetary savings across nine arrays of consumption from transport to health including the one where the savings occurred, namely food. As a result, reduced energy consumption is overcompensated by 140 % and consenting with the findings from Lenzen and Dey (2002) reporting backfire of greened diets.

A more recent study by Murray (2013) differentiates between efficiency and conservation scenarios. The conservation scenario includes behavioural changes due to e.g. going by bike instead of by car, taking shorter showers or turning off lights and stand-by appliances. In terms of greenhouse gases, applying the conservation scenario in the field of mobility and fuel use comes with a rebound effect between 12 and 17 %, respectively. Households with lower income show higher rebound effects. A similar effect can be seen when the conservation strategy is applied to household electricity, showing rebound effects between 4.5 and 6.5 %. In

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[3] A comprehensive methodological analysis of studies on indirect rebound effects from technical and behavioural changes can be found in Sorrell (2010).

both cases, rebound effects from the application of the conservation scenario are lower than from the efficiency scenario. However, the identification of conservation scenario by Murray (2013) is rather opaque. Fuel use reduction is assessed to be equally high using the conservation scenario and efficiency scenario. All in all, the behavioural changes concerning household electricity are a conglomerate of actions that can save about a hundred Australian dollars.

Druckman et al. (2011) and Chitnis et al. (2014), however, make a clearer distinction of sufficiency behaviour. They analyze rebound effects connected to the reduction of the indoor temperature by lowering the temperature set on the thermostat by 1 °C, the effects connected to a reduction of the amount of food bought due to reducing food waste by one third, as well as the effects after substituting short distance car trips by walking or cycling. The rebound effect is found to be the lowest for setting the thermostat to a lower temperature (7 %) and the highest for a reduction of food waste (59 %), for changing the travel mode for short distances, the rebound effect is assessed to be 22 % in terms of greenhouse gases. The relatively high rebound effects in the food consumption is caused by the re-spending of money originally used for foodstuffs with relatively low GHG emissions in favour of highly GHG-intensive fuels in transport or energy in housing.

We refrain from a comparison of the presented findings since all differ in their methodological approaches and definitions of the rebound effects. Nonetheless, all studies have in common that they report indirect rebound effects either in terms of energy use or greenhouse gas emissions. We contribute to the growing literature on indirect rebound effects from behavioural change by analyzing rebound effects in terms of resource use. The next paragraph introduces into resource sufficiency and derives abatement actions with respect to resource sufficiency accordingly.

3.2 Identifying Resource Sufficiency

According to Alcott (2008), studies on sufficiency rebound effects need to address the over-consumption in affluent “rich world” societies. He considers sufficiency to be an environmental strategy that counteracts or lowers the consumption of the most affluent, seeking to lower per capita resource consumption. The strategy is supposed to cut material and energy consumption even if the “poor” consume more. In this regard, Schmidt-Bleek (2009) claims a necessary reduction of resource use by 90 %. Well developed and industrialized countries should reduce their resource use or Material Footprint disproportionally by a factor of 10 in order to compensate the resource use of still developing economies. The respective resource accounting method is described as the concept of the Material Input per Service-Unit (MIPS).

Interestingly, Alcott (2008) doubts that the MIPS concept is able to account for sufficiency just as the efficiency strategy is insufficient to account for absolute decoupling: “MIPS computations assume that the denominator (whether expressed as monetary GDP, services, utility, or material consumption) remains constant or rises while the numerators of resource inputs are minimized, whereas sufficiency intends a lower output, a smaller denominator, lower global demand" (Alcott 2008, p. 771). Indeed, a constant service output by minimizing the material input lowers the ratio of Input per service delivering a more resource efficient production or consumption. However, MIPS asks for an integrative picture of sustainability strategies advocating sufficiency. The authors of MIPS explicitly allow for sufficiency: "Fundamentally, opportunities for integrative sustainable design lie in the denominator of MIPS, the service unit S. $S = 0$ is optimal, most efficient [sic!], since no resource based service is demanded" (Liedtke et al. 2013).

For instance, the Resource Use Footprint (in terms of Total Material Requirement per capita (TMR)) in Germany and the US accounts for 70–90 t (Bringezu et al. 2009, p. 61). In this respect, Bringezu (2015, p. 48) suggests that a "potential sustainable corridor for total resource flows could range between half and full of the absolute global level in 2000, distributed equally among the future population, i.e. 6–12 t/person TMC of abiotic resources". Lettenmeier et al. (2014) define a sustainable level of total material consumption (TMC)—that is the total material globally required for domestic consumption—of 8 t per capita and year by 2050. Mobility, housing, food make up more than 80 % of the resource use induced by private consumption (see Lettenmeier et al. 2014 or Sect. 3.4). Abatement actions in mobility, housing and food bear the most potential for a relevant reduction in resource use. Lettenmeier et al. (2014) suggests a reduction of resource use per capita of 49 % in nutrition by, e.g. preventing food waste, of 88 % in mobility by e.g. reducing car traffic and of 85 % for housing by e.g. reducing living space. Estimating rebound effects from resource sufficiency behaviour may provide a more realistic picture of the expected savings from the proposed abatement actions.

Hence, we derive abatement actions in daily life practices for the fields of housing, transport and food as well as the corresponding monetary savings for German households.

We orientate on the suggestions made by Lettenmeier et al. (2014) and by Druckman et al. (2011)—just applied to private households in Germany.

3.2.1 Housing

The Federal Environmental Agency in Germany states a potential cost savings of 6 % per lowered degree Celsius of the indoor temperature. Precht et al. (2007, p. 197) even believe the reduction of the heating energy demand to be more than 6 %. In favour of a conservative estimation, we calculate with a drop in costs for households of 6 % while modelling a lowering of the indoor temperature by one degree.

3.2.2 Transport

Half of the private car trips in Germany are trips of less than 6 km (VDC und VZBV 2010). According to the Mobility Panel for Germany, this makes 282 trips per household. Given an average fuel consumption of 7.6 l per 100 km or 0.46 l per 6 km and an average fuel price of 1.5 €/l for 2008 in Germany, this makes an average saving of 30 % of costs for fuels since average expenditures for fuels were around 636 € per household in Germany in 2008 (MOP 2008/2009,[4] EVS 2008,[5] own calculations). We derive cost savings of 30 % from avoiding short trips by car.

3.2.3 Food

According to Kranert et al. (2012), avoidable food waste accounts for 10–14 % of the whole expenditures for food and non-alcoholic drinks. Conservatively, we assume that households save up to 10 % of their expenditures for food and non-alcoholic drinks from reducing food waste.

3.3 Method

We estimate the rebound effects from sufficiency arising due to the introduced abatement actions. We opted to basically follow the approach of Druckman et al. (2011). For one, because we consider their studies to be the most elaborated work on indirect rebound effects as the result of actions undertaken by households to reduce their resource and energy consumption. And second, because we can then compare their findings on rebound effects in terms of greenhouse gas emission to our results in terms of resource use.

When interpreting our results one has to bear several assumptions in mind. In line with Druckman et al. (2011), we find it counterintuitive to assume direct rebound effects as a result of deliberate abatement actions. It seems unlikely that one chooses to turn up the temperature after lowering the temperature. The same applies to deliberate actions on food waste reduction and short distance car trips. Abatement actions are only associated with indirect rebound effects. Consequently, this means no re-spending is taken into consideration for foodstuffs, when food waste is avoided, no re-spending of savings on fuels is taken into consideration when short distances are avoided and no re-spending of savings on heating energy is taken into consideration when indoor temperature is lowered. We assume that avoided expenditures due to abatement actions equal a proportional raise in income that can be saved or re-spent (income effects). Moreover, we assume that abatement actions do not come with price-induced substitution effects between energy services (see also Druckman et al. 2011).

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[4] Results from the German Mobility Panel (MOP) for 2008.

[5] Survey of Household Income and Expenditures in Germany (EVS) for 2008.

3.3.1 Household Demand Model

Whereas Druckman et al. (2011) rely on their Econometric Lifestyle Environmental Scenario Analysis (ELESA) to estimate the income elasticities, we apply an Almost Ideal Demand System (AID System) to do so. An AID System is commonly used when it comes to estimations of complex demand systems. An AID Systems is characterized by a flexible functional form that allows to derive "first-order approximations to any set of demand functions derived from utility-maximising behavior" (Deaton and Muellbauer 1980: 315). Deaton and Muellbauer (1980) solve budget share equations in the following form

$$w_i = \propto_i + \sum_{j=1}^{n} \gamma_{ij} \ln p_j + \beta_i \ln (y/P) \tag{3.1}$$

where $w_i = x_{ij}/y_i$; x_{ij} being the expenditures for a good j of a household i and y_i being the total expenditures of a household i across j. The estimation of an AID System integrates the adding-up restriction $\left(\sum_i^n \propto_i = 1, \sum_i^n \gamma_{ij} = 1, \sum_i^n \beta_i = 0\right)$, as well as homogeneity $\left(\sum_i^n \gamma_{ij} = 0\right)$, and symmetry restrictions $(\gamma_{ij} = \gamma_{ji})$.

Deaton and Muellbauer (1980) suggest the replacement of the Price Index P by a Stone Price Index. If no price variation is available in a cross-sectional analysis, those may be constructed by household-specific Stone–Lewbel (SL) prices by using sub group budget shares and price indices such as Consumer Price Indices (CPIs) (Lewbel 1989; Castellon et al. 2012). Following Beznoska (2013), we take advantage of a variation between households budget shares by constructing household-specific commodity group prices. Therefore, we relate the prices of the commodities with the expenditure shares within the group under the assumption of Cobb-Douglas preferences. The aggregated price for a commodity group j is calculated by

$$p_{ij} = \sum_{j=1}^{n} w_{ij} p_j \tag{3.2}$$

where p_j is the Consumer Price Index for a commodity group j and w_{ij} is the budget share of the commodity group j for a household i. The household-specific aggregated prices are calculated for the commodity groups defined below.

Eventually, we are able to calculate the income elasticities η_j based on the budget shares w_i and the parameter β_i estimated in (3.1) for a commodity group j in the form of

$$\eta_{ij} = 1 + \frac{\beta_{ij}}{w_{ij}} \tag{3.3}$$

3.3.2 Rebound Effect Model

As we adopted the approach according to Druckman et al. (2011) to identify sufficiency behaviour, we also follow the definition of rebound effects of Druckman et al. (2011). As the authors derive their model in detail, we give a more brief but still comprehensible derivation of their rebound effect model.

In principle, rebound effects are defined by the relative compensation of potential or engineered savings of resource use (ΔH) by additional resource use (ΔG) due to re-spending of monetary savings saved due to sufficiency behaviour.

$$\text{Rebound Effect} = \frac{\Delta H - (\Delta H - \Delta G)}{\Delta H} \tag{3.4}$$

The change in resource use ΔG due to re-spending is given by

$$\Delta G = \sum_{j=1}^{13} \eta_j \text{exp}_j r_j \tag{3.5}$$

where r_j is the resource intensity of the spending category j. This is the ratio of the Material Footprint in terms of total material requirements (TMR) and final expenditures induced by private consumption of households in the spending category j.

As mentioned before, we assume that avoided expenditures due to abatement actions equal a proportional raise in income that can be saved or re-spent. We define savings s as the share of the income that is put into savings. Druckman et al. (2011) did not discover a relevant rebound effect of savings (investments) using a sensitivity analysis, but emphasize that literature lacks research on the relevance of saving rates for the estimation of indirect rebound effects. We accordingly assume that savings do not come with induced resource use, which seems to be justifiable given the findings from Druckman et al. (2011).

The change in disposable income y_j that is re-invested as a result of changing expenditures exp_j is defined as

$$\sum_{j=1}^{13} \Delta \text{exp}_j = (1 - s)\Delta y_j \tag{3.6}$$

The empirically estimated income elasticities are introduced in the next equation and a change in expenditures is referred to as a change in income accordingly.

$$\Delta \text{exp}_j = \eta_j \frac{\Delta y_j}{y_j} \text{exp}_j \tag{3.7}$$

After inserting (3.7) in (3.6) and re-arranging the equation, a change in expenditures is noted as

$$\Delta \mathrm{exp}_j = \eta_j \frac{(1-s)\Delta y_j}{\sum_{j=1}^{13} \eta_j \mathrm{exp}_j} \mathrm{exp}_j \tag{3.8}$$

In a last step, Eq. (3.8) is inserted into the rebound effect definition (3.4). After re-arrangements, the rebound effect is defined as

$$\text{Rebound Effect} = \frac{1}{\Delta H}\left[\left(\frac{(1-s)\Delta y}{\sum_{j=1}^{13} \eta_j \mathrm{exp}_j}\right)\sum_{j=1}^{16} \eta_j \mathrm{exp}_j r_j\right] \tag{3.9}$$

where

- Δy is the costs avoided and expenditure saved by resource sufficiency actions, exogenously determined in Sect. 3.3.
- ΔH is the engineered saving potential in resource use, also exogenously determined in Sect. 3.3.
- s is the savings ratio, defined as the share of disposable income (i.e. the total expenditures and savings) that is put into savings.
- exp_j is the expenditure in the category j which is the absolute term of budget share w_j.
- η_j is the according income elasticity. It is estimated in the household demand model.
- r_j is the resource intensity in the expenditure category j.

The resource use in terms of the Total Material Requirement (TMR) induced by the consumption of German households was calculated using the Environmentally Extended Input-Output Analysis. A model based on the Leontief production function was applied. The applied model includes the estimation of all materials globally extracted from the environment for a final consumption in Germany. Such estimation is based on the attribution of a part of the TMR of the German economy to the (domestically produced and imported) products consumed by the German private households. By doing so, the total direct and indirect material required along the whole production chain of each domestically produced or imported consumed product has been taken into account. Thus, each calculated value represents the resource use footprint of the corresponding product group consumed by the households in Germany. For a detailed rationale of calculations of the total material requirement, please refer to Watson et al. (2013, annex A) and Moll and Acosta (2006).

3.4 Data

Resource use intensities are estimated in terms of total material requirements per category of household final consumption expenditures (HFCE) using the Classification of Individual Consumption according to Purpose (COICOP). Figure 3.1 shows the distribution of the resource use per household in Germany for 2005. Categories, which account for less than 1 % of the overall consumption are summarized and added up. These are "Health", "Miscellaneous goods and services", "Communication", "Clothing and footwear", "Alcoholic beverages, tobacco and narcotics" and "Education". The resource use in terms of total material requirements is allocated accordingly.

Abatement actions in the fields of housing, transport or food are considered to be most effective, since its resource use induced by private consumption adds up to 80 % of the total material requirements in Germany. 40 % of the total resource use in terms of TMR are consumed in housing, 29 % of the total resources are used for food and 11 % of the total resource use are consumed for transport.

We differentiate between 11 main categories and final expenditures according to COICOP for 2005. The data on expenditures relies on the German survey of household income and expenditure (EVS) for Germany in 2008. The EVS is a representative sample of Germany´s income, expenditures and equipment surveyed every 5 years with 44,088 respondents. When no EVS is conducted, harmonized continuous household budget surveys (LWR) are available. Those consist of a

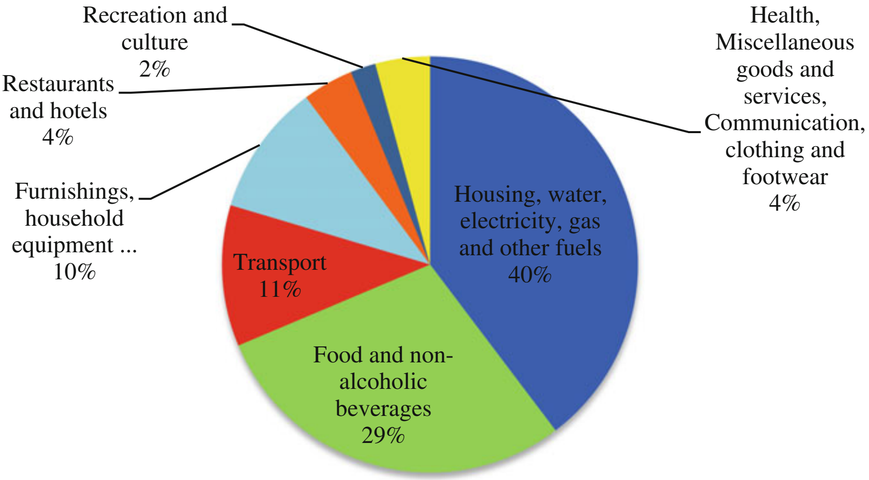

Fig. 3.1 Distribution of resource use of private households along consumption categories. *Source* Acosta and Schütz (2011), see also Buhl (2014). *Note* Resource use in terms of total material requirement induced by the consumption of private households in Germany in 2005 along the Classification of Individual Consumption according to Purpose (COICOP)

Table 3.1 Resource use, final expenditures and resource intensities according to COICOP

COICOP	Spending category	Resource intensities (in kg*/€**)
4	Housing, water, electricity, gas and other fuels	3.18
1	Food and non-alcoholic beverages	5.09
7	Transport	1.50
5	Furnishings, household equipment, …	2.99
11	Restaurants and hotels	1.40
9	Recreation and culture	0.41
6	Health	0.60
12	Miscellaneous goods and services	0.19
8	Communication	0.37
3	Clothing and footwear	0.19
10	Education	0.48

**Source* Acosta and Schütz (2011); *Total material requirement induced by the consumption of private households in Germany in 2005* and Buhl and Acosta (2016)
***Source* Harmonized continuous household budget surveys of the Federal Statistical Office; Final expenditures of households (in current prices)

representative subsample of the previous EVS with 8000 observations. As resource use by private consumption along COICOP is available for 2005, resource intensities are calculated with final expenditures of households from the harmonized continuous household budget surveys of the Federal Statistical Office for the same year for 11 categories in COICOP (see Table 3.1).

Budget shares are calculated on the basis of micro data from the German survey of household income and expenditure (EVS) for Germany in 2008 in order to run the household demand model from Sect. 3.3. We mainly followed COICOP, but used different subcategories for energy and other expenditures in housing, separating imputed rent as well as expenditures on fuels and other expenditures in transport comprising the residual expenditures in transport. With doing so, we are able to differentiate between income elasticities according to the identified abatement actions. Otherwise, we would have to assume the same elasticity for all goods in the main consumption category.

3.5 Results

3.5.1 Household Demand Model

Taking a look at the main categories without further disaggregation into housing and transport, the budget shares for food, housing and transport as well as leisure activities are the highest. The budget shares for education, communication and health are the lowest (Table 3.2).

Table 3.2 Description of budget shares for commodity groups

Variable	Obs.	Mean	Std. dev.
Food and non-alcoholic beverages	11,022	0.171	0.079
Other housing	11,022	0.142	0.160
Energy (electricity, gas, oil)	11,022	0.074	0.072
Other transport	11,022	0.090	0.113
Personal transport fuels	11,022	0.058	0.049
Clothing and footwear	11,022	0.058	0.047
Furnishings, household equipment and routine household maintenance	11,022	0.055	0.078
Health	11,022	0.048	0.078
Communication	11,022	0.038	0.024
Education	11,022	0.010	0.031
Recreation and culture	11,022	0.139	0.104
Restaurants and hotels	11,022	0.063	0.065
Miscellaneous goods and services	11,022	0.053	0.053

Note In the following, the results base on a 25 % subsample of the EVS due to computational requirements of the household demand model. A two sample *t*-test on the quality of means reveals no significant differences in the budget shares. The results are statistically representative for Germany for the year 2008

We estimated an Almost Ideal Demand System (AID System) according to the definition above. We show the results after the estimation of the respective elasticities according Eq. 3.3 (Table 3.3).

Table 3.3 Income elasticities along commodity groups

Variable	Obs.	Mean	Std. dev.
Food and non-alcoholic beverages	11,015	0.898[a]	0.112
Other housing	7596	−0.877[a]	8.076
Energy (electricity, gas, oil)	10,735	1.058[c]	0.059
Other transport	10,499	2.721[a]	4.845
Personal transport fuels	9306	0.722[a]	0.572
Clothing and footwear	10,606	0.780[a]	0.602
Furnishings, household equipment and routine household maintenance	10,352	1.440[b]	0.967
Health	10,541	2.096[a]	2.317
Communication	10,971	0.865[a]	0.215
Education	2533	0.642[b]	0.823
Recreation and culture	11,002	1.006[c]	0.017
Restaurants and hotels	10,260	0.940[c]	0.126
Miscellaneous goods and services	10,969	0.975[c]	0.039

[a]Significant on 1 %, [b]significant on 5 %, [c]not significant on 10 %

Reading example: A 10 % increase in expenditures for food and non-alcoholic beverages increases the average demand for food and non-alcoholic beverages by approx. 9 %

The elasticities for energy and private transport fuels are similar to the ones calculated by Beznoska for "Mobility", "Heating" and "Electricity" (Beznoska 2013, p. 100). All commodity groups are normal goods except for residual housing expenditures. This is to be explained by the fact that higher incomes are less likely to pay renting costs as we excluded imputed rents. Expenditures for health, other transport and furniture are highly elastic. The demand for other transport comprises flight trips for instance. Eventually the average income elasticity balances out across commodity groups as expected (being close to 1). However, the elasticities for energy as well as recreation, restaurants or miscellaneous goods rely on insignificant income effects (maybe due to subsampling) and should thus be interpreted cautiously. The demand for furniture comprises the use of household equipment and electronic articles. Private expenditures for health comprise pharmaceutical articles as well as health care services. The literature on income elasticities on health care disagrees whether health care is a necessary or superior good. However, as the budget shares for food or clothes which are bare necessities decline, the average private expenditures for health care have become higher than the average raises in income of private households in Germany between 1992 and 2013 (Federal Statistical Office, own calculations), suggesting that health expenditure of private households have become more relevant. However, normal, inferior and superior goods are balanced in such a way that the average income elasticity does not suggest an exceeding budget constraint.

3.5.2 Rebound Effects

The elasticity estimates are introduced in the sufficiency rebound effect model. The resulting rebound effects are shown in Fig. 3.2. For food, the rebound effect is relatively low for all households (Fig. 3.2a). Only 11 % of the expected savings from food waste prevention are compensated by re-spending effects, reducing the expected savings in resource use from 682 kg per household and year by 97 kg per household. Rebound effects are higher for lower income households. Re-spending for housing induces higher rebound effects so that savings in resource use are compensated by 59 %, reducing the expected savings of 158 kg per household by 94 kg per household (Fig. 3.2b). Again, rebound effects are higher for low-income households. Re-spending in mobility, however, backfires on resource use (Fig. 3.2c). The expected savings in resource use of 184 kg are fully compensated by 240 kg per household due to re-spending. However, this is not the case for high-income households. This is mostly due to the relative resource intensive re-spending in housing and food.

As far as the decrease of rebound effects with respect to income is concerned, rebound effects decline the fastest per growing household's net income in mobility with averagely 0.06 % per euro. In food, rebound effects decline with 0.03 % per euro and in housing with 0.02 % per euro. Those decreasing rebound effects with growing income are to be explained by the higher saturation levels for foodstuffs and heating energy than for fuels for private mobility.

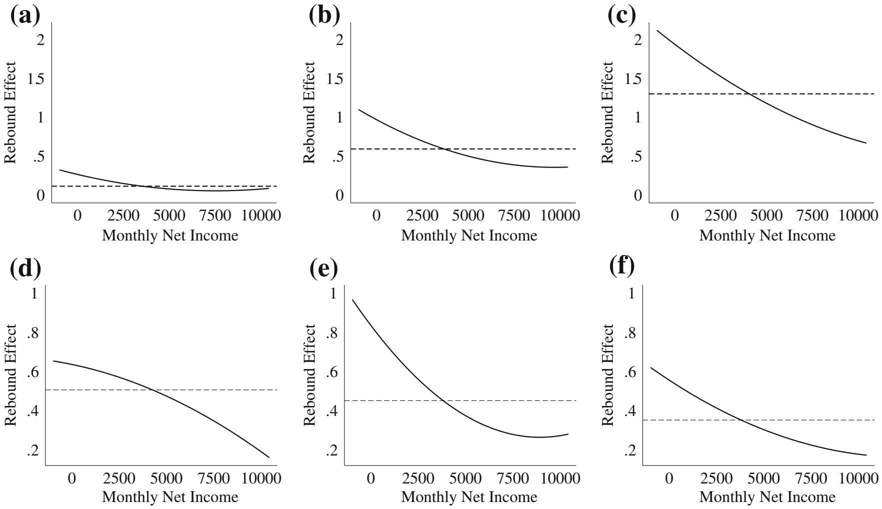

Fig. 3.2 Results of quadratic prediction of rebound effects from abatement actions in food (**a**), housing (**b**) and mobility (**c**) on net income. *Data* German survey of household income and expenditure (EVS) for 2008. *Note* The *dashed line* shows the average rebound effect in case of a single abatement action being observed—either avoiding food waste (**a**), turning down the thermostat (**b**) or avoiding short distances by car (**c**). Rebound effects decline with the household's monthly net income increasing. Confidence intervals are not shown. Results of quadratic prediction of rebound effects of combined abatement actions allowing for direct re-spending in food (**d**), in housing and mobility (**e**) and "not at all" (**f**). *Data* German survey of household income and expenditure (EVS) for 2008. *Note* The *dashed line* shows the average rebound effect. Rebound effects decline with the household's monthly net income increasing. Confidence intervals are not shown. The graph shows the rebound effects in case of all three abatement actions to be observed—avoiding food waste, turning down the thermostat, avoiding short distances by car. However, we differentiate between the observed re-spendings. Whereas the scenarios **d** and **e** allow direct re-spending and thus direct effects, only **f** is consistent with our original assumption that we only observe indirect effects

In Fig. 3.2d–f, we show rebound effects for a combination of all abatement actions in three experiments. In the first part, we allow the re-spending of savings for foodstuffs, but not in the fields mobility and housing (Fig. 3.2d). In the second part, we allow re-spending for mobility and housing, but not for food (Fig. 3.2e). In the third part, we do not allow any re-spending in the consumption array where the savings occurred, neither in food, nor in housing or mobility (Fig. 3.2f). This is most consistent with our assumption that it is unlikely that consumers spend money in arrays where they are trying to save money. In turn, one might think that it is unlikely to re-spend *no* monetary savings due to sufficiency behaviour *at all* in the most consumptive arrays at stake. For the latter, we decided to estimate two experiments where we allow for direct effects.

In the first case, consumers re-spend their savings in the food category as well as in all main categories where no money was saved. Then, the households compensate 51 % of the expected savings. Once we do not allow consumers to re-spend their savings for food, but for housing energy and fuels for private mobility in a second case, only 45 % of the expected savings are cancelled out, namely 540 kg per household. If we do not allow to re-spend for food or for housing or mobility, only 35 % or 400 kg are compensated. This is the best-case scenario for a combination of abatement actions in food, housing and mobility and comparable to the estimates in Druckman et al. (2011). Again, rebound effects are higher for low income households. The convex predictions suggest in all cases (except in Fig. 3.2d) that rebound effects decline faster, the higher the household´s monthly net income increases.

3.6 Discussion and Conclusion

Comparing our results with the results in Druckman et al. (2011), rebound effects from combined abatement actions show similar effects of 35 and 34 % respectively. Once we take a closer look at the isolated rebound effects of abatement actions in the consumption arrays food, housing and mobility, rebound effects are the highest in mobility and the lowest in food. This is contradictory to the results found in the analysis of rebound effects regarding energy use or emissions of greenhouse gases (see Druckman et al. 2011; Chitnis et al. 2014). What are the reasons for this?

GHG-intensities in the category food are relatively low for foodstuffs, whereas GHG-intensities for transport are relatively high. In turn, resource intensities for foodstuffs are relatively high, whereas resource intensities for transport are relatively low. In comparison, the difference between the resource intensities is higher than between the GHG-intensities. That is why indirect rebound effects from abatement actions in private mobility backfire (for a comparison of GHG-intensities and resource intensities see Watson et al. 2013, p. 58f). In case households re-spend savings in mobility for foodstuffs, the high resource intensity of foodstuffs cancels out the expected reduction of resource in mobility. In the case of GHG-intensities, this is the other way around. In sum however, the effect balances out in such a way that the rebound effects of combined abatement actions are similar to studies regarding GHG-intensities. Our findings suggest that the research on rebound effects should not only differentiate between sustainability strategies (sufficiency vs. efficiency) as a cause, but also in their effect on sustainability goals (climate change mitigation vs. resource conservation). In case of policies trying to mitigate the depletion of natural resources from consumption, given our findings on indirect rebound effects, it would be favourable to articulate (efficiency or sufficiency) strategies for the reduction of consumption in resource-intensive areas, that is foremost food. When it comes to the mitigation of greenhouse gas emissions (GHG), the advice might alter in favour of policies that try to reduce consumption of fuels for housing or transport. Our findings on indirect rebound effects support the observation in Watson et al. (2013): "[…] the often large differences in environmental pressure intensities found *between* household expenditure categories […]

highlights a second potential means for decoupling environmental pressures from growth in consumption. That is to channel increasing income towards consumption categories with relatively low environmental pressure intensities."[6] Those are expenditures on education, communication or recreation and culture—in terms of resource intensities as well as GHG intensities.

However, we need to keep in mind that our data on resource use only allows for a limited differentiation between resource intensities of goods and services. As we only regard the average resource intensities in groups like foodstuffs or transport, we assume equal resource intensities for meat and vegetables and equal resource intensities for a trip by train and airplane. A more detailed analysis would more appropriately account for differences within the main consumption categories.

In line with previous studies, our results show declining rebound effects with higher income. This suggests robust findings when it comes to social heterogeneity of rebound effects with respect to income. Lower incomes show higher rebound effects. When considering social heterogeneity, a major issue emerges in terms of social equity when dealing with sufficiency rebound effects. Addressing lower incomes in order to deal with rebound effects effectively is, however, a misleading conclusion. As Buhl (2014) shows for Germany, the resource use of higher incomes is averagely more than 50 % higher than it is of low incomes. In the end, it is not about rebound effects that need to be effectively mitigated, but affluent consumption patterns. This is foremost a matter concerning the (relatively) rich and not the poor.

More important, we find it worth discussing whether it is possible to apply microeconomic demand models for an accurate estimation of sufficiency rebound effects. Instead of assuming a representative consumption pattern to take effect after sufficiency behaviour, we suggest to survey consumption and expenditure patterns that truly represent typical sufficiency lifestyles and (marginal) consumption patterns. And even if it would be possible to conduct a study of rebound effects for different sufficiency lifestyles, we wonder to what extent sufficiency rebound effects would be driven by monetarily induced rebound effects or rather by socio-psychological or time induced effects (see Buhl and Acosta 2016 for such an attempt on time use rebound effects). To our understanding, it would be substantial progress if future studies on rebound effects would extend microeconomic demand functions by psychological and sociological dimensions. Psychological dimensions may encompass personal and social norms, whereas sociological dimensions may encompass variables that enable to differentiate between lifestyles. Then, rebound research would, first, be able to differentiate between economically and psychologically driven rebound effects and, secondly, be able to differentiate between, e.g. materialist and postmaterialist or sufficiency-oriented lifestyles (and not only between income).

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[6] Our information on resource intensities (in terms of kg/€) rely on purchaser prices. That means environmental taxes are included. Excluding environmental taxes would result in more dominant resource intensities in transport and housing. In turn, if environmental taxes are applied consistently, those smoothen the differences in intensities (see Watson et al. 2013, p. 56), lower intensities and thus theoretically lower indirect rebound effects eventually.

Eventually, we strongly recommend future research to consider alternative social differentiation and action models from sociology or psychology. Empirical studies on rebound effects may thus reveal more efficient and consistent estimations (not only from sufficiency behaviour). Taking those ideas into consideration, our estimation of sufficiency rebound effects are likely to be overestimated by its conventional microeconomic demand function relying on representative micro data. But still, we do not expect sufficiency to be a strategy immune to rebound effects.

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Chapter 4
The Global South: New Estimates and Insights from Urban India

Debalina Chakravarty and Joyashree Roy

Abstract With increasing knowledge through empirical investigations, we now realize it is difficult to support a blanket statement that 'rebound effect' is high and will take back 'all' the energy savings benefits of efficiency improvements in countries of the Global South like India. In this article we review past literature, and report some new evidence of rebound effect estimates with insights that we draw from primary data collected on selected mobility service categories in India. The purpose of this article is to flag certain important observations that need further attention in the rebound discourse, which, we believe, promise to advance the subject both theoretically as well as for policy guidance in particular in the transport sector. The observed small proportion of super conservation behaviour and moderate partial rebound behaviour in mobility service can be scaled up by appropriate incentives going beyond price mechanisms and communication strategies. For example, improvement in promotional materials, comfort level of public transport systems, infrastructure to reduce congestion, and congestion management strategies can all remove behaviourial barriers to realise full potential of technical efficiency improvement.

Keywords Energy efficiency · Rebound · Backfire · Super conservation · Mobility service · Households · India

Past empirical literature on the rebound effect has concluded that the rebound effect in the Global South is higher than in the Global North (Schipper 2000; Roy 2000; Herring and Roy 2007; Sorrell et al. 2009; Stern 2011; Wang et al. 2012; Fouquet and Pearson 2011; Chakravarty et al. 2013). Literature so far suggested that this may

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D. Chakravarty (✉)
Department of Humanities, Social Science and Management,
National Institute of Technology, Jamshedpur, India
e-mail: c.debalina85@gmail.com

J. Roy
Department of Economics, Jadavpur University, Kolkata, India
e-mail: joyashreeju@gmail.com

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be true due to greater unmet demand (Roy 2000), unsatiated demand for energy services (Sorrell 2007a, b), greater price responsiveness at lower level of absolute energy service demand and thus, greater direct rebound effect (Stern 2011). However, there are a variety of socio-economic and behavioural factors that affect responsiveness in any given market (Greening et al. 2000; Roy and Pal 2009), such as income, urbanization, changes in consumer preferences, and available information, which may all cause rebound effects. Such studies concluded that, for 'developing countries', energy demand will continue to increase despite efficiency improvements, since gains of technological advancement will be taken back by behavioural responses in the form of activity growth/higher service demand (Roy 2000; Herring 2006; Sorrell 2007a, b; Sorrell et al. 2009; IPCC 2001; Roy et al. 2013). Still, as can be gleaned from some recent case-specific empirical studies, energy conservation behaviour is at work in developing countries as well; and therefore such general conclusions could benefit if viewed through a fresh lens (Roy et al. 2013). However, other studies (Semboja 1994; Glomsrod and Wei 2005; Lin and Liu 2013a) have shown that there can be cases of high rebound effects in the Global South countries. The wide variation in the magnitude of rebound estimates from various studies can be due to diversity in estimation methods and can therefore raise questions on comparability of magnitudes. It is well recognised in the literature that the size of rebound effects is context as well as sector specific. Technological development for energy efficiency improvement has a direct impact on GHG emissions (IPCC 2014), and therefore, developing a deeper understanding of rebound effects that may or may not take place in a 'Global South' context is important. This study is, therefore, a humble attempt to add some new evidence and insights from India for the rebound literature.

The article has been organized in four sections. Section 4.1 briefly presents evidence of rebound effects in the Global South from the past literature. Section 4.2 describes the data and method we use for the empirical estimation of rebound effect for mobility service in Indian context. The findings and insights have been explained in Sects. 4.3 and 4.4 compares rebound estimates across methods. Section 4.5 presents concluding remarks.

4.1 Rebound Effects in the Global South: Past Studies

Empirical literature on rebound effects in the Global South is limited to a few country contexts (from China, India, Sudan and Kenya); it is summarized in Table 4.1. Available estimates show a very wide range of results. For a set of energy services that reflect operational energy consumption in residential buildings—like lighting, space cooling, washing—the estimates vary between super conservation (−127 %) on the one hand, which means that energy service demand has even declined more than the technical savings potential promised, to backfire (288 %) on the other hand, which means energy service demand increased by almost a factor of three without actually realising any savings potential. For transportation services (both public and

Table 4.1 Empirical evidence on rebound magnitudes in the Global South

Energy services	Country	Time period	Rebound effect estimates		Reference
			Short run	Long run	
Transportation	India	1973–74 and 1989–90	−9[a] to 50 %		Based on Roy (2000)
	China	1994–2009	96 %		Wang et al. (2012)
		1999–2011	16 %	84 %	Wang and Lu (2014)
		1995–2011	107.20 %		Lin and Liu (2013a)
Household: set of household energy services	Sudan	1983	54–59 %		Dufournaud et al. (1994)
	China	2007	<30 %		Ouyang et al. (2010)[b]
		2009–2011	31.61 %		Yu et al. (2013)
		1996–2010	72 %	74 %	Wang et al. (2014)
		1986–2007	165.22 %		Lin and Liu (2013a, b)
		1994–2011	−127 % (urban area)		Lin and Liu (2015)
		1994–2011	288 % (rural area)		
		1994–2011 (urban area)	66.5–8.5 % (average 82 %)		Lin and Liu (2015)
		1994–2011 (rural area)	127.0–236.3 % (average 159 %)		
	India	1995	50 %		Roy (2000)[b]
Industry	China	1979–2007		46.38 %	Guo et al. (2010)
	India	1973–2008	34–134 %		Roy et al. (2013)
		1973–74 to 2011–12	−2[a] to 136 %		Dasgupta and Roy (2015)
Commercial	India	2004–2005	488 % (case study)		Roy et al. (2013)[b]
Economy wide	Kenya	1976	170–350 %		Semboja (1994)
	China	1995	>100		Glomsrod and Wei (2005)
		1981–2009		53.2 %	Lin and Liu (2012)
		2007	52.38%	178.61%	Li and Lu (2011)
		1954–2010		39.73 %	Shao et al. (2014)
		1986–2005		53.68%	Liu and Liu (2008)
		1981–2004		62.80 %	Wang and Zhou (2008)
		1979–2004		30–80 %	Zhou and Lin (2007)
		1978–2010	34.24 %		Xie and Zhang (2013)

Source Based on Chakravarty et al. (2013) with additional information

[a] Statistically insignificant

[b] These estimates are derived using direct measure of rebound effect. All other estimates are from indirect measure of rebound effect. For further details please refer Chakravarty et al. (2013)

private transportation), the range again shows super conservation (−9 %) and backfire (107.2 %), although the impact of super conservation is relatively less in magnitude. In industrial sector, rebound estimates are also between super conservation (−2 %, although not statistically significant) and backfire (136 %), depending on the type of industrial sector (for example iron and steel, glass, and paper industry), and its level of energy intensity. In the case of commercial buildings, one case study shows high backfire (where rebound magnitude is 488 %) (Roy et al. 2013). Interestingly, economy wide rebound effect estimates do not show super conservation in the Global South, but only partial rebound to backfire (are 30–178 % and 170–350 %, respectively for China and Kenya). This may be due to the fact that perverse price elasticity values do not fit into economy wide models. To sum up, the diversity in methodologies of these studies makes it difficult to draw a firm conclusion about the estimates of rebound effect in the Global South (Sorrell 2009; Chakravarty et al. 2013).

Generally, the scope of rebound effects varies between low rebound to backfire in the Global South, but some recent publications demonstrate cases of super conservation in China and India (Saunders 2013; Roy et al. 2013). One explanation for this might be that with rising income and energy consumption in the two countries, unsatiated demand is declining for the fast emerging middle class (Sorrell et al. 2009). Another plausible hypothesis is that the behavioural response of people in the Global South is getting influenced by increased awareness of economic gains from energy efficient behaviour, introduction of various incentives to use energy efficient appliances, and larger factors like environmental and climate impacts of rising energy consumption. However, so far only limited evidence exists on variation across different socio-economic groups within the Global South (Chitnis et al. 2013).

It is important to generate more empirical evidence from Global South countries as energy demand is projected to grow faster in these countries due to economic and population growth, and can have major implications for climate mitigation policies. A number of studies claim that rebound effects are expected to be high in the Global South due to increasing energy demand and income (Wang et al. 2012; Fouquet and Pearson 2011; Sorrell 2007a, b; Milne and Boardman 2000).

Against this background, in this chapter we intend to develop an empirical analysis of a less researched area in rebound research: potential rebound effects in transportation in the case of India. Our focus on the transport sector is primarily due to the increasing demand for energy intensive mobility from private car owners in metropolitan cities. Literature shows that one of the major drivers of fossil fuel use in the coming decade for India is going to be the private car-based mobility service demand (Tiwari 2002; Pucher et al. 2007; Census 2011). One major policy response and intervention also favours increasing fuel use efficiency through vehicle efficiency standard specification, and various incentive designs. To achieve local environmental benefits as well as climate benefits, penetration of energy efficient technology and mandatory standards of appliances/technologies are becoming national strategies in many Southern countries, including India (IEA 2012; GEA 2012; ACEEE 2014; IPCC 2014; Sutherland 1991; Brookes 1990a, b; Stern 2007; Levine et al. 1995).

4.2 Estimating Direct Rebound Effects in Mobility Service in India: Method and Data

Mobility service by private car is an emerging service for urban households in India. Energy efficiency improvements in India are usually incentivized by top down policy efforts that aim at the removal of structural barriers. However, it is also important to understand how observed behavioural barriers such as attitudes towards energy efficiency, perceived risk of investment in energy efficiency strategy, information and incentive gaps are changing to help fuel use efficiency improvements (Carlsmith et al. 1990). Our goal is to assess the behavioural responses of urban households from different socio-economic groups towards energy efficient cars and their associated rebound effects. With any efficiency improvement of market-based products, usual practice is to rely on information supplied by the producers, e.g. on fuel mileage of cars or star rating of bulbs determined by lumens per watt and lumens depreciation rate, to estimate expected energy savings through any specific efficient technology penetration. However, after implementation, actual energy savings can be observed. The rebound effect can be measured by taking into account the difference between expected and actual energy savings (Haas and Biermayr 2000; Roy 2000; Berkhout et al. 2000; Ouyang et al. 2010). This method is a kind of quasi-experimental approach, which measures the demand of the energy service before and after the actual implementation of an energy efficiency improvement (Meyer 1995; Frondel and Schmidt 2005). However, we are aware that the methodological quality of the majority of studies involving such a method is relatively weak, since most of them only conduct a simple before–after comparison without presetting a control group or explicitly controlling for confounding variables (Sorrell and Dimitropoulos 2008). In addition, sample selection bias and small sample size are other flaws of this approach. It also has some limitations in the sense that it cannot control variables other than the efficiency improvement. Income effect, in particular, is a very important factor in this context, which is omitted from the analysis. This method is named 'direct estimation' in most of the papers, because it directly uses energy efficiency and energy use data. Then, the magnitude of the rebound effect can be calculated using the following formula,

$$\text{Rebound Effect }(\%) = \frac{(\text{Expected Savings} - \text{Actual Savings})}{\text{Expected Savings}} \times 100 \tag{4.1}$$

As mentioned earlier, our objective is to measure rebound effects using Eq. 4.1 for mobility services of urban households with private car ownership in India for different income groups. In India, there are approximately 78.87 million urban households (Census 2011). Following the so-called NCAER-criteria (National Council for Applied Economic Research), around 60 % belong to the middle and high income group (estimated from NSSO data 2012). Approximately, 6 % of these households own a four-wheel drive as their mode of private transportation (Census 2011). The data is collected from urban households. It shows energy consumption for private cars is the highest in middle and high income group of urban households (Census 2011; NSSO 2014). We collected primary data from various cities in India through an online survey as there is no secondary source of information available on efficient technology users. For this online survey, our target population was households with access to the Internet. We used the method of 'Respondent Driven Sampling' (see Heckathron 1997). In the first stage of our survey from our own city, 60 middle to high income urban households (from different age and gender groups) were listed who have internet connection and own four-wheel drive for personal mobility. Then each of these 60 households were requested to share contact information of at least 50 households from various cities in India. From the total universe of collected contact information, around 2200 contact information were randomly selected from 16 different cities, and were requested to send their responses. They were given an option to opt out any time, so as to minimise biased and erroneous responses. Of 2200 addresses where the questionnaire had been sent to, 572 household representatives voluntarily participated in this survey. The survey responses were collected between July 2013 and June 2014. From each sample household at least one representative member responded to the questionnaire.

In order to estimate rebound effects through the method of 'direct estimation', we need data on consumption of energy for private car-based mobility services, price, socio-economic variables and behavioural variables. The fuel types in use for cars in India are diesel, petrol, Compressed Natural Gas (CNG), Liquefied Petroleum Gas (LPG). Through the survey, we collected information on car purchase details by households to get a reflection of their decision towards fuel efficient cars, fuel type in use in the car, monthly fuel consumption (quantity and value), monthly distance travelled, kilometre per litre (mileage) as specified by the manufacturing company and actual run or kilometre per litre realized on road for the newly purchased car replacing the old car. The questionnaire was divided into three sub sections. The first section dealt with basic questions about the ownership of the car. The main objective of this section was to know whether the household owned at least one car. The second section consisted of questions related to the household's purchase behaviour, including on fuel efficient cars. Respondents had to answer if they have replaced their old car for a new one. The follow-up question was about the details of both the discarded and the newly purchased car, and corresponding travel patterns, to elicit the technical savings potential and the actual net savings. The third section consisted of questions about the household's travel budget. This information also served to highlight their expenditure share in mobility services through private vehicles. The last part of the questionnaire dealt with the personal details of the respondent for evaluating the socio-economic status of the household. We display the results of this survey in the following Fig. 4.1.

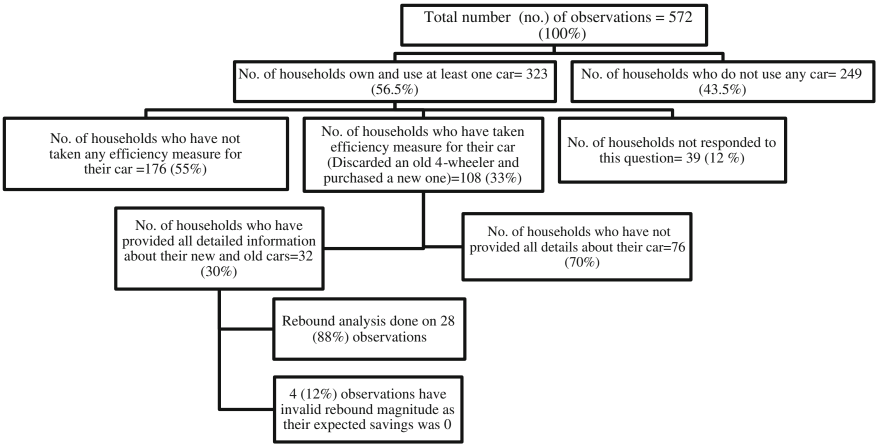

Fig. 4.1 Number of observations in the sample survey. *Source* Survey data

4.3 Findings

Following the NCAER (2012) income-group classification criteria, 45 % of our surveyed households are in the middle income group (with annual household income between 2 lakhs INR and 10 lakhs INR). 55 % are high income households (annual household income over 10 lakhs INR). The respondents have completed at least an under-graduate degree; 63 % have post graduate degrees; 41 % have degree(s) beyond post graduation. 30 % of the respondents are working in private firms, 30 % in government organisations, 16 % are self-employed or engaged in family business, 10 % are retired from their permanent jobs, and the remaining 14 % have either temporary jobs or are unemployed, but the family owns a car. From all households in this survey, the estimated average annual household income is INR 2,475,873. After taking out the outliers, the average household income is INR 1,484,407. Average family size of the sample households is three. Average earning member of each family is two (2.06). 94 % of the responding households own private residences/apartments with an average living space of approximately 1300 ft^2. Of the 572 households, 56.5 % own and use at least one private car, the majority of which (71 %) own only one car. Among these 56.5 %, 33 % have discarded an old inefficient car and purchased a new and more efficient car. Overall, 19 % of total respondents have done so, and these respondents are eligible for our empirical investigation for estimating rebound effects of mobility services. 75 % of the cars are run by petrol, 25 % by diesel. There is no car owner in the sample who uses CNG or electricity.

Households mostly prefer private mobility services due to comfortable mobility. Other reasons for choosing private mobility are: flexible mobility option for family; more secure/safer mobility compared to public transport; accessibility to places unreachable by public transport; availability of more ‘private space’ while travelling; and greater flexibility for transporting small items or goods. Although government regulation states that urban households should discard their car after every 15 years of use, on average, the surveyed households prefer to change their car after 7 years. One of the reasons given by respondents is that the cost towards service and maintenance of an old car generally increases over its life span, and it usually ceases to perform satisfactorily in terms of fuel efficiency and mileage performance. 33 % of the households discarded their old car and purchased a new one mostly due to reasons such as increased cost of running an old car, operating problems with the old one, preference for improved fuel efficiency, and better mileage performance. Most of the households (82 %) reported that they had discarded their old car and purchased a new one for better mileage, which is the indicator of preference for fuel efficiency. Among the households that discarded their old car and purchased a new one, 74 % reported that they had purchased a more fuel efficient car (which is reflected in their answer to question on mileage (km/l) of the car), and 64 % reported that they became more conscious about fuel saving after purchasing the fuel efficient car. When they were asked to report whether they had changed total kilometers travelled per month after purchasing the new efficient car, 44 % of the households reported increased mobility, while it remained unchanged for 39 %. However, interestingly enough, monthly travel budget mostly remained unchanged. The reasons of those households not taking a decision to purchase an efficient car were: households did not know where to purchase such products; the initial purchase cost of such vehicles were too high; they were not sure about the performance of such vehicles; fuel type was not the priority while purchasing a new car; limited availability of efficient fuels like LPG or CNG at petrol stations; possible operational/driving difficulties with these vehicles; lack of information about efficient fuel powered cars; no awareness of the benefits of using cleaner fuels; and to avoid fear about sudden accidents such as LPG cylinder bursting.

Household responses for buying in future a fuel efficient car, or LPG and CNG cars were mostly driven by the following reasons: fuel bill saving benefit; efficient fuels are less polluting; perception that the performance of LPG or CNG car is better than a petrol or diesel powered vehicle. We used in our questionnaire ‘five point likert items’ for households responding to multiple reasons for buying a new car. Analysis of household responses to several likert questions show price of the vehicle, mileage and after sale service from manufacturing company are top three important factors while social status of owning a car is least important factor. As mentioned above, the quasi-experimental method of ‘direct estimation’ measures the demand of the energy service before and after an energy efficiency improvement (Meyer 1995; Frondel and Schmidt 2005). On this basis, rebound effects can be measured using Eq. 4.1 (see Sect. 4.2). Finally, we used data for each of the 28 households who had purchased an efficient car to calculate their individual rebound effects. We can put them in various categories as shown in Table 4.2.

It is important to note that what we define as ‘over achievers’ (super conservationists) in Table 4.2 are very few in number, while the majority of our respondents belong to the categories of ‘underachievers’, (with partial rebound)

Table 4.2 Household categories by rebound response

Household categories	Rebound response	Rebound magnitude in % in sample households	Number of households (in %)
Super Conservationist	Over achievers	−100 to −19 %	4 (14 %)
With zero rebound	Exact achievers	None	None
With partial rebound/take back	Under achievers	2–90 %	12 (43 %)
With full rebound/take back	Non achievers	100 %	7 (25 %)
Those who backfire	Negative achievers	136–886 %	5 (18 %)
Total		54 % (weighted mean of group mean)	28 (100 %)

Source Survey data

followed by 'non achievers' (full rebound) and 'negative achievers' (backfire). If we take weighted average of each individual rebound, then rebound turns out to be 54 %, which implies that 100 % increase in fuel efficiency will lead to a decrease in fuel consumption by only 46 %. The remaining 54 % will be taken back by enhanced mobility service demand. It is interesting to note that most of the households plan their mobility with a fixed share of family expenditure budget. Given the continuous rise in fuel prices in India over the past one decade, they feel a pressure on their budget. Households are also well aware of energy efficiency and how it helps providing more mileage with same quantity of fuel.

Explaining behavioural responses to efficiency improvements:

It is important to know who is a super conservationist, who backfires, who realizes technical saving potentials (no rebound) and who are the ones partially or fully taking back the savings potential. Probing deeper into the nuances of household responses to various questions, and how rebound is measured, we get many new insights to enrich the existing literature. Such more detailed insights may prove to be helpful in a more successful designing of policies and plans that aim at realising the full savings potential by avoiding rebound effects. In the following, we are focusing on those three groups from our sample (see Table 4.2) who are deviating from the expected behaviour (no rebounders) in order to better understand their motivations.

The 'super conservationists': In general, super conservationists are likely to be 'sustainability champions' and seem to be individuals whose behaviour has high public visibility (Roy et al. 2013). Thus, these champions may often times be 'conscious choice makers' of reduced fossil fuel use for mobility services, but also for coal power electricity use for residential activities. They have clear intentions to create an example/message for others on lifestyle choice in a carbon constrained world. They represent households that do not have major constraints on access to (private) mobility services, full satiated demand and full knowledge. They can be thought of as households whose actions are mostly triggered by public appreciation, mass visibility and example setting can be identified as the motivation behind the specific super conservationist choice (Roy et al. 2013).

From the responses to various questions in our empirical survey on household mobility (see Table 4.2) study, the super conservationists appear to be very aware of the properties of an efficient and fuel saving car. However, the observed super conservationist behaviour can also be associated with a selfish motive of saving energy costs to stay within the personal travel budget. It is seen from the survey that they are the only ones who change their privately owned car frequently, every 3–5 years, and are ready to pay higher prices for new car if affordable. Our super conservationists were conscious of savings in their travel budget, which is paid out of their own pockets or is prefixed by the organization which they work for. They stick to shorter routes even in case of congestion. It is interesting to note that each one was interested in fuel switch to save fuel costs, despite being doubtful about supply reliability. Like the other groups outlined in Table 4.2, the super conservationists also prefer new equipment to avoid high maintenance costs associated with an old car. They also want to maintain comfortable, secure mobility services through their privately owned car, and do not consider it a status symbol. It is also interesting to note that each one was aware of the climate change implications of private car mobility.

Those who generated 'Backfire': Backfire usually occurs with unmet/unsatiated demand. In one previous case study, we have observed that the commercial entity whose objective was not to increase their total energy bill but to get better illumination and indoor thermal comfort adopted efficient lighting and space cooling appliances but ended up not only taking back all energy savings potential but also enhancing their consumption level to satisfy the unmet demand (Roy et al. 2013). In the present study, compared to the super conservationists, the group that generated backfire bought efficient cars either because an attractive offer was made by the car dealer, or because they needed a bigger car to accommodate a larger family size. Unlike super conservationists they very often take detours to avoid congestions, but are at the same time in favour of changing their cars less frequently, i.e. at 5–10 years interval. Secure and comfortable travel is the priority, and not status symbols in any way. Full rebounders also fit nicely into this behaviourial category who take back all energy savings potential although does not backfire.

The 'Partial rebounders': The Partial rebounders' new efficient car purchase is mostly driven by the good financial deal offered by car dealers in terms of price of the car as well as long term maintenance guarantee. They change cars at intervals of 4–10 years; mostly do not change their travel distance nor travel budget; consider detours in case of congestion in roads; have smaller family sizes; 50 % are willing to go for LPG/CNG based cars; and are fully or partially aware of environmental issues but not convinced about the likely problems of driving and ease of access to new infrastructure associated with these new fuel using cars. They have more of a risk-averse attitude. They also use the car for comfortable secure mobility and not for status symbol.

Based on the insights presented above, we can provide new potential incentive mechanisms for managing risk attitudes and rebound responses. The following strategies may be appropriate: give clearer and detailed information on national and/or subnational energy efficiency goals; provide necessary new infrastructures, e.g. LPG/CNG filling stations, comfortable public transport systems, more road spaces; introduce congestion fees; provide visibility through mass communication of champions' behavior, and achievements and reward mechanisms in order to nudge 'under achievers', 'non achievers' and 'negative achievers' to become at least 'exact achievers'—if not 'over achievers'. However, more research along these lines is needed in order to provide an even better understanding of the strengths and potential risks of each of the above proposed instruments and strategies.

4.4 Comparing Rebound Estimates Across Methods

Estimations of rebound effects from price elasticity parameters have been in the literature for long. However, as outlined above, these estimations were usually not based on direct measurement, but rather represent 'indirect' methods, which seldom collect genuine energy efficiency and consumption data directly. We used the data not only to collect information on potential direct rebound effects, which have been described in the preceding section, but also to derive insights on indirect rebound effects. To achieve this, we combined our empirical data with further parameters and variables that we derived from standard literature. For the same 28 households, we applied the following seven variables: fuel consumption at time period t (Y_t) by a household as dependent variable; unit price of energy input (P_t) at time period t; household annual income (I_t) at time period t; relative fuel efficiency (E_t) of the cars in use at time period t; lagged fuel consumption (Y_{t-1}) at time period ($t-1$); family size (S_t); and floor area (C_t). We carried out a regression analysis to arrive at a rebound magnitude based on price elasticity estimates. The fuel consumption function specified in Eq. 4.2 has been applied for the observations through the stochastic model defined by Eq. 4.3. Both Ordinary Least Squares (OLS) and Bootstrap techniques are applied to this equation.

Fuel Consumption function,

$$Y_{it} = f\left(P_{it}, I_{it}, Y_{i,t-1}, E_{it}, S_{it}, C_{it}\right) \tag{4.2}$$

The stochastic model estimated here,

$$\begin{aligned} \ln Y_{it} = \beta_0 + \beta_1 \ln P_{it} + \beta_2 \ln I_{it} + \beta_3 \ln E_{it} + \beta_4 \ln Y_{it-1} + \beta_5 \ln S_{it} \\ + \beta_6 \ln C_{it} + u_t \end{aligned} \tag{4.3}$$

Table 4.3 Regression results for mobility services

Variable	Coefficient	Standard error	*t*-statistic	Comment
Fuel price	0.68	0.25	2.66	Statistically significant
Household income	0.96	0.44	2.16	Statistically significant
Lag consumption demand	0.03	0.29	0.10	Statistically insignificant
Efficiency	0.67	1.72	0.39	Statistically insignificant
Family size	1.46	0.81	1.81	Statistically significant
Floor area	−0.62	0.56	−1.11	Statistically insignificant
Constant term	−7.41	9.98	−0.74	Statistically insignificant

$R^2 = 0.32$, Adj $R^2 = 0.22$, statistical significance tested for at least 10 % level of significance
Source Estimated from primary data

In this analysis, unit values for fuel input are used (monetary expenditures divided by the physical quantities of consumption; see Filippini and Pachauri 2004), which includes costs such as annualised purchasing cost of the car, maintenance costs and operating costs along with other costs (e.g. insurance costs, pollution test costs, toll tax). At first stage, an MWD test[1] (MacKinnon, White and Davidson test; see MacKinnon et al. 1982) has been conducted to check the appropriateness of the functional form of the regression. The MWD test result shows that the log-linear model is preferable (Eq. 4.3). The slope coefficients represent the elasticities. This cross-section data analysis is also tested for the presence of heteroscedasticity and multicollinearity through Bruesch-Pagan test and Variance Inflation Factor (VIF).[2] The test results satisfy the absence of heteroscedasticity and multicollinearity. The bootstrapping regression results with 1000 time replication also find out similar results. So, it can be concluded that the data set is fairly random in nature. For cases, where income and price variables are statistically significant, our results are presented in Table 4.3.

Income has been one of the important explanatory factors in the literature on the choice of domestic fuel consumption (Arnold et al. 2003). The income elasticity of fuel consumption (0.96) is close to one. This implies that demand for fuel consumption for private automotive mobility in India for middle and high income group grows proportionally with rising personal income.

The own-price elasticity is estimated to be 0.68 with a positive (perverse) sign which implies ‘negative rebound effect’ of −68 % or, in other words, super conservationist (Chakravarty et al. 2015). When a technology becomes efficient and when a given super conserver is consciously guided by the larger goal of reducing his/her carbon footprint while not looking at the fuel price alone and personal financial gains, then we would in fact get perverse price elasticity. This is consistent

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[1] The MWD test is usually conducted to check whether the regression model specification (e.g., linear or log-linear) is appropriate for the sample data structure or not.

[2] The Variance Inflation Factor (VIF) is used to test multicollinearity among the different independent variables.

with the elasticity values found in a number of small sample analysis in India (Hyde and Köhlin 2000). There is also some evidence for positive short run fuel price elasticities in other countries like Germany (Scholmann et al. 2009), Switzerland (Sterner 1991) and the USA (Greening et al. 1995). Comparison between direct rebound estimates and price elasticities based on indirect rebound estimates for sample households provides interesting insight and conclusion. Our direct rebound estimate produces an average rebound effect in the order of 54 % (Sect. 4.2). In contrast, when using price elasticity figures based on methods of 'indirect estimation', our results show an average 'negative rebound effect' of −68 %. These contradictory results need deeper understanding.

Our understanding is that the new efficient technology led to an implicit price reduction of transport fuel. However, there is no actual fuel price change. So, the corresponding behavioural responses need to be differentiated for all practical reasons. We hypothesise that a consumer who increases demand when a fall in market prices occurs might not be increasing demand when only an implicit change in price occurs. Why is this discrepancy happening? We feel framing the rebound issue just in terms of implicit price change and associated behavior issue is not the correct method of framing and, therefore, produces very limited scope for intervention through specific economic instruments like fuel taxes. Rather we can frame it as somewhat similar to human decision making under a situation of free deals in the market place (Ariely 2010). As found in Roy et al. (2013), in the case of an end user with rebound effect in the order of 488 % who contracted the consultant to introduce efficient lighting and space cooling appliances in the building, inefficient lighting equipments were all replaced by the efficient ones but overall lighting operational load increased due to increase in usage hours of efficient equipments as reduction in electricity bill provided additional financial space. Thus, efficient technology deployment strategies through market mechanisms generate the opportunity for additional 'free goods/services' (i.e. 'free mileage'). In other words, the price for extra mileage appears to be zero for the new car purchaser. In the logic of market principles, free goods will be demanded abundantly and will fail to get into the optimum bundle selection process of a utilitarian consumer. So we see that—except for super conservers—all are excited about free offers and increase consumption as we found zero exact rebounders. To manage this perceived benefit of free goods coming at zero-price, policy-makers can apply non-economic instruments, which drive decision-making processes of end users. Full economic, social and environmental benefits of (energy) efficiency improvements can be realized through better strategic management of operational behaviour of the end users as there is no psychological pain of paying extra for enhancement in total demand. This clearly justifies why low carbon strategy be championed/promoted as a 'social good' and 'social norm' (Roy and Pal 2009), rather than a personal economic/financial benefit that can be left to market forces and, hence, policy-making with market-based instruments. Changing automobile companies' product promotional deals, congestion management to avoid detours, better information and infrastructure for new fuel types and the like, can allure consumers away from such a 'free good syndrome'.

4.5 Conclusions

Mobility service by private car is an emerging service for urban households in countries of the Global South like India. Our study illustrates that demand for fuel consumption for private automotive mobility in India for middle and high income groups grows roughly proportionally with rising personal income. However, the number of middle and high income households that opt for the replacement of existing cars by more fuel efficient cars is still limited in India. Furthermore, our study shows that even if structural barriers are removed through penetration of new efficient cars, attention needs to be focussed on implementing appropriate incentives for removing behavioural barriers towards adoption of efficient equipments.

Our observations indicate the need for going beyond price mechanisms to strategically manage the rebound response that may emerge after more energy efficient technologies are introduced. In particular, the challenge starts when after purchase of a more efficient car, extra demand for mobility services generates from the ‘free mileage’ of efficient cars. This calls for the introduction of non-economic policy instruments like congestion management, better infrastructure for new fuel types and appropriate communication strategies. For instance, car dealers can influence the behaviour of consumers by changing their current promotional materials. In India, current promotional materials of car dealers show mostly ‘how much extra mileage’ (kilometer per litre) the new car can offer. Our observed behavioural responses show that people are more concerned with how much fuel and fuel bill they can save from any new buy. So, the focus of promotional material highlighting “extra/free mileage” can attract more buyers but, at the same time, increases the likelihood and magnitude of accompanying rebound effects. Revising promotional materials towards ‘fuel bill saved per 100 km’ may better deliver the policy goals by touching the right chord for removing behavioural barriers and help in achieving super conservationist or partial rebounder behavior among households with private cars. In addition, lessons learned from success stories arising out of energy conservation award programmes by the Government of India for good performing industries can also be used for rewarding non rebounders or super conservationists in the mobility service sector, which can help also in creating more champions.

Therefore, more research and empirical evidence on behavioural responses and attitudes need to be done (see Chaps. 6–8 in this volume). More specifically, future empirical research could try to support our analysis above of various attitudes and categorisation of super conservationists as the risk takers, backfires and exact rebounders as risk neutrals and partial rebounders as risk avoiders. Our behavioural analysis shows that super conservationist households are taking risks in believing the claims made in promotional materials, taking chances on the performance outcome of a new technology, and change their cars comparatively fast. Those who are partial rebounders wait for detailed information and multiple incentives to ensure the benefit from change. If our claims are supported by further empirical findings, policy-makers are better prepared to develop strategies and instruments how risk management can be improved to overcome behavioural barriers to reduce energy demand, and better realize technical savings potentials. As regards future research, another question is whether direct measures are needed for assessing rebound magnitudes, and whether price elasticity-based estimates can be deceptive representation of consumer behavior, given the fact that fuel saved through efficiency gain may be perceived as a 'free offer' by consumers.

We are aware of the limitations of the data and simplicity of the methodology applied in this study, but logical conclusions derived provide scope for further research. At least, now there is some more evidence from mobility services (as well as from lighting and space cooling, see Roy et al. 2013) to demonstrate that it may no longer be true to state that high rebound will take back 'all' the energy savings benefits of efficiency improvements in countries of the Global South. More than half of the surveyed households, with ownership of at least one car for private mobility, who behave as 'partial rebounders' or 'super conservationists' in urban India do send a very important policy relevant message: unsatiated demand is declining for the fast emerging middle class (Sorrell et al. 2009) in the Global South. Behavioural responses of people in the Global South are getting shaped by increased awareness of economic gains from energy efficiency improvements, as well as larger issues like environmental and climate impacts of rising energy consumption. High and middle income households in the Global South who still continue with high and exact rebound can be expected to quickly reduce their unmet demand through faster penetration of energy efficient cars (Chakravarty et al. 2013).

However, through complementary non-price policies they can be induced to save/switch fuel, which is not happening right now. Congestion management and road space expansion can encourage them to avoid taking longer detours. And appropriate infrastructure development for easy access to alternative fuels, communication of information about level of risks associated with old and new technologies can remove behaviourial barriers that lead to their high current rebound response besides being induced by unmet demand. However, some questions remain. For instance, when the current level of low car ownership for private mobility gets gradually replaced by high car ownership levels with the emergence of new car owners: what will be the aggregate impact in the Global South? The answer cannot be fully concluded from this study. But this study suggests that with rising income, declining unmet demand, penetration of efficient technologies in developing countries combined with non-price strategies to overcome behaviourial barriers and provisioning of comfortable mobility through public transport system —policies can succeed in breaking the long believed hypotheses in the literature that in the Global South, all savings are taken back by rebounds, and that rebounds in the Global South would necessarily be higher than in the Global North.

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Chapter 5
Production-Side Effects and Feedback Loops Between the Micro and Macro Level

Tilman Santarius

Abstract Research on the rebound effect has so far mainly considered 'micro-economic rebound effects' at the level of consumers and households, as well as 'macro-economic rebound effects' in the sense of energy efficiency-induced economic growth. This chapter focuses on an area of rebound research that has not yet received sufficient attention, namely on 'production-side rebound effects', at the company level, as well as sector-level rebounds at the level of industry branches and markets. The chapter summarises and systematises reasons why companies generate rebounds, distinguishes market- and sector-level rebounds from macro-economic growth effects, identifies a number of 'feedback loops' by which production-side and sector-level rebounds multiply or nullify consumer-side rebound effects, and finally discusses some conclusions on the potential quantitative dimension of production-side rebound effects.

Keywords Rebound effect · Energy efficiency · Energy economics · Sustainable production and consumption

More than 30 years of research on the 'rebound effect' (or 'take back effect', 'feedback effect') have identified a number of different effects that run under the label of 'rebound'. For the vast part of rebound literature, these have considered direct effects at the end-use consumer side. In addition, about a dozen articles are available about macro-economic effects at the aggregated, national effect. Only in the past few years, a few articles have been published on indirect rebound effects at the end-use consumer-side as well as rebound effects at the company level (see chapter introduction to this volume).

T. Santarius (✉)
Department of Economic Education and Sustainable Consumption,
Technical University of Berlin, Marchstr. 23, 10587 Berlin, Germany
e-mail: santarius@tu-berlin.de

T. Santarius
Institute for Ecological Economy Research, Potsdamer Str. 105, 10785 Berlin, Germany

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This chapter focuses on a number of rebound effects that have achieved too little attention so far. Besides various consumer-related micro-economic rebounds as well as macro-economic growth effects there are several production-side and market-level rebound effects, which may be ascribed to the meso-economic level. While such producer-side and market price effects have been raised earlier in the literature, e.g. by Greening et al. (2000), Birol and Keppler (2000), Sorrell (2007), and Saunders (2008, 2013), authors like Madlener and Alcott (2009), Borenstein (2015), and Turner (2013) still identify significant gaps in the research of such effects. Yet the overall dimension of production-side rebounds could be significant, since roughly two thirds of global energy is used in the production process, and only about one third during consumption.

Although the level of the single firm can still be considered a micro-economic unit, historically rebound research has mainly treated consumer- or household-related rebounds as micro-economic rebound effects. This chapter intends to investigate production-side rebound effects that range from the level of the firm up to the level of a sector or market. After briefly analysing the state of research on these effects, it will discuss specific reasons why companies may generate rebound effects after having invested in energy efficiency measures. The focus then moves from company-specific rebounds to market- and sector-related rebound effects, still distinct from macro-economic growth effects (as of Brookes 1978, 1992). A number of 'cascade effects' show how production-side rebounds may interact with consumer-side effects, either multiplying or nullifying them. Finally, this chapter will discuss some assumptions on the potential quantitative dimension of production-side rebound effects.

5.1 State of the Research

On the theoretical side, only few studies acknowledge the importance of production-side rebound effects as a separate and identifiable factor and area of research. Greening et al. (2000) devote one paragraph to rebound effects by 'firms' and point out two distinct rebound mechanisms, namely 'output effects' and 'factor substitution' (see Sect. 5.2 for a discussion, and for more potential effects), which correspond exactly to the direct rebounds that arise from the income and substitution effect on the consumer side; Sorrell et al. (Sorrell 2007, 2009; Sorrell et al. 2009) also mention these two effects, as does Saunders (2008, 2013). In the case of the substitution effect, the more efficient use of energy as a means of production results in firms substituting labour, time, capital and other production-side resources with increased energy use. The two effects can of course also occur in combination. Building on Greening et al. (2000), Jenkins et al. (2011) also describe an output effect on the production side, equivalent to the income effect on the consumption-side, which they term the 're-investment effect': "*Producers who secure net energy savings from efficiency improvements (after direct rebound effects) may use the savings to increase output of one or more of their products. In addition to increasing demand for energy inputs, demand for other production* *inputs (capital, labour, materials) will rise, and each in turn requires energy to produce or support as well, leading to further indirect rebound in energy demand"* (Jenkins et al. 2011, p. 20). The authors highlight the systemic links between direct rebound effects and subsequent additional indirect rebounds. The limited number of other publications that offer a theoretical perspective on production-side rebound effects (e.g. Michaels 2012; Borenstein 2015; Turner 2013) mention the same linkages that occur in the case of macro-economic effects—namely, the fact that the interaction of labour, capital and energy as factors of production changes throughout the economy ('composition effects'), which can lead to overall economic growth (macro-economic rebound effect).

Research on the empirical side is considerably better than on the theoretical side. Bentzen (2004) and Saunders (2013) are two studies that calculate production-side rebound effects for multiple sectors—not at the level of individual firms. Using time series data covering the period 1949–1999, Bentzen estimates a 24 % rebound effect for the US manufacturing sector on the whole (Bentzen 2004). Saunders disaggregates US manufacturing into 30 sectors. Using records from 1960 to 2005 for 30 sectors of the US economy, he simulates the rebound effects that would have occurred if there had been no improvements in efficiency after 1980. Rebound effects calculated for the aggregation of all sectors average 120 % between 1981 and 1990 and 60 % between 1991 and 2000. However, a few sectors, e.g. electricity production, significantly peak out; for most sectors analysed, rebounds range between 30 and 60 %. Yet if Saunders combines energy efficiency with productivity gains for labour and capital as production factors, apparent rebound effects amount to 649 % between 1981 and 1990 and 172 % between 1991 and 2000 (Saunders 2013). Due to non-existing comparable studies, interpretation of such empirical data has to be treated carefully.

In addition, few studies are available on singular sectors. For instance, for the Chinese steel industry, a paper by Guo et al. (2010) calculates a 46 % rebound effect during the period of 1979–2007, while Kai et al. (2011) calculate a 130 % rebound in the period of 2000–2007. While the validity of such singular studies is hard to evaluate, five studies on freight transport in European countries provide a more comprehensive picture. The empirical findings put the level of direct rebound effects in freight transport at between 17 and 80 % (see Gately 1990; Graham/Glaister 2002; Anson/Turner 2009; Matos/Silva 2011; De Borgera/Mulalic 2012), which in any case, and despite a still significant variation, portraits a scope significantly higher than the average level of consumer-side rebound effects in personal automotive transportation, which is put at between 10 and 30 % (Sorrell 2007). In addition, a study by Evans and Schäfer (2012) on aviation in the United States finds a rebound of 19 % for this sector—which is, given the high share of fuel costs of that sector, a surprisingly low result.

Rebound effects could also be derived from studies estimating elasticities of substitution for certain industry branches or sectors. Saunders (2000a) as well as Birol and Keppler (2000) postulate the theorem: the greater the elasticity of substitution between the production factors energy and capital—or more accurately: the energy elasticity of substitution of energy for capital—the greater the rebound effects. Yet regrettably, from a broad review of various estimates, Broadstock et al. (2007) conclude that the literature is far from uniform on this question: "*The most striking result from the analysis is the lack of consensus that has been achieved to date, despite three decades of empirical work. (…) If a general conclusion can be drawn, it is that energy and capital typically appear to be either complements (…) or weak substitutes*." (Broadstock et al. 2007, p. 51). In any case, estimates of elasticities of substitution for industry branches and sectors need to be interpreted with great caution, as results much depend on the kind of production functions and the specific exogenous parameter used in the models (see also Saunders 2008; Safarzynska 2012; Santarius 2014).

5.2 Reasons for Production-Side Rebounds

Daniel Khazzoom already identified three reasons why consumers may transform an increase in income that stems from an energy efficiency gain into an increase in energy demand: consumers can either intensify the use of the good, e.g. by driving more kilometres with the more efficient car; they can intensify their comfort, e.g. by driving faster or heavier cars; or they can increase the stock of goods, e.g. by buying a second or third car per household (Khazzoom 1980). In addition, of course, consumers may generate various indirect rebound effects, when using the extra money to consume other goods and services. Most rebound effects can be explained by either an income effect—the increased energy efficiency saves money and thus allows for additional demand—or a substitution effect—the increased energy efficiency incentivises more demand for the now-efficient product at the expense of less demand for other (conventional) products.

Five reasons can be identified why companies demand more energy after an energy efficiency increase. First of all, investments in efficiency technologies necessarily increase demand for energy in order to produce such technologies. This energy use is termed 'grey energy' because it is 'embodied' in the efficiency technologies. The associated increased demand has been called the 'embodied energy effect' (e.g. Kaufmann 1992; Sorrell 2009; Jenkins et al. 2011; Chitnis et al. 2013).

Two other reasons can be explained in terms of an income effect. They rest on the assumption that companies generate extra profit after having invested in an energy efficiency increase. For example, a firm can use the additional profit arising from an efficiency-boosting measure to expand production of the same product; this is equivalent to a direct rebound effect in the form of expansion of production. Greater emphasis may for instance be placed on marketing the product, or it may be sold at a lower price—not only because the improved energy efficiency is reflected in lower production costs, but also because the new expansion of production can result in further cost savings if economies of scale are realised and if fixed costs (e.g. for production buildings and systems) can be distributed over a larger number of produced goods.

Alternatively, a company can use its increased profits to invest in new products and services; this is equivalent to an indirect rebound in the form of diversification of the product palette. In this case, the production costs saved as a result of the improved efficiency of the production process for Good 1 are not used to produce more of Good 1 and sell it more cheaply; instead the money 'cross-subsidises' production of another product, Good 2. This makes sense if, for example, the market for Good 1 is considered to be saturated or if Good 2 is expected to yield a higher profit margin.

Another reason can be explained in terms of substitution effects. In contrast to consumption-side rebounds that may rest on the substitution of end-use products, companies can substitute factor inputs in the production process. Most commonly, companies will make use of energy efficiency increases to substitute labour through energy (and capital), e.g. through increased mechanisation, automation or digitalization. However, all economic inputs may partially be replaced by energy. For instance, in the case of steel production, the replacement of capital- and energy-intensive blast furnaces through electric arc furnaces did not only increase energy but also capital productivity (Saunders 2000b). Likewise, other material resources, time or space may be saved through increased energy use, as the example of just-in-time logistics shows, which has accelerated delivery times while reducing storage capacity and warehousing.

Finally, in addition to these effects as variants of the income and substitution effect on the production side, firms can also generate a rebound effect if expected cost savings for consumers lead them to invest in redesigning the original product, perhaps to improve its convenience. In this case companies are not acting *in response* to a production-side effect but *in anticipation* of a consumption-side income effect; more precisely, by redesigning the product they are exploiting the anticipated income effect on the consumer side *ex ante*. In the past, for example, improvements in the efficiency of engine technology have seldom been used to produce cars that consume less fuel; instead, manufacturers have focused on marketing cars that have the same fuel consumption per kilometre but are heavier, faster and more powerful. The fuel consumption figures of the classic 1955 VW Beetle, which uses 7.5 l of petrol per 100 km, and the modern 2005 Beetle, which uses 7.1 l over the same distance, are almost identical. But while the earlier model, which had a 30 hp engine and reached a top speed of 110 km/h, weighed just 730 kg, the later one has a 75 hp engine, a top speed of 160 km/h and various additional features such as air conditioning; it weighs in at around 1200 kg (Santarius 2012). This is a clear case of the rebound effect, measured in tonne-kilometres per litre of petrol. While such effects have not been sufficiently considered in the rebound literature so far, it can be debated whether they should be considered a consumer-side or producer-side rebound. In any case, Sect. 5.4 of this paper argues that research more thoroughly needs to look at the interrelationship of rebound effects at multiple levels.

5.3 Market Price Effects

Rebound effects at the ‘meso-economic’ level can also be generated by market price effects if a large number of individual actors in the market act collectively; this can occur not only on the production side or within a sector but also through the combined effect of the actions of large numbers of consumers. In past rebound research, the aggregated impact of market price effects have been discussed as part of the macro-economic, economy-wide rebound (see, e.g., Greening et al. 2000; Dimitropoulos 2007; Sorrell 2009). Yet market price effects related to the demand for energy can arise in various markets separately, such as those for electricity (power), motor fuel (petrol, diesel), heating oil, coal and lignite and gas. In the past, the prices of the various energy resources have often been linked, so that market price effects in one market are transferred to the market for other forms of energy and then exert a combined effect at macro-economic or economy-wide level. Nevertheless, efficiency improvements always operate initially on one market and will also generate (direct) rebound effects initially on this market. They are therefore discussed in this chapter as meso-economic rather than macro-economic growth effects.

The market price effect arises—as in an economic text book situation—from the interaction of supply and demand. According to the theory, a fall in demand always leads to a reduction in supply, until supply and demand once again stabilise at a lower price level. Thus, if as a result of improvements in energy efficiency end consumers and firms demand less of a particular form of energy, its price will fall (relatively). However, the interaction of supply and demand means that lower prices for electricity, gas, petrol or coal incentivise increased demand for one of these forms of energy. In this manner, the market price effect of efficiency improvements can elicit a rebound effect.

The quantity of market price effects depend on elasticities of supply and demand, with inelastic demand or elastic supply resulting in less rebound effects and elastic demand or inelastic supply resulting in larger rebounds. Usually, supply has been rather inelastic in oil markets while more elastic in gas, coal and electricity markets (Borenstein 2015). Therefore, high market price effects are particularly probable in oil markets as well as secondary markets, which largely depend on oil prices but face high demand elasticities from consumers.

The market price effect tends in the same direction as the income effect at individual level, but a clear distinction should be made between the two. In the case of the income effect, rebound effects occur because the initial reduction in people’s consumption of an energy resource that results from an efficiency improvement reduces the *cost* of energy to individuals and hence creates an incentive to express more demand for energy—even if the price of energy remains unchanged. The market price effect creates an additional incentive to increase demand if the reduced *price* of an energy resource reduces the cost of a particular level of energy consumption. For example, the income effect means that petrol costs fall by 50 % when a driver switches from a car that consumes 6 l of petrol per 100 km (a ‘six-litre car’) to one that uses only 3 l (a ‘three-litre car’). This releases money for increased energy use—whether for additional journeys or for other energy-consuming goods and services. Moreover, a market price effect can also occur if there is broad-scale replacement of six-litre cars by three-litre ones and this leads—at least in theory—to a halving of the price of petrol. However, because there is demand for petrol not only in the sector that has become more efficient but also in other sectors and countries, and because, moreover, the prices of different energy resources are at least partially linked, the price of petrol is in reality unlikely to be halved, but it will fall relatively.

There are two ways in which this general fall in price can result in increased demand. First, the lower price of one form of energy can trigger rebound effects by stimulating demand from other sectors. For example, a fall in the price of petrol can result in increased demand for other petrol-using products, which are now cheaper to operate: municipal authorities may now invest in more motorised leaf blowers, or stock-keeping may be increasingly replaced by transport-intensive just-in-time logistics. The market price effect can trigger direct rebounds—for example, if municipal authorities now extend their use of motorised leaf blowers and clean streets that for cost reasons were not previously cleaned at all. Alternatively, indirect rebounds can be triggered if a substitution process is set in motion—for example, if municipal authorities start using motorised leaf blowers instead of sweeping the streets with conventional brooms, or if freight transport is switched from rail to road.

Several authors (e.g. Turner et al. 2009; Jenkins et al. 2011) use the term 'composition effect' to describe this effect—that is, the way in which the market price effect influences indirect rebound effects. Reduced market prices can indeed alter the composition of the portfolio of goods and services in a country's economy. Just as the market price effect tends in the same direction as the income effect, the composition effect amplifies the impact of the substitution effect described above. But in contrast to the substitution effect, which can also occur in the absence of any income effect, the composition effect is ultimately only a variant of the market price effect: there can be no composition effect without a market price effect. Either the composition of the economy changes simply as a result of the sum of all micro-economic substitution effects, or the interaction of micro-economic income and substitution effects gives rise to a market price effect, one of the impacts of which may be to alter the composition of the economy's portfolio of goods.

5.4 Cascade Effects and Feedback Loops Between Production- and Consumption-Side Rebounds

Second, the market price effect can amplify the direct rebound effect on the consumer side. For example, drivers of three-litre cars may use their cars more because they benefit from a double real income gain. Figure 5.1 shows the additive interaction of income and market price effects. The lower fuel consumption of the three-litre car initially means that drivers spend less on petrol and hence can drive

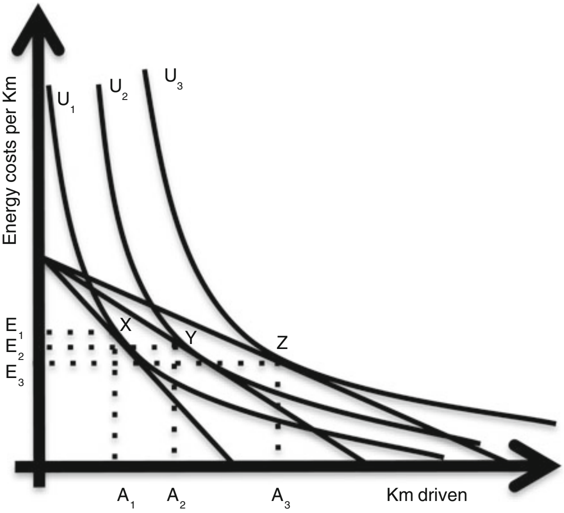

Fig. 5.1 Reinforcing effect from market price- on consumer-side income effect. *Source* Author's own design

further (from A_1 to A_2), which increases the driver's utility (from U_1 to U_2). At the same time the lower price of petrol following broad-scale introduction of three-litre cars acts as an additional income effect, so that drivers can now travel even further (from A_2 to A_3) and their utility increases again (from U_2 to U_3).

In addition market price effects can result in new consumers entering the market who would previously have been deterred by the high energy prices or high energy consumption costs (see also Herring 1998). If such consumers respond to prices below a certain threshold (market entry price), market price effects can again serve to multiply micro-economic rebounds.

The occurrence of market price effects is an important part of the case for arguing that meso-economic rebound effects cannot be regarded merely as equivalent either to the sum of micro-economic effects or to macro-economic growth effects. For market price effects do not necessarily lead to macro-economic growth. If we follow Brookes and Saunders and regard macro-economic rebound effects as being primarily growth effects on the entire economy induced by energy productivity, production-side and other meso-economic rebound effects can be distinguished as a separate factor.

Income and market price effects can trigger a second form of feedback loop that leads to an additional increase in demand. If the level of the income and market price effects is significant, demand for the goods or services concerned rises significantly in society as a whole. This increased demand requires production of the corresponding goods and services to be expanded; this can result in economies of scale that again cause prices to fall and produce a further relative income gain. The further production is from a low level of falling marginal costs, the greater the economies of scale. Figure 5.2 illustrates the typical correlation between rising demand and falling unit costs: as the marginal costs of production fall, expansion of the quantity produced leads initially (from A_1 to A_2) to a significant increase in

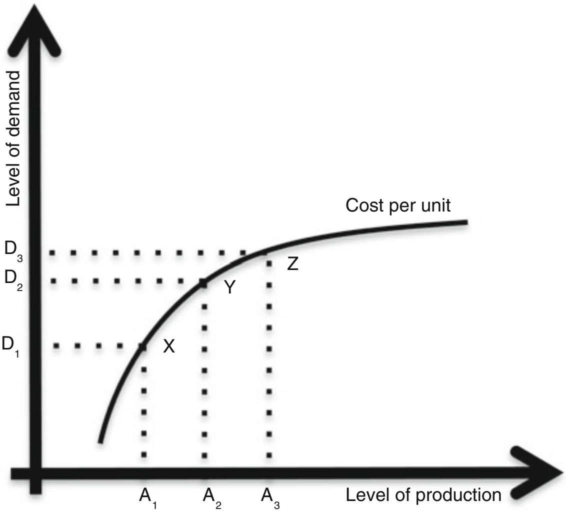

Fig. 5.2 Feedback loop between income-, market price- and economies of scale-effect. *Source* Author's own design

demand (from D_1 to D_2); which is to say, in our case, to high rebound effects. Further expansion of production, though, (from A_2 to A_3) results in only small additional cost savings and hence in only a smaller increase in demand (from D_2 to D_3), i.e. to smaller rebound effects.

It should, however, be borne in mind that these different rebound effects can in some circumstances cancel each other out. For example, if the broad-scale switch from six-litre to three-litre cars means that consumers now drive twice as far, no market price effect can occur because the demand for petrol is unchanged. The combined impact of income and market price effects must therefore always be less than 100 %. Leaving the case of new market entrants in domestic or international markets out of sight for a moment, this means that cascade effects of income and market price effects do not increase the probability that backfire will occur.

If the rebound effects are indeed less than 100 % and, hence, only partially offset the theoretical savings potential, the overall fall in demand can in fact lead to negative economies of scale that counteract the effects of market price and income. For example, despite lower consumption levels petrol prices may fall by a disproportionately small amount or perhaps not at all, because oil refineries and petrol station operators must now spread their fixed costs over a smaller quantity of petrol sold. In this context, Turner has described how improvements in energy efficiency can trigger a cascade of ‘negative rebounds’, which she calls ‘disinvestment effects’ (Turner 2002, 2013; Turner et al. 2009). Such effects may constrain the elasticity of supply of energy, increase the actual price of energy, and hence decrease the demand for energy.

So contrary to assumptions by, e.g. Brookes (1990) or Saunders (2008) that macro-economic rebounds will be larger in the long-run than in the short-run, at the market or sector level it may be the other way around if the return on capital investments fall due to decreasing demand. However, even when this takes place in certain sectors, it does neither prejudge the efficiency-induced macro-economic growth effect nor the sum of all rebound effects at all economic levels. Again, meso-economic rebounds should be considered separately form macro-economic ones.

Despite this, it is also possible for the effects of income, market price and scale to amplify each other—for example, if increased capital costs for the procurement of a more energy-efficient technology are reduced by economies of scale. It is, for instance, conceivable that a (legally enforced) introduction of three-litre cars will produce only a moderate income effect initially, because these cars are more expensive to buy than conventional ones. However, demand for petrol will fall significantly, because the new cars are significantly more fuel-efficient. This can generate market price effects, to some extent boosting the demand for car journeys and inducing some shift of freight transport from rail to road. As a result, more vehicles with these efficient engines will be needed for both passenger and freight transport: this will enable manufacturers to benefit from economies of scale and reduce the selling price of these vehicles. The resulting income gain can in turn trigger further direct and indirect rebound effects.

Finally, a third form of feedback loop between the production- and consumption-side is possible: firms can use the additional profit generated by improving the energy efficiency of the production process to raise workers' wages (as already noted by Wackernagel/Rees 1997). This produces an income effect on the consumer side. In such a scenario, efficiency gains on the production side act as a multiplier of consumption-side income effects.

However, this does not mean that this feedback loop increases the demand for energy to a greater overall extent than if firms invest their additional profit in expanding production. A glance at the structure of econometric model calculations for macro-economic rebound effects suggests that different assumptions about nominal and real income rises have significant effects on the rebound effect. For example, in a model created by Allen et al. the total macro-economic rebound effect falls from 37 to 33 % if it is assumed that the workers are given pay rises and the number of jobs is not increased. The total rebound effect rises from 37 to 52 % if it is assumed that the number of jobs rises by 1 %, while wages remain unchanged (Allen et al. 2007, p. 24; see also Allen et al. 2006). This suggests that transferring potential production-side rebound effects to consumption-side ones by raising workers' income (instead of generating more jobs) might reduce the total economy-wide rebound effect.

5.5 Generalisations on the Potential Scope of Meso-Level Rebound Effects

Birol and Keppler (2000) put forward the following hypothesis:

> The rebound effect (…) increases with the level of aggregation. We would expect the rebound effect at the level of the single firm or the single consumer to be smaller than at the level of the sector, and the rebound effect at the sectoral level to be smaller than the rebound effect at the national level (Birol/Keppler 2000, p. 463).

However, the authors did not provide any systematic justification of this hypothesis. What arguments support the suggestion that rebound effects may increase with the level of abstraction?

This chapter has identified economies of scale and market price effects on the meso-economic level that may amplify micro-economic rebound effects via various feedback loops. It has, however, also been shown that in certain circumstances they may reduce the total rebound effect. There are nevertheless three further reasons why production-side rebounds generally tend to be larger than consumption-side ones.

As was identified in the discussion about macro-economic rebound effects—in particular by Saunders (1992, 2000a)—and critically examined by Howard (1997), the level of the rebound effect depends not only on the elasticity of substitution between individual goods and services but also on the substitution elasticity of the factors of production: labour, capital, energy and materials. It can be assumed that the higher the level of aggregation (from a single firm to a branch to a sector), the greater the scope for substituting factors of production with one another (see also Birol/Keppler 2000). For example, the potential for replacing labour with energy use through automation or digitalisation, or for replacing energy use with capital, is likely to be greater within production processes than within the individual consumption of private households. In other words, the elasticity of substitution between energy, labour and capital increases with the level of aggregation. This is all the more the case since companies usually do not produce a single homogeneous product but rather a range of different products, each requiring a different input mix.

Moreover, much of the output from any industry is used as input by other industries, i.e. in the form of intermediate inputs, and as such never reaches consumers as ‘final output’ of a given economy. An efficiency gain in any one industry reduces the cost of its output, thereby reducing the cost of intermediate inputs to other industries, which in turn will respond by increasing output and thus dragging up their energy use. Thus, resulting reductions in the cost of ‘final outputs’ that consumers see create complex demand shifts that generate complex energy use shifts through the production-consumption system. As Broadstock et al. have phrased: ‘*changes in factor prices could lead to a change in the relative contribution of individual subsectors to the output of a sector, or the relative contribution of individual sectors to the output of an economy. The scope for such changes is likely to increase with the level of aggregation for which the elasticity of substitution is estimated*’ (Broadstock et al. 2007, p. 31).

In addition, a technological innovation developed in a pioneering company is often quickly taken over by the entire sector. Consumers, by contrast, often take decisions on the basis of status, prestige or aesthetics; for this reason, cost- or energy-saving technologies, once they have come onto the market, are rarely adopted by all consumers. For example, many consumers opt to buy a luxury car rather than a low-priced one, while freight companies are swayed mainly by cost arguments when choosing vehicles for their fleet. In general, it can be assumed that firms are more likely than consumers to act in ways that spread more broadly and more quickly in the quest to maximise their profits. In accordance with this, income and substitution effects will result in firms and/or sectors exploiting the potential of rebound effects to the full.

Nevertheless, as has been highlighted in this paper, elasticities of substitution as well as the likelihood to generate feedback loops between the meso- and the micro-economic level can highly differ between sectors, and all the more between single firms. So while the above-mentioned hypothesis of Birol and Keppler (2000) can be supported, it needs to be qualified. The following rather more cautious hypothesis about the quantitative aspect of production-side rebound effects thus seems more appropriate: *The volatility of the scope of rebound effects increases with the level of economic action and aggregation. In general, one can expect the rebound effect at the level of the single firm to be larger than at the level of the single consumer, and the sum of rebound effects at the level of industry sectors and markets to be larger than the sum of rebound effects from households.*

Further research on meso-economic rebounds is urgently required. Thanks to the large number of empirical studies in consumer-related rebound effects, their quantitative dimension can now be better assessed; to match this, the deficient attention of research relating to production-side rebound effects needs to be engaged by additional empirical analysis of investment decisions along the lines of company- and sector-specific price and substitution dynamics.

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Part II
Multidisciplinary Perspectives on the Rebound Phenomenon

In the earliest publication that marks modern rebound research, Khazzoum (1980) states that 'energy efficiency improvement have a price content'. Ever since, in the vast majority of rebound publications throughout the last 35 years, the impacts of energy efficiency improvements on production or consumption have been analysed according to their price contents. Both income and substitution effects at the microeconomic level as well as substitution, composition, and output effects at the macroeconomic level build on assumed (or observed) changes in prices and cost structures. Yet doubts are arising that this perspective on potential impacts of energy efficiency improvements on the economy—or even society—might be too narrow. Could it be that rebound effects arise from (energy) efficiency improvements having other and additional economic, behavioural, social, political or even cultural effects than just altering prices?

In their early meta-analysis of rebound research, Greening, Greene and Difiglio (2000) distinguish four different types of rebound effects: "*(1) direct rebound effects, (2) secondary fuel use effects, (3) market clearing price and quantity adjustments (especially in fuel markets) or economy-wide effects, and (4) transformational effects*" (Greening et al. 2000, p. 390). It is the fourth type that is of key relevance to the question raised above, and to Part II of this volume. Greening et al. define such 'transformational effects' as follows: "*Changes in technology also have the potential to change consumers' preferences, alter social institutions, and rearrange the organization of production. We refer to these potential effects as transformational effects. However, there is no all-inclusive theory for predicting those effects, which could result in more or less energy consumption. […] Therefore, for this discussion we have chosen to neglect transformational effects.*" (Greening et al. 2000, p. 391f.) Part II of this volume will help fill the gap of such neglected analysis.

Chapters 6–8 focus on the microlevel and deal with the question how efficiency improvements can change consumer preferences. Theories and methodologies applied mainly dwell on psychology and behavioural sciences. Chapter 9 then focuses on the macrolevel and investigates how efficiency improvements can alter social institutions and rearrange the economy. This chapter combines theories and discourses from sociology and economics. Hence building on, but much broadening and advancing the energy economic view of the previous four chapters of Part I of this volume, the following chapters of Part II will endeavour inter- and multidisciplinary approaches on the issue; namely, how energy efficiency improvements impact on human motivation and the structure of society and economy.

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Chapter 6
Exploring Rebound Effects from a Psychological Perspective

Anja Peters and Elisabeth Dütschke

Abstract The analysis of energy efficiency rebound effects from a psychological perspective has just begun, and empirical studies analysing psychological factors in relation to the rebound effect are still scarce. In this chapter, we first identify possible psychological drivers to explain rebound effects based on psychological action theories. The outlined psychological framework suggests that energy efficiency improvements have different effects on behaviour depending on the interaction of psychological factors such as attitudes, personal and social norms and response efficacy. In a second step, we present results from an empirical study using focus group discussions to explore rebound effects and psychological drivers in the transport and residential sectors. The results are in line with the outlined psychological framework and indicate that need satiation, habits and mistaken beliefs about the optimal usage of a technology also seem to play a role. Finally, research questions are outlined to help further develop and test hypotheses on the psychological factors influencing rebound effects.

Keywords Consumer behaviour · Theory of planned behaviour · Norm activation model · Focus groups

The replacement of appliances and other energy using products and services by more efficient ones is generally regarded as an effective strategy to reduce energy demand. However, the savings realised by this strategy may be lower than those theoretically expected or calculated from a technological point of view due to changes of behaviour following the acquisition. This phenomenon is known as the rebound effect. The majority of the body of literature on rebound effects stems from the field of economics. Neo-classical economics usually assumes that rebound effects are *induced by the changes in energy service costs* following energy efficiency improvements: For example, if consumers reduce their costs per vehicle

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A. Peters (✉) · E. Dütschke
Fraunhofer Institute for Systems and Innovation Research ISI,
Breslauer Strasse 48, 76139 Karlsruhe, Germany
e-mail: anja.peters@isi.fraunhofer.de

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kilometre using more efficient vehicles than before, they are expected to turn these financial savings into higher mileage (direct rebound effect).[1] This chapter will focus on direct rebound effects in one of the first attempts to extend psychological theory to this issue.

Focusing on the cost argument as the main cause of direct rebound effects seems too simplistic: Some authors have already suggested factors which might additionally influence and limit or enhance rebound effects, such as the degree to which needs are already satisfied (Hofstetter et al. 2006; Madlener and Alcott 2009; Wörsdorfer 2010 or Chap. 8 by Suffolk and Poortinga in this volume), or certain norms and attitudes towards the relevant behaviour and the environment (see, e.g. de Haan et al. 2006 for car purchase and use, and Matiaske et al. 2012; cf. Chap. 4). In analogy to the accounting of financial expenditures and savings, Girod and de Haan (2009) postulate that individuals or households may also apply some kind of mental accounting to the environmental impacts caused by their behaviour, so that environmentally-friendly behaviour in one area might justify less environmentally-friendly behaviour in the same or other areas. Similar mechanisms, referred to as "moral licensing" can be found in studies investigating the role and neglect of moral norms (Mazar and Zhong 2010; Merritt et al. 2010) or negative spillover (Thøgersen and Crompton 2009). Thus, if individuals switch to more efficient products and services, they might feel justified in consuming more of these products and services.

Psychological research has developed psychological action theories to explain human behaviour. These theories combine cognitive (e.g. action skills, knowledge) and personality variables (e.g. locus of control) and have identified various specific factors such as norms and attitudes as relevant determinants of human behaviour (cf. Bamberg and Möser 2007). These factors, which are well established in the field of energy-relevant behaviour, are rarely considered in the discussion of rebound effects.

Thus, if rebound effects occur, they may not necessarily correspond to the exact amount of financial (or other) savings and they can have different causes, e.g. lower usage costs, but also changes in psychological variables.

The psychological analysis of the rebound effect has just begun and empirical studies analysing psychological factors in relation to the rebound effect are still scarce (Santarius 2014). In order to contribute to closing this gap in the scientific literature, it seems worthwhile to systematically consider, discuss and explore the contribution of psychological action theories in the context of rebound effects.

Thus, the aim of this chapter is to develop a psychological framework to explain rebound effects and to present the findings from a qualitative study.

The remainder of this chapter is structured as follows: In Sect. 6.1, we discuss psychological concepts to explain general energy-relevant behaviour and then go on to identify factors that may be relevant for explaining rebound effects. Based on

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[1] Alternatively, the saved money is spent on other goods and services which are likely to be energy-consuming as well, e.g. more extensive plane travel (indirect rebound effect).

this, we present the method (Sect. 6.2) and results (Sect. 6.3) of a qualitative focus group study conducted to explore behavioural effects following energy efficiency improvements and psychological factors in the transport and residential sector. In Sect. 6.4, we discuss the results and their implications for future research and for the policy debate.

6.1 Psychological Action Theories and Rebound Effects

Psychological action theories enable a deeper analysis of the reasons for specific behavioural patterns by identifying relevant determinants of behaviour and by explaining behaviour as the result of individual processing and evaluation of information influenced by individual psychological factors. We chose this theoretical approach because we assume that the energy efficiency increase may induce the re-evaluation of relevant behaviours and lead to behavioural changes.

The action theories which are most often applied to explain environmentally-relevant behaviours are the theory of planned behaviour (TPB; Ajzen 1991) and the norm-activation model (NAM; Schwartz 1977; Schwartz and Howard 1982).

According to the TPB, behaviour is directly influenced by an individual's intention to perform the behaviour. Intention, in turn, is determined by (1) an individual's attitude towards the behaviour, defined as an overall evaluation of its possible consequences, (2) subjective norms, referring to the perceived expectations of other important persons, e.g. family, peers, neighbours (we use the term 'social norms' in the following) and (3) the perceived behavioural control (PBC), defined as a person's perceived ability to perform the behaviour due to non-motivational factors such as the actual and perceived availability of opportunities and resources. Fishbein and Ajzen (2010) point out that PBC (and intention) can be used to directly predict behaviour if actual behavioural control is perceived accurately. The attitude towards behaviour is conceptualised by Ajzen (1991; cf. also Fishbein and Ajzen 2010) as an expectancy-value model. According to the model, expectancy (that a specific behaviour results in particular consequences) and evaluation (i.e. the valence of these consequences) are assumed to determine the overall evaluation of the behaviour. The main idea is that attitudes are based on information accessible in memory and that this information may be partial, i.e. suffers from human limitations due to a variety of cognitive and motivational processes (cf. Ajzen 2012). This means attitudes are influenced by individual motives as well as individual values which steer information processing as well as valence formation.

Studies using the NAM explain behaviour as influenced by (1) a personal norm to engage in the specific behaviour denoting a strong intrinsic feeling of obligation. Prerequisites of the formation and activation of this personal norm are (2) the awareness of a related problem that needs to be solved, (3) the awareness or

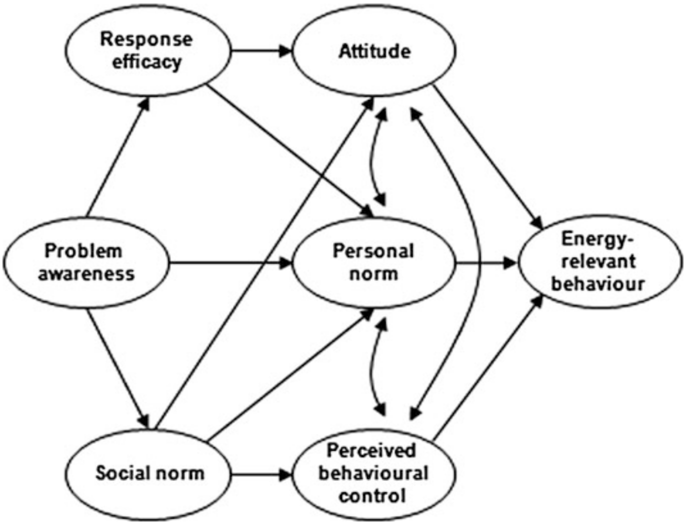

Fig. 6.1 Integrated model to explain energy-relevant behaviour using psychological variables adapted from Bamberg and Möser (2007) and Peters et al. (2011) (*arrows* indicate direction of influence)

identification of the specific behaviour as an effective action that contributes to mitigating the specific problem[2] (we refer to ‘response efficacy’ in the following) and (4) the recognition of the personal ability to engage in such action. This may correspond very well to the TPB’s PBC. Besides personal norms, behaviour is also influenced by the consideration of (5) the perceived expectations of others, i.e. a perceived social norm, as well as (6) the non-moral implications of action. These influences are also included within the TPB using the subjective norm and attitude concepts. Another influential variable in the NAM approach is (7) the assumption of responsibility for one’s own actions and their consequences.

Substantial empirical evidence has been collected in support of these models explaining environmentally-relevant behaviour (for the TPB, e.g. by Haustein and Hunecke 2007; Kaiser and Gutscher 2003; Kalafatis et al. 1999; Tonglet et al. 2004; for the NAM, e.g. by Gärling et al. 2003; Hopper and Nielsen 1991; Hunecke et al. 2001; Thøgersen 1999). More recently, various researchers have proposed integrating both concepts into one model (cf. Bamberg and Möser 2007; Matthies

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[2] This construct relating to the awareness that one’s own behaviour has an effect and, hence, can make a difference has appeared in the literature under different labels, e.g. as efficacy (e.g. Kerr 1992), response efficacy (e.g. Lam and Chen 2006), or perceived (consumer) effectiveness (e.g. Thøgersen and Ölander 2006). However, it has to be distinguished from concepts which relate to judgements of how well one can execute the behaviour in question (e.g. Ajzen’s (1991) concept of perceived behavioural control; Bandura’s (1977) concept of perceived self efficacy).

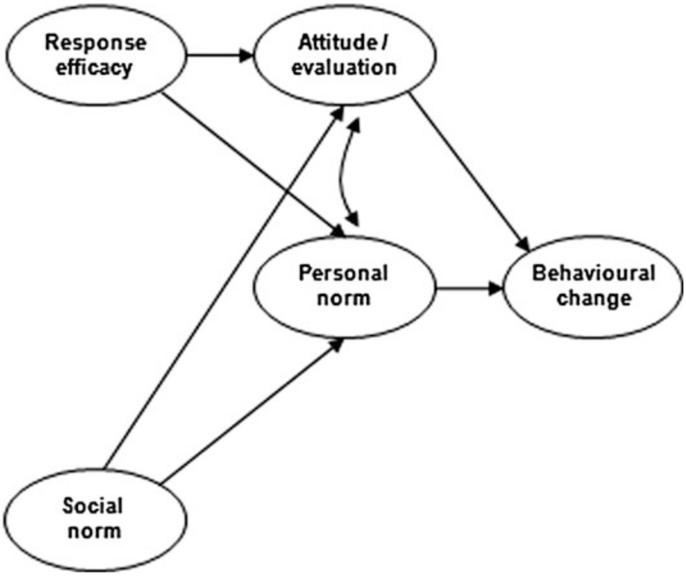

Fig. 6.2 Hypothesized variables assumed to influence whether an investment in an energy-efficient product leads to rebound effects (*arrows* indicate direction of influence)

2005; Peters et al. 2011). Figure 6.1 illustrates an integrated model adapted from Bamberg and Möser (2007) and Peters et al. (2011) to explain energy-relevant behaviour, i.e. the adoption and use of an energy-consuming product or service.[3]

Within the frame of psychological action theories, changes of behaviour can be explained by changes in the determinants of the behaviour. Thus, in order to explain rebound effects, i.e. changes of behaviour due to an efficiency improvement to a product or service used by an individual, we aim to identify the variables which are most likely to change when a product or service becomes more efficient.

As we will outline in the following, we assume that four variables of the psychological model presented in Fig. 6.1 could be influenced, i.e. changed, by the improved energy efficiency of a product or service (cf. Fig. 6.2). The main focus is on possible triggers of rebound effects, but contrary effects following improvements of energy efficiency and inducing behavioural changes in the other direction leading to even more energy savings are also considered.

- *Attitude*: The overall evaluation of a certain behaviour may change because an investment is made in the energy efficiency of a product or service. As outlined above, the attitude towards a specific behaviour is conceptualised as an

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[3] In contrast to the NAM and the model of Bamberg and Möser (2007), our model does not explicitly include the internal attribution of responsibility for the consequences of one's action or inaction, as this should be closely related to response efficacy, i.e. the awareness that one's own specific behaviour has an effect with regard to the problem.

expectancy-value model. This means that individuals take into account the expectancy that a specific behaviour results in specific consequences as well as the valence of these consequences. After the energy efficiency of a product or service has improved, it is likely that some of the perceived consequences may change, e.g. that use is perceived as less harmful to the environment as well as inducing lower operating costs. While this perception is generally correct, it may lead to a more efficient car being used more intensively than the former vehicle, thereby reducing the potential energy savings the purchase of the car could have realised, i.e. inducing rebound effects. However, another effect on attitude might also come into play. According to the self-perception theory (Bem 1972), people develop attitudes by observing their own behaviour. The behaviour of investing in efficiency improvement could make people perceive themselves as citizens with pro-environmental attitudes, and could therefore strengthen or create a (more) positive attitude towards subsequent energy-saving behaviour (see, e.g. McKenzie-Mohr 2011). This latter effect also restricts rebound effects and might even increase energy savings above and beyond the purely technical potential of the efficiency improvement.

- *Personal norm*: Similar to attitude, mixed effects are possible for personal norms. On the one hand, the strength of personal norms related to the relevant behaviour may decrease, i.e. the inner feeling of obligation to use a car in an environmentally-responsible way, and not to use it, e.g. for a trip to the nearby bakery, may be weakened if using the more efficient car is perceived as less harmful than before. In this context, according to Thøgersen and Crompton (2009), a contribution ethic may underlie this phenomenon: People feel less obliged to perform a specific environmental behaviour, the more they have performed another behaviour to address the problem. On the other hand, according to the self-perception theory, the personal norm for energy-saving behaviour could be enhanced, i.e. rebound effects could be contained by a strengthened personal norm.
- *Social norm*: The strength of the perceived social norm may be reduced. Generally, individuals may have the perception that their relevant others, e.g. their peers and families expect them to use environmentally-friendly modes of transportation. Therefore, after purchasing a more efficient car, they may perceive fewer expectations to refrain from car use than before. However, in line with the argumentation presented for personal norms, the opposite effect is also possible: By presenting oneself as an individual who invests in energy efficiency, a person may also believe that others then expect him/her to engage in consistent behaviour.
- *Response efficacy*: The effects of response efficacy, i.e. the awareness of the specific behaviour as an effective action to mitigate a perceived problem, seem to be more straightforward. For example, individuals might evaluate driving or refraining from driving as having less impact on their overall energy consumption because they have changed to a more energy-efficient vehicle. Although this re-evaluation is correct up to a certain point, it might lead to a decrease of the individual behavioural effort to lower energy consumption and

reduce the potential impact of improved energy efficiency that would have been realised had behaviour remained unchanged.

As outlined, improvements in energy efficiency, therefore, may have negative effects on response efficacy (i.e. reduce response efficacy), but mixed (both positive and negative) effects on attitudes and personal as well as social norms.

As indicated above and in Fig. 6.2, these determinants partly influence each other, e.g. the personal norm may be influenced by a change in the social norm and by a change in attitude, i.e. the overall evaluation of the behaviour.

In contrast to these variables, we do not expect the problem awareness variable to change as a direct response to the increased energy efficiency of a product or service. For example, we do not consider it likely that the awareness of car use contributing to climate change will increase or decrease due to the purchase of a more efficient car. High problem awareness, in turn, might be an important general factor that prevents or contains rebound effects. However, while problem awareness is still assumed to be relevant and influential for individual behaviour, we do not assume that it will change directly due to an improvement of energy efficiency and thereby cause direct rebound effects. Similarly, we do not expect any change in perceived behavioural control with regard to an environmentally-responsible, i.e. restricted usage of the more efficient technology. That means, the energy efficiency improvement is not likely to reduce or introduce barriers to less driving.

Accordingly, we hypothesise that an analysis of rebound effects should not be conducted solely from an economic point of view, but should also include an analysis of psychological factors. As shown in Fig. 6.2, we hypothesise that the occurrence of rebound effects can also be explained by changes in attitudes, personal norms, social norms and response efficacy. These changes can be induced by the improved energy efficiency of a technology.

6.2 Method

We conducted a focus group study to explore whether our proposed model is appropriate and comprehensive enough to study rebound effects from a psychological point of view and to discover which of the outlined and partly mixed effects are relevant. The study was intended to explore the changes in behaviour and the influencing factors perceived by individuals who adopted an energy-efficient product. Focus groups are an appropriate method if the behaviour to be studied is complex and caused by the interaction of various drivers. The inter-individual exchange between participants is intended to help them reflect upon and remember their own behaviour. In total, we conducted ten focus groups between May and July 2011. Of these, four were held on residential behaviour in general (including space heating, use of electric appliances and lighting), four were for transport behaviour in general, and the final two were focused specifically on residential heating and lighting behaviour respectively.

Individuals were recruited among individuals living around the German city Stuttgart by an agency via calls for participation published using various media, e.g. internet-forums, newspapers and posters. In the subsequent selection process, individuals were chosen whose household had recently invested in a more energy-efficient product (home insulation, switch to more efficient appliances or lighting, purchase of a more efficient vehicle). The focus groups were attended by 61 participants. About 3/4 of them were male. On average, the participants were 42.5 years old and lived in households with 2.6 persons.

A guideline for the focus groups was prepared with relevant topics and questions and socio-demographic data was gathered via a short questionnaire. After an introduction, participants talked about their energy efficiency investment and their motives for making it. Then a discussion followed on whether and how their behaviour had changed following the investment. Participants were then asked to recount how and why changes occurred (or did not do so).

Discussions lasted between 3 and 4 h, including breaks and were recorded and later transcribed. A preliminary coding guideline was developed based on the theoretical framework outlined above, previous knowledge and short summaries of the discussions, which were written immediately after the respective focus group discussion. The transcripts were then coded, and the list of codes and the guideline were extended and adapted where necessary.

6.3 Results

First of all, we present the findings on the behavioural changes following an energy efficiency investment. Then we discuss the results regarding the psychological factors in line with the model outlined above. Following this, we analyse additional issues that emerged in the focus groups.

6.3.1 Rebound Effects: To What Extent Do Participants Perceive and Report Behavioural Changes After an Energy Efficiency Investment?

According to the statements of the participants, various effects resulted from the energy efficiency investments. Participants described (i) behavioural changes in the sense of rebound effects, but also (ii) stabilisation of behaviour as well as (iii) changes in the other direction leading to even more energy savings.

Increased usage of or the switch to a relatively more efficient, but also larger or more powerful vehicle was reported by some of the participants in the transport focus groups. Also for the residential sector, in particular for lighting, some participants indicated such changes and stated that they are now no longer as consistent about switching off energy-saving lamps, or prefer to leave them on compared to the former, less efficient bulbs, even if their light is not directly needed. However, for other energy efficiency measures like the installation of a more efficient heating system, an increase of usage intensity was hardly reported. Participants mainly reported no behavioural changes at all. For all areas of energy consumption discussed in the groups, some participants also reported the reverse behaviour, i.e. decreasing the intensity of usage.

Various drivers were addressed in the discussions as explanations for these different effects and are described in the following. On the one hand, statements indicate the relevance of the hypothesised psychological variables; on the other hand, the discussion also indicated the presence of further variables which seem relevant with regard to changes of usage behaviour in the sense of rebound effects, such as beliefs about the optimal usage of an efficient technology and need satiation.

6.3.1.1 Attitudes

Due to an energy efficiency investment, in particular in the case of transport and lighting, several participants seemed to re-evaluate their usage behaviour: They perceive energy-efficient vehicles and bulbs as causing fewer financial and environmental burdens than conventional ones which often leads to more relaxed usage:

> I don't bother about these 10 minutes, because I think: it is an eco-bulb, after all. I can let this burn for another 10 minutes, because it is more efficient, rather than switching it on and off. (HT, FG05: 161)
>
> You drive more light-heartedly, you think less about it and sometimes you drive somewhere you would not have driven to before, because it is less expensive now. (MS, FG08: 442)

With regard to more efficient cars, participants argue that driving is more fun for them now, especially if the new vehicle is an electric vehicle. However, in this context, it is not possible to differentiate from the data whether this leads to increased car use.

However, in many cases, the attitude towards the specific usage behaviour seems to remain unchanged. Some participants argued that increased usage only costs more money and does not help to save anything:

> Otherwise, I would not achieve any energy savings, even if it uses less [electricity] than before; letting the bulb burn would be just as pointless as before (EM, FG05: 164)

In some cases, the energy efficiency investment and the perception of reduced energy demand motivated greater efforts to further reduce consumption. Thereby, not only financial consequences seem to be relevant, but also other consequences as well as an increase in awareness of the issues surrounding energy use.

> Well, I myself believe I have a greater awareness simply from dealing more with this topic and regularly checking consumption figures. I am paying more attention to this [saving energy]. (AP, FG02: 212)

6.3.1.2 Personal Norms

Some statements, in particular concerning transport and lighting, provide evidence that a personal norm may be relaxed due to the energy efficiency improvement. Thus, some participants reported that they felt better or had less of a bad conscience about driving an efficient car or letting energy saving bulbs burn longer.

> In this case a couple of bulbs may continue to burn. This doesn't really bother me [...]. So, definitely, one cares less about it. (TB, FG05: 111)

However, the discussions also hinted that strong personal norms are less vulnerable to such effects and have a stabilising effect on behaviour; especially when a person identifies strongly with the behaviour.

> I am not one of those people who use the car unnecessarily. I always really think before using the car. I prefer to abstain from something before using the car again. (SG, FG09: 458)

Accordingly, some participants with apparently strong personal norms regarded increasing the usage of a more efficient product as absurd, counterproductive and unnecessary. Besides, the following statements might indicate that, according to self-perception theory, a person's own behaviour might serve to derive or confirm that person's attitudes, norms and intentions:

> I see it like this: If I own an energy saving lamp, I intend to save energy. But if I let it burn all the time, then I achieve just the opposite effect. I don't get that. (JP, FG05: 192)

6.3.1.3 Social Norms

The origin for such strong personal norms and also for strong habits often seems to be an internalised strong social norm regarding energy-saving behaviour, which is still guiding the individual:

> Otherwise my daily habits are those instilled by my parents, even though I became aware of this much later. [...] For example, when I leave the room and it is dark, I just switch off the light. (KR, FG04: 97)

However, some participants argued that they think others have lower expectations that they will refrain from certain behaviours after the energy efficiency investment.

> There is societal pressure to act in accordance with saving the environment, e.g. not driving unnecessarily because it is bad for the environment. And this pressure disappears with these new vehicles. (JP, FG08: 463)

6.3.1.4 Response Efficacy

In the focus group discussions, some statements indicated that respondents perceive reduced effects of energy saving behaviour after an efficiency investment:

> So I think to myself, for only four Watts [consumption of office desk lamp]: well, I will come back later anyway and continue working. So I may as well leave it on. (TB, FG05: 163)

Other comments suggest that a process of awareness raising can be induced or enhanced due to the usage of more energy-efficient technologies resulting in an increased awareness of the efficacy of one's own behavioural options (i.e. response efficacy).

> Driving behaviour has actually not changed drastically, except […] that you are made aware of energy consumption and that you drive in a more forward-looking way. (WK, FG08: 416)
>
> What has also changed is my usage behaviour. I am much more sensitised, I think about it in a different way. (VH, FG03: 145)

6.3.1.5 Further Drivers of Rebound Effects

Besides the variables which were hypothesised as the determinants of rebound effects within the theoretical framework underlying this study, the focus group discussions indicated other factors which seem to play a role in whether or not rebound effects occur.

Many statements indicated the role of need satiation in different ways. On the one hand, there are some changes to transport and lighting behaviours if the respondents previously constrained their usage behaviour, e.g. due to cost or environmental reasons:

> Well, I can only say that I have always been a passionate driver and I have always constrained driving because I knew it is a matter of expense. (JB, FG08: 462)

On the other hand, many statements, especially in the residential area but also for transport, indicate that the relevant needs were already satiated before:

> I would make the trip either way. It is not the case that I drive more. (SD, FG08: 492)

In this case, changes of behaviour do not imply any additional positive consequences from the perspective of the individual. The discussions show that the individually appropriate degree of need satiation is influenced by various factors, e.g. problem awareness, norms, attitudes and motives:

> Actually, I would even say that it is not a constraint, but an improvement of life quality because I have a better conscience. And this is of much more value to me than two or three degrees more in my flat. (BB, FG03: 286)

Needs which were satiated before can also be postponed for more expensive investments. This can also induce a learning process in which needs can lose their relevance:

> [One] postpones many other things due to this [investment]. […] You can no longer go on holiday every year. […] However, I have also noticed that I do not need this at all. (SJW, FG02: 72)

Moreover, when discussing factors which could explain why behavioural changes do not occur, some participants mentioned the role of habits which may stabilise usage behaviour:

> If your light bulbs have always burned for so long, you will not switch them off after you have installed energy-saving lamps, or let them burn longer; you simply follow your previous daily routine. (KR, FG04: 416)

The focus group statements also showed that mistaken assumptions and beliefs about the correct or optimal usage of energy-efficient technologies can also lead to rebound effects. This was especially apparent for lighting where some participants stated that they let energy-efficient bulbs burn for longer as they believed that switching them on and off more frequently actually increases energy consumption or shortens their life span.

> One should not always switch them on and off [energy efficient bulbs] – I had to teach this to my husband at the beginning. […] It is switched on once, and when we go to bed, we switch it off. (MW, FG05: 36)

6.4 Summary and Discussion

In this paper, we applied two well-known psychological theories to enhance the classical economics' explanation of rebound effects as mainly driven by price and income effects. We hypothesised that attitudes, personal and social norms and response efficacy may be relevant psychological drivers of behavioural changes as they may change in the course of making efficiency improvements in various ways. The induced behavioural changes include rebound effects, which are the focus of this book, as well as contrary effects, i.e. further increases in energy-saving behaviours, depending on changes in the above mentioned psychological variables.

Against this background, we explored individual perceptions of rebound effects and psychological drivers in greater detail based on focus groups for transport and residential behaviour. The empirical results reveal a range of behavioural changes in response to the adoption of a more efficient technology: First of all, several focus group participants reported that they did not perceive any changes in their behaviour due to improved energy efficiency. In contrast, some reported increased usage or the choice of a larger or more powerful product, i.e. reported direct rebound effects, while others stated a decreased usage, i.e. indicating a positive reinforcement of the energy efficiency improvement on their behaviour. This means that events like the adoption of an efficient technology may act as a trigger to change former behaviour (via psychological factors), but this is not necessarily the case. If behavioural patterns change, according to our assumptions, both directions are possible (increasing and decreasing intensity). Across the behavioural domains studied, changes in the sense of rebound effects seem to be more prevalent for transport and lighting behaviour, while the reported behaviour for the heating sector is more stable, as far as this can be discerned based on qualitative data.

With regard to the psychological drivers explaining rebound effects, the empirical focus group study provides some evidence that, as assumed beforehand, *attitudes* are relevant determinants of usage behaviour that can be influenced by the energy efficiency improvement: The statements of the participants indicate that re-evaluation processes regarding the usage behaviour have taken place, i.e. using the energy-efficient technology is evaluated as less costly and less environmentally harmful than the use of the former technology. Regarding norms, some statements of the focus group participants confirmed our assumption that the adoption of more efficient technology made people feel they had fulfilled personal or social norms sufficiently, or that it had relaxed their norms of using the technology parsimoniously. However, statements by other participants are in line with self-perception theory and indicated that the adoption strengthened or further enhanced their norms. Moreover, it seems that strong norms have helped to stabilise their behaviour. Thus, one further hypothesis indicated by the focus group findings is that the relationship between norms and rebound effects might be U-shaped: While rebound behaviour might be increased in the case of moderate norms, strong norms might act as buffers. With regard to response efficacy, the focus group discussions indicate that the perceived efficacy of using a specific technology parsimoniously can decrease in relation to its efficiency improvement. However, it was also found that awareness of the efficacy of the specific usage behaviour in general may increase if people pay more attention to the topic of energy consumption after adopting a more efficient technology.

Overall, as assumed, mixed effects were observed after energy efficiency improvements for personal norms, but not explicitly for attitudes or social norms. In addition, the focus group results also indicate mixed effects for response efficacy which we did not anticipate.

Our study also yielded pointers to other factors that might induce or prevent rebound effects. Participants repeatedly addressed needs and their satiation as an important moderator: the statements indicate that unsatiated needs are a precondition to direct rebound effects. If needs are already satisfied in relation to a product or service (including aspects like comfort or status), changes of behaviour do not imply any benefit. Consequently, the overall attitude towards a behaviour and the behaviour itself might remain stable. For example, in-door temperature is limited by the upper level of what is perceived agreeable—individuals would probably not want to go beyond this level, even if they could afford it. This finding is in line with earlier argumentation and findings in the literature about need satiation as a relevant factor limiting rebound effects (Galvin 2014; Hofstetter et al. 2006; Madlener and Alcott 2009; Wörsdorfer 2010; see Sect. 6.1 and Chap. 8 by Suffolk and Poortinga in this volume).

Furthermore, our empirical results suggest the relevance of mistaken beliefs about the correct or optimal usage of energy-saving technology. Especially in the case of lighting, such mistaken beliefs might lead to behavioural changes contributing to rebound effects (for similar results cf. Huebner et al. 2013). Thus, rebound effects may also be induced by the consumer's lack of knowledge about optimal usage behaviour.

The focus group method applied in this study has advantages as well as drawbacks which affect the validity of the results and have to be considered when interpreting them. We relied on participants self-reports about rebound behaviour and about possible underlying drivers. We did not assess data on actual energy use before and after the efficiency investment and did not calculate expected energy savings due to the investment which would have been necessary to derive a quantitative estimation of resulting rebound effects which were, however, not in the focus of this study. To increase the validity of the self-reported statements, we applied a corresponding selection procedure for the focus groups (i.e. only including participants who had actually undertaken an energy efficiency improvement), and introduced the notion of rebound effects to the participants only in a later stage of the discussion. However, individuals might have a poor memory or might not be fully aware of their behavioural changes following the efficiency improvement or of possible behavioural drivers. In addition, the group situation might encourage statements in line with what respondents perceive to be socially desirable and inhibit statements indicating rebound effects or drivers that might violate perceived social norms. On top of this, as the main aim of this study was explorative our sample was not intended to be representative. However, this implies, that conclusions are limited to uncovering possible relationships etc., but it is not possible to come to (quantitative) deductions how often certain behaviours result or about the strength of these relationships.

Thus, our study represents a first step to widening and empirically enriching the discussion of the possible determinants of rebound behaviour by developing and exploring a first psychological framework to explain rebound effects.

In sum, our findings support the notion that variables from psychological action models might be helpful to explain the mechanisms underlying rebound effects as well as contrary effects. Our findings also indicate that the financial savings repeatedly addressed as a driver of rebound effects in the economic literature are also relevant as part of the attitudinal evaluation process. However, perceived changes of the environmental consequences of usage behaviour due to efficiency improvements were also shown to be relevant. Moreover, the study reveals the relevance of factors stabilising behaviour such as strong personal norms and other factors that were not included in the theoretical framework underlying our study. Further empirical research and more elaborate analyses are needed to further develop a psychological theory of rebound effects and to corroborate these results.

For a policy perspective on rebound effects and how to minimise them, our study shows that efficiency improvements can lead to different effects at the level of individuals—ranging from rebound effects through no behavioural change to increased energy-saving behaviour. Considering the interplay of need satiation and psychological drivers contributes to explaining these effects. These insights into psychological factors should be used in addition to the previous results on rebound effects in different areas in order to estimate where rebound effects of efficiency policy are likely to occur and to correct the theoretical estimations of energy-saving potentials.

At the same time, these drivers represent factors which can be addressed by policy in order to contain rebound effects. In general, it seems recommendable to embed efficiency promotion and improvement in policy measures that also strengthens and promotes the relevant norms, a positive evaluation of energy-saving behaviour and the perceived response efficacy in order to stabilise behaviour, or even induce increased engagement in energy-saving behaviours.

For example, if financial fees on energy consumption are designed and introduced in parallel with efficiency improvements in order to absorb financial savings partly or totally, they should be introduced in a way that simultaneously draws attention to the relationships between energy consumption, CO_2 emissions and the purchase and usage of efficient products. While giving advice on energy-efficient products and energy consumption, consultants should be instructed to highlight usage behaviour as an important factor for energy consumption besides the adoption of efficient technology. Moreover, energy-efficient technology should provide individual feedback on the possible and actual savings achieved by its user in order to promote awareness and perceived response efficacy and encourage further energy-saving behaviour. Also, defaults (such as "eco mode" as the standard) could be used in energy-efficient technology in order to promote energy-efficient usage behaviour. Users can change the mode but their attention is drawn to the characteristics of the technology and its modes. A general recommendation that is underlined by our findings is the necessity for consumers to be given understandable advice and, if necessary, training on how to use efficient technologies in order to minimise energy losses through uninformed usage.

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Chapter 7
Towards a Psychological Theory and Comprehensive Rebound Typology

Tilman Santarius and Martin Soland

Abstract Based on considerations how energy efficiency improvements can interfere with processes of human decision-making, this chapter develops a theoretical model of how energy efficiency improvements—via psychological processes—may lead to rebound effects as well as to 'beneficial effects', which countervail rebounds. The chapter then advances a typology of rebound and beneficial effects that integrates, but goes beyond, the typology currently used in the microeconomic rebound literature. Model and typology explain how (economic) rebound research could benefit from psychological theory and provide the basis for empirically investigating rebound effects on more solid theoretical ground.

Keywords Energy efficiency · Energy and behaviour · Rebound effect · Consumption growth · Sustainable consumption

From William Stanley Jevons' (1906) first discovery of the rebound mechanism all the way to today's rebound discourse of the last 35 years (e.g. Khazzoom 1980), the phenomenon of the rebound effect is solely explained by economic categories. Microeconomic rebound research highlights two effects that explain how rebound effects are generated by consumers: the income effect and the substitution effect. In the previous chapter, Peters and Dütschke introduce additional parameters that explain rebounds other than through price effects. Most notably, they discuss how

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T. Santarius (✉)
Institute of Vocational Education and Work Studies,
Technical University of Berlin, Marchstr. 23, 10587 Berlin, Germany
e-mail: santarius@tu-berlin.de

T. Santarius
Institute for Ecological Economy Research, Potsdamer Str. 105, 10785 Berlin, Germany

M. Soland
School of Applied Psychology, University of Applied Sciences
Northwestern Switzerland, Riggenbachstrasse 16, 4600 Olten, Switzerland
e-mail: martinsoland@yahoo.com

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technical energy efficiency may impact on an individual's attitude, personal norm, response efficacy, as well as social norms. Peters and Dütschke then present qualitative empirical evidence from ten focus groups they had conducted (in Germany in 2011), which support the hypothesis that energy efficiency improvements (EEI; i.e. purchase of efficient technology) may generate 'psychological rebound effects' (see also Girod and de Haan 2009; Peters et al. 2012a, b; Otto/Kaiser/Arnold 2014; Santarius/Soland forthcoming).

In this chapter, we would like to (1) further elaborate the theoretical reasoning how, i.e. through which processes, such psychological rebounds can be explained; (2) deduce several hypotheses how energy efficiency improvements impact human behaviour; and whether EEI lead to either rebound or to countervailing 'beneficial effects' (i.e. 'negative rebound effects', here defined as behavioural changes that reinforce the technical savings potential), or to mixed effects; (3) present an inclusive theoretical model that integrates both psychological and economic rebound effects, and (4) suggest various types of efficiency-induced behavioural effects that can be derived from that model and—if available—underline these types with quantitative empirical evidence from related studies. Most notably, and in addition to 'income effects' and 'substitution effects' as the key rebound explanations from the economic literature (see introductory chapter as well as Madlener/Turner in this volume), our theory suggests three psychological rebound effects—'moral licensing effects', 'diffusion of responsibility effects', 'attenuated consequences effects'—as well as two beneficial effects that countervail rebounds (i.e. 'negative rebound effects'): 'improved responsibility effects' and 'improved control over frugal use effects' Finally, we (5) draw some policy implications from our theoretical elaborations. In order to keep the complexity of our contribution on a reasonable level, we will focus on direct rebound (and beneficial) effects only (effects related to the use of the very technology that has improved its efficiency).

7.1 Psychological Rebound Explanations in a Nutshell

As has already been introduced in the foregoing chapter, psychological rebound effects can be pictured both through expectancy-value theories, such as for example the Theory of Planned Behaviour (TPB; Ajzen 1991, as well as through moral norms theories, such as the norm activation model (NAM; Schwartz 1977). While Peters and Duetschke mainly draw on NAM and TPB theories, in this chapter we add the concepts of diffusion of responsibility (Darley and Latané 1968) and moral licensing (e.g. Khan and Dhar 2006). In addition, we dive deeper into the explanatory model of the NAM and include the arousal of feelings of moral obligation and responsibility, which Peters and Duetschke only mention on the sideline.

The NAM describes the cognitive process from the perception of a problem, over the formation and activation of a personal norm, to the performance of an action. Personal norms are "feelings of moral obligation to perform or refrain from specific actions" (Schwartz and Howard 1981, p. 191). Schwartz' theory sets two criteria that have to be met for a personal norm to be generated: awareness of adverse consequences (AC), and ascription of responsibility (AR). Now: how can energy efficiency improvements (EEI) cause changes in the process of norm activation? If a person perceives the acquisition and use of an energy efficient technology as a means to reduce the negative anthropogenic consequences on the environment (AC) or to reduce his/her own contribution to these negative consequences (AR), it appears to be plausible that such acquisition and use can cause changes regarding the generation of feelings of moral obligations. On the one hand, a person may perceive that the adverse consequences of, say, driving a hybrid car are smaller than those of driving the previously owned conventional car. Consequently, feelings of moral obligation to refrain from, e.g. using the car to run short distance errands may decrease. On the other hand, and in line with findings of Fazio et al. (Fazio and Zanna 1981; see also Eagly and Chaiken 1993), the acquisition of an energy efficient technology may increase the salience of environmental norms, values or consequences. Namely, the acting individual can become more aware of actual, negative, environmental consequences of the hybrid car (maybe further advanced by detailed information on gas mileage on those vehicle's dash boards), which will increase his or her feeling of responsibility. This may lead to a decrease in frequency or intensity of driving and, hence, generate beneficial effects that actually countervail rebound effects.

Additionally, two processes can be distinguished that describe how EEI may affect a person's AR: diffusion of responsibility (Darley and Latané 1968) and moral licensing (e.g. Khan and Dhar 2006). EEI may decrease feelings of personal responsibility if a person believes that other actors are potentially responsible. According to Leary and Forsyth (1987), within groups responsibility diffuses particularly to leaders and experts. Having adopted an EEI, a person may thus perceive that the responsibility for alleviating the environmental problem is now partly shouldered by the experts (e.g. engineers) that created this EEI or by the leaders (e.g. policy makers) that promoted its adoption. For instance, purchasing an energy efficient technology can make a person aware of the persons who invented (or promoted) the technology. These persons are perceived to be competent regarding their ability to solve environmental problems and thus to be capable of carrying a large share of responsibility. Similarly, with a view to contribution ethics (Thøgersen and Crompton 2009), EEI can provide the feeling that someone has 'played one's part' and that it is now up to others to do the same. Note that the explanation for 'diffusion of responsibility' is different from 'moral licensing' processes. In such diffusion of responsibility processes, the reference point for the ascription of responsibility are other agents (e.g. engineers, politicians, other citizens, etc.).

In contrast, in moral licensing processes, reference points are an individual's past actions. Miller and Effron (2010, p. 115) define a moral license as "people's perception that they are permitted to take an action or express a thought without fear of discrediting themselves". As postulated in the moral balance model (Nisan 1991), individuals seek to keep a balance concerning their moral self, which is sustained by the sum of good deeds and bad deeds. This model postulates that individuals do not strive for a perfect morality, but for "a reasonable level of moral self-regard"

(Monin and Jordan 2009, p. 348). By adopting an EEI, a person may perceive that he/she has already partly lived up to the felt responsibility to contribute to the alleviation of environmental problems, leaving the individual with only a low AR for further pro-environmental actions.

7.2 Hypotheses on How Energy Efficiency Improvements Impact Human Behaviour

From the theoretical discussions of Sect. 7.1 as well as from the foregoing chapter by Peters and Dütschke, several processes can be identified that explain motivational behavioural changes due to energy efficiency improvements. Accordingly, an EEI can affect the motivation to use a technology in four ways: as a result of re-evaluation of responsibility, a re-evaluation of the personal as well as the external consequences and a re-evaluation of the behavioural control of an action (see also Santarius and Soland forthcoming). This may either lead to rebound effects, i.e. to an intensified or more frequent use of the given technology. Or it may lead to opposite effects (i.e. ‘negative rebound effects’) that we coin “beneficial effects”, because the technological savings potential gets reinforced through additional behavioural changes. Yet different from existing research on spillover effects (see e.g. Thøgersen 1999; Thøgersen and Ölander 2003), such “beneficial effects” do not describe how environmentally relevant behaviour transfers from one behavioural domain (e.g. transport) into others (e.g. waste), but rather how the purchase of an energy efficient technology subsequently changes the use of that very technology, compared to the previous use pattern when that technology was still comparatively inefficient.

First, increased efficiency can lead to a re-evaluation of responsibility regarding the use of, or the impact of the use of, a given technology. The re-evaluation either depends on whether a person perceives other potentially responsible actors, to which she/he can transfer some of her/his own responsibility (diffusion of responsibility). Or it depends on how the EEI changes the individual’s perceived moral balance. From this the following hypotheses can be deduced: EEI generate rebound effects due to a decreased attribution of personal responsibility when the EEI leads to the belief that that other actors are now more responsible and will take care of the problem (diffusion of responsibility); or, when the EEI improves the moral balance as the societal or environmental consequences of using the technology are perceived to be less harmful (moral licensing). Equivalently, it may be hypothesized: EEI generate beneficial effects, due to an increased attribution of personal responsibility when the EEI leads to an increased salience of personal responsibility in general or to an increased salience of the (still) negative environmental consequences of using the technology (increased responsibility).

Second, EEI can lead to a re-evaluation of the personal or external consequences of the use of a technology. Consequences can include monetary, emotional or social consequences related to status and prestige. The following hypotheses can be derived: EEI generate rebound effects if from the perspective of the individual the EEI reduces costs (e.g. less remorse when driving) or increases benefits (e.g. social prestige) (attenuated consequences). It is theoretically possible that a person faces negative personal consequences from using a more efficient technology. However, in practical terms such a scenario seems largely implausible. Why would a person invest in the acquisition of a more efficient technology in the first place when she/he expects disadvantages?

Third, EEI can lead to a re-evaluation of the behaviour control for the use of a technology. The re-evaluation depends on whether or not a person actually perceives that her/his behavioural control has improved de facto, e.g. through an income effect. Hence an enlarged behaviour control implies attenuated personal costs/ consequences, which may lead to an increased use of that technology. Besides, changes of perceived behavioural control may bring about beneficial effects that countervail potential rebounds. For instance, EEI may raise a person's awareness that he/she now has more/better means to mitigate environmental impacts. This could strengthen his/her self-efficacy beliefs regarding pro-environmental behaviour. Accordingly, EEI generate beneficial effects if the EEI leads to an enlarged perceived control of using the technology in a frugal way (improved perceived control over frugal use).

Note again that a de facto change in behaviour control is not necessarily always perceived by the individual. Yet, only the changed perception can give rise to a re-evaluation of behavioural control and, as a result, to a change of the motivation of using the technology. This makes up one of the main differences between the explanatory approaches of microeconomic rebound research and the psychology of rebound effects. For example, perception of lower fuel costs after purchasing a hybrid car might well be perceived, just like the potentially higher upfront costs for purchasing such car. In contrast, perception of a lower household electricity bill after installing LED light bulbs seems rather unlikely. Whether the perception of behavioural control changes or not may distinguish between economic rebound mechanisms or psychological rebound mechanisms, as the theoretical model and Fig. 7.1 in the next section will highlight.

7.3 Theoretical Model for Economic and Psychological Rebound Effects

Based on these hypotheses as well as the theoretical considerations from the expectancy-value perspective and the moral norms perspective, we suggest the following model for explaining both rebound effects and beneficial effects (see Fig. 7.1). The model distinguishes two prototypical mechanisms leading to rebound effects: psychological mechanisms and economic mechanisms. Characteristic for the psychological mechanisms is that the adoption of more energy efficient technologies leads to a re-evaluation of behavioural antecedents (i.e. personal and external consequences, responsibility, control), which via a change of motivation

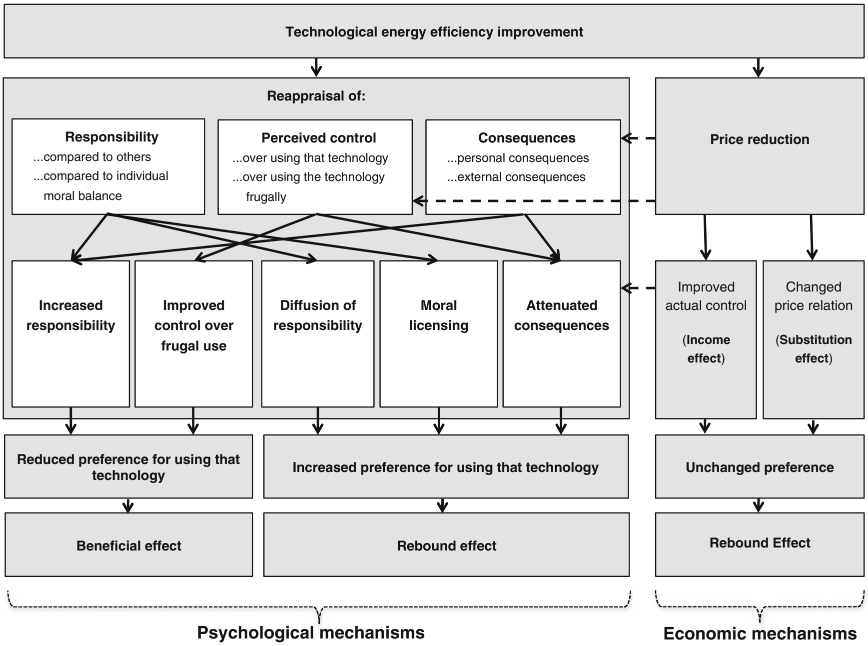

Fig. 7.1 Theoretical process model for explaining rebound and beneficial effects. *Source* Authors' own design

(or, in economic terms: a preference change) leads to either rebound or beneficial effects. In contrast, economic rebound research generally assumes that the motivation of using a technology (i.e. the consumer preference) remains stable and constant over time (cf. 'stationarity in preferences', see Santarius 2015; Houthakker 2010). Against this background, we term it an economic rebound mechanism if the adoption of a more efficient technology leads to rebound effects without affecting motivational processes. As the introduction as well as previous chapters in this volume explain, these economic rebound mechanisms encompass two price effects: income effects and substitution effects.

The model allows for hybrid forms of economic and psychological mechanisms. For example, 'improved actual control' may be perceived by the individual and may impact the individual's motivation through a re-evaluation of monetary consequences as well as a change in the perceived behavioural control; this is expressed by the two dashed arrows pointing from the right to the left side of the diagram. Hybrid forms may lead to rebound as well as beneficial effects.

In the next section, we transform this theoretical model into a comprehensive typology of rebound effects by postulating distinct rebound types on the basis of clearly defined criteria. The suggested typology consists of three types of psychological rebound effects and two types of psychological beneficial effects, which complement the 'income effect' and 'substitution effect' as the key rebound explanations from the economic literature (see Chap. 1 in this volume). The latter can be distinguished from the psychological rebound (and beneficial) types because they do not arise from a motivational change. Because plenty of econometric evidence exists for microeconomic rebound effects (see, e.g. Chap. 2 in this volume), the next section focuses on the psychological effects only.

7.4 Typology of Psychological Rebound and Beneficial Effects

Each type of rebound or beneficial effect postulated here will (where possible) substantiated by empirical findings. As for qualitative empirical evidence, we refer to the previous Chap. 6 by Peters and Dütschke. We find that arguments and reasoning of statements by focus group participants presented in that chapter distinctly support our rebound typology (see in greater detail, Santarius and Soland forthcoming). As for quantitative evidence, we will discuss selected studies that did not test rebound effects as such, but certain motivations of pro-environmental or anti-environmental behaviour, which relate to the rebound discussion. This existing quantitative evidence, which by no means claims to be exhaustive, further supports several—though not yet all—of the rebound types drawn from the psychological model above and outlined in the following.

‘Diffusion of responsibility effect’: Due to the purchase or use of an efficiency-improved technology, perceived responsibility for protecting the environment through frugal usage of that technology diffuses to other agents (e.g. engineers, policy makers, other consumers as potential adopters of efficient technologies), which leads to a decreased motivation to frugally use that technology.

The ‘diffusion of responsibility effect’ (like the ‘moral licensing effect’) occurs via a decrease in feelings of responsibility to refrain from environmentally damaging behaviour. Note that we distinguish the ‘diffusion of responsibility effect’ from the ‘moral licensing effect’ by the point of reference against which the individual compares her/his individual responsibility: As of the diffusion of responsibility effect, individual responsibility is compared against relevant other’s responsibility; as of the ‘moral licensing effect’, it is compared against the personal moral balance (cf. ‘good deeds vs. bad deeds’).

Quantitative evidence for the diffusion of responsibility effect can be derived from Soland (2013). In his online survey including 169 participants he finds: the more participants believe that environmental problems can be solved by environmentally friendly technologies, which Soland calls ‘greentech optimism’, the weaker their feelings of moral obligation to show pro-environmental behaviour are. However, such negative ‘greentech optimism’ effects only appear in the context of behavioural categories for which the pro-environmental choice is related to increased behavioural costs (i.e. using train instead of airplane). Thus, Soland observes no negative greentech optimism effects regarding conservation behaviour in the household, such as switching off unused lights or avoiding standby power.

‘Moral licensing effect’: The purchase or use of an efficiency-improved technology is perceived as a good deed that licenses an increased use of that technology, which via a decreased motivation to frugally use that technology leads to less frugal behaviour. Hence the ‘moral licensing effect’ occurs via a decrease in feelings of responsibility to refrain from environmentally damaging behaviour, subsequent to a comparison of individual responsibility against the personal moral balance (cf. ‘good deeds vs. bad deeds’).

Numerous studies present quantitative evidence for moral licensing effects (e.g. Bratt 1999; Kivetz and Simonson 2002; Khan and Dhar 2006; Zhong et al. 2009; Mazar and Zhong 2010; Merrit et al. 2010; Clos et al. 2011; Ohta and Fujii 2011; Eskine 2012; Kaklamanou et al. 2013; Tiefenbeck et al. 2013), although none directly address rebounds. Note that some of these studies have been criticized on methodological grounds (see, e.g. Thøgersen 2011; Gneezy et al. 2012). Blanken et al.’s (2014) meta-analysis of five moral licensing studies suggests that moral licensing effects generally are relatively small.

The ‘Attenuated consequences effect’ can be defined as follows: The purchase or use of an efficiency-improved technology leads to a re-evaluation of personal monetary, social or emotional consequences of using that technology, which increases the motivation to use it.

As of the current state of literature, it is hard to find quantitative evidence that supports this effect, because relevant studies do not explicitly isolate the aspect of ‘personal consequences’ from other behavioural antecedents (some indication for the ‘attenuated consequences effects’ may be derived from Klöckner et al. 2013). However, qualitative evidence can be derived from Peter’s & Dütschke’s focus groups: “If once in a while you drive a bit farther, you can say to yourself: I act in favour of the environment, and I save money.” (Peters et al. 2012b, p. 32).

Besides these three types of psychological rebound effects, our theoretical model shows two types of environmentally beneficial effects (i.e. ‘negative rebound effects’), which reinforce the technological savings potential (efficiency) through environmentally benevolent behavioural changes (‘sufficiency’):

‘Improved control over frugal use effect’: The purchase or use of an efficiency-improved technology leads to a re-evaluation of the behavioural control over using that technology in frugal ways, which decreases the motivation to purchase/use that technology.

There is ample anecdotal empirical evidence that beneficial behavioural effects may rest on enhanced consumer information, social pressure or incentives to ‘copy’/replicate pro-environmental behaviour from peers, neighbours, or other relevant agents (see, e.g. several contributions in Ehrhardt-Martinez and Laitner 2010). Yet, we cannot find sufficient empirical data that supports ‘improved control over frugal use effects’ as a generalizable phenomenon. Learning processes that build on enhanced consumer information alone usually do not generate lasting pro-environmental behaviour change (Homburg and Matthies 1998; Schultz and Kaiser 2012). In a meta-analysis that reviews 38 empirical studies on energy behaviour, Abrahamse, Steg, Vlek and Rothengatter carefully conclude: “Information tends to result in higher knowledge levels, but not necessarily in behavioural changes or energy savings. Rewards have effectively encouraged energy conservation, but with rather short-lived effects." (Abrahamse et al. 2005, p. 273) Another meta-analysis of 253 studies by Osbaldiston and Schott (2012) finds that increased information and perception of pro-environmental behaviour options can contribute to actual pro-environmental behavioural performances, but by itself does not deliver a sufficient incentive to actually change behavioural performance. Hence according to current evidence, 'improved control over frugal use effects' are likely to occur only when additional effects (e.g. net income gains, increased felt responsibility and others) occur in parallel (this is also suggested by Dietz et al. 2009; Schultz and Kaiser 2012).

'Increased responsibility effect': The adoption of an efficiency-improved technology increases the awareness of negative external consequences as well as individual responsibility for environmental protection, which increases the motivation for a frugal use of that technology. Accordingly, the key process in the improved responsibility effect is an increase in felt responsibility (responsibility compared to others or compared to the individual moral balance).

Limited quantitative evidence for increased responsibility effects can be drawn from two studies by Thøgersen (1999) and Thøgersen and Ölander (2003). These studies were designed to test potential environmental spillover effects, i.e. how successful environmental behaviour might induce additional pro-environmental behaviours in other areas as well. As such, they rather concern indirect effect (where behaviour spills over from one area to another), while this chapter investigates direct rebound effects (which considers how behaviour within one area changes). Moreover, Thogerson et al. only find weak incidence for such spillover effects, as well as some incidence for 'negative' countervailing effects—what in our theory could be interpreted as incidence for 'diffusion of responsibility' or 'moral licensing' effects. Another study by Clos et al. (2011) illuminates under which circumstance either 'moral licensing' or 'increased responsibility' effects may occur. It finds 'moral licensing effects' for intrinsically motivated people who had been forced to do a good deed before, while they find 'increased responsibility effects' for those who had voluntarily decided to do a good deed before. At the same time, the authors find 'moral licensing effects' for non-intrinsically motivated people who voluntarily accomplished good deeds before.

7.5 Conclusions and Outlook on Future Research

Discussions on rebounds as a challenge for sustainability politics have so far been restricted to the realm of economics. By opening up this topic to other social and behavioural sciences, this chapter as well as the previous chapter by Peters & Dütschke hope to spur further empirical and policy-related research on the rebound phenomenon that will address this challenge from a multidisciplinary perspective. More specifically, public and political debates over how to eventually contain rebound effects have so far been limited to economic instruments, such as energy or carbon taxes, emissions trading or energy caps (see, e.g. Maxwell et al. 2011). Yet, the behavioural perspective brought forward in these chapters suggest that endeavours to curb rebounds must also involve policies and measures that address human knowledge, motivation and decision-making directly. For instance, the issue of rebounds could be integrated into sustainability communication measures, such as environmental education, sustainability advertising campaigns, eco-label schemes, as well as environmental management systems, or environmental audits (Santarius 2012).

Future empirical research is needed for one, to support the theoretical model developed here with sound data. Santarius & Soland (forthcoming) present a matrix that shows which parameters are keys for defining each of the above rebound types, and how their parameter values are expected to change ex post an EEI. The following Chap. 8 by Suffolk & Poortinga also exemplifies an attempt to quantify psychological rebound mechanisms; however, their approach focuses on another psychological antecedent, namely environmentally ‘self-identity’. Hence, future research is also needed to further elaborate the theoretical model of this chapter.

Moreover, future empirical research should investigate which kind of (policy) interventions best suit to mitigate psychological rebound effects. This approach can build on a broad body of literature that intends to increase environmental knowledge and tries to bridge the knowledge–action gap in sustainable consumption (see Barth et al. 2012 and others). Yet, these chapters on psychological rebound effects may help in two regards: first, to highlight how rebound effects can work as structural impediments to more frugal, sufficiency-oriented consumer patterns; literature on sustainable consumption has so far not appropriately incorporated the behavioural mechanisms that lead to rebound effects into their considerations. Second, to diversify the discourse on how to overcome barriers to sustainable consumption along the mechanisms outlined in the theoretical model developed here. For instance, much of the past psychological research on sustainable consumption has focused on either information barriers or moral licensing. Yet, this chapter suggests that research should also focus on how to enhance behavioural control and social learning processes.

Last but not least, the complexity of the rebound issue presented here may contribute to debates about modern industrial societies’ notion of progress, prosperity and continuous economic growth. For consumer motivations that pursue the accumulation of material wealth will always tend to generate rebound effects (see also Sorrell 2010; Santarius 2012). Hence, our theory may also inform the controversial debate about ‘limits to growth’ and alternative societal paradigms beyond output maximization (see, e.g. Meadows et al. 1972; Latouche 2009; Jackson 2009; Heinberg 2011; and others). How can individuals in capitalist societies break their ‘habit’ of output maximization, which continuously gives way to rebound effects? (see also Santarius 2015).

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Chapter 8
Behavioural Changes After Energy Efficiency Improvements in Residential Properties

Christine Suffolk and Wouter Poortinga

Abstract This chapter investigates occupants' behavioural changes as a result of energy efficiency improvements in the home. A controlled intervention study was set up to examine potential rebound effects and the psychological constructs that might contribute to these effects. Residents of a number of economically deprived communities in Wales were sent self-completion questionnaires before and after they received energy-efficiency improvements under the Arbed scheme. Residents of three nearby communities served as controls for the study. Utility meter readings and indoor air temperatures were also taken for a sub-sample of the study. While there were very few differences in indoor air temperatures between the two groups, the Arbed group was found to use less energy after energy efficiency measures were installed. Observed energy savings were however lower than predicted, suggesting an average rebound effect of 54 %. Although no evidence was found for changes in other energy-related behaviours, there were some changes in a number of associated psychological constructs. Self-reported environmental identity increased for the Arbed group after energy efficiency measures were installed. Similarly, significant differences were also found between the two groups for attitudes towards reducing the amount of heating used in the home. The results provide an indication that psychological mechanisms may underlie the rebound effect.

Keywords Direct rebound · Energy efficiency · Intervention · Residential properties

Improving the energy efficiency of existing buildings is regarded as a vital part of climate change mitigation in Europe. In the United Kingdom, the domestic sector is responsible for a third of all carbon dioxide emissions and it is thought that reducing the energy used in the domestic sector and in buildings in general can provide quick and cost-effective reductions in CO_2 emissions (Boardman 2012).

C. Suffolk (✉) · W. Poortinga
Welsh School of Architecture, Cardiff University, Bute Building,
King Edward VII Avenue, Cardiff CF10 3NB, UK
e-mail: suffolkc@cardiff.ac.uk

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Additionally, a large majority (80 %) of the buildings that will exist in the UK in 2050 are buildings that have already been built. Improving the energy efficiency of these existing buildings is therefore crucial if the greenhouse gas reduction target set out in the UK 2008 Climate Change Act is to be achieved. The Royal Commission on Environmental Pollution (2007) calculated that CO_2 emissions from the UK housing stock could be reduced by 75 % and this can mostly be achieved by improving the energy efficiency of buildings, lighting and appliances. However, it has long been recognised that energy efficiency measures such as these do not always produce the expected energy savings due to so-called rebound effects. Since their first description by economist Jevons (1865), these effects have mostly been explained and discussed from an economic perspective. However, as discussed in the previous two chapters of this book, it is not only economic changes from energy efficiency improvements that people respond to, but psychological constructs affecting behaviour also need to be taken into consideration.

In this chapter, we empirically investigate energy use and indoor air temperatures, in low-income communities in Wales, before and after energy efficiency improvements were carried out. We further explore psychological factors that may contribute to behavioural changes after energy efficiency measures are installed. The chapter is organised as follows: First, we will give a description of the rebound effect and estimations of the size of rebound after energy efficiency improvements are carried out in residential properties. Second, we will discuss a number of psychological factors contributing to the rebound effect. We will then present a mixed-method study in which we empirically examine both rebound effects and psychological factors that may contribute to rebound effects.

8.1 Direct Rebound Effects After Energy Efficiency Improvements

There are numerous definitions of the rebound effect; Madlener and Alcott (2009) counted 28 different descriptions. The term rebound effect is used to describe when the actual energy saved after an energy efficiency improvement is found to be less than the predicted or potential saving (Druckman et al. 2010, 2011). As mentioned in previous chapters in this book (e.g. Chap. 2), rebound effects are further categorised into *direct*, *indirect* and *economy-wide rebound effects*. This chapter focuses particularly on direct rebound effects. Direct rebound effects occur when the energy efficiency improvement of one type of energy or energy service increases the consumption of the same energy or energy service (Gavankar and Geyer 2010). This can be calculated as follows (Druckman et al. 2010, 2011):

$$\text{Direct rebound} = \frac{(\text{potential saving} - \text{actual saving})}{\text{potential saving}}$$

This calculation has been widely used by rebound economists (Sorrell et al. 2009; Guerra and Sancho, 2010; Thomas and Azevedo 2013) and is used in this chapter to calculate the size of the rebound effects after energy efficiency improvements are installed in low-income areas in Wales.

The econometric and quasi-experimental evidence reviewed by Sorrell et al. (2009) estimated that the average direct rebound effect for household heating is around 20 %. This was later confirmed by Galvin (2015) who calculated that the average rebound effect for the UK housing stock is around 19 %. Gavankar and Geyer (2010) suggest that the rebound ranges between 30 and 60 %, depending on the time of year and level of household income. They suggest that a rebound effect will generally be higher in lower income groups than in higher income groups and argue that this may be because the demand for certain energy services has not been fully satisfied. When the cost of energy services such as heating is reduced, as a result of energy efficiency improvements, then households with lower incomes may be more likely to use the potential savings to heat their home to a more satisfactory temperature. In Chap. 6, Peters and Dütschke found some evidence to support this. Participants whose needs were satisfied before energy efficient investments made were more likely to say that changes in behaviour were not necessary.

Milne and Boardman (2000) found that the internal temperature before energy efficiency improvements were carried out was the main determining factor of the amount of potential energy savings that was taken as extra warmth. Based on the results from the monitored projects, they suggest that at 16.5 °C (the average temperature of housing in Great Britain in 2000), the direct rebound effect will be around 30 %. However, at a lower pre-insulation temperature of 14 °C, 50 % of the potential energy saving is taken as warmth. Milne and Boardman (2000) further suggest that it is not until indoor temperatures are around 20 °C that 80–90 % of the potential energy savings will actually be achieved. This suggests that the size of the rebound effect is inversely related to satisfaction with the indoor temperature before improvements in energy efficiency are made; the lower the levels of satisfaction with the indoor temperature, the higher the rebound.

The research discussed above suggests that the direct rebound effect from energy efficiency improvements are somewhere between 20 and 60 %, with a larger rebound being found in properties with lower initial indoor air temperatures where occupants are less satisfied with the temperature of their home.

The economic literature suggests that the lower costs of energy caused by improvements in energy efficiency are the main driver for the increased consumption of energy services in terms of warmth. However, there may be other factors that play a role. From a price effect perspective, external wall insulation would lower the cost of energy used to heat the same house. The occupants may decide to use the financial saving to heat more rooms or to heat their rooms to a higher temperature (direct rebound), or use it on other energy services (indirect rebound). However, this ignores physical changes in the house brought about by the insulation. When external wall insulation is installed, draughts, air infiltration and conduction from the walls may be reduced. This physical effect (Galvin 2015) may alter the way that the occupants use the heating in their home and also how they behave in their home. For example, they may open more windows. Furthermore, occupants may be less familiar with the new heating controls, which could result in higher than needed energy use to maintain a desired indoor air temperature. New energy efficiency measures installed may be less ‘compatible’ with householders. For example, under-floor heating can take up to 24 hours to heat up and cool down (Galvin 2015) and this might not match the periods when the occupants are at home. This socio-technical mismatch effect might also have an effect on how they use the energy efficiency measures. There may also be faults in the technology used, such as gaps in the insulation and this technology failure may also be a contributing factor for rebound occurring. Galvin (2015) argues that the above mentioned technical effects are so closely interwoven with price effects that it is almost impossible to differentiate between them. He therefore suggests that when examining rebound effects it is more useful to see the home as a whole socio-technical system, rather than price and technical aspects being separate entities.

In addition to price (Jevons 1865; Sorrell 2009; Druckman, et al. 2011), income (Gavankar and Geyer 2010), unsatisfied demand (Gavanker and Geyer 2010; Milne and Boardman 2000), and technical factors (Galvin 2015), there may be other aspects that contribute to the rebound effect. The next section of this chapter will explore psychological factors that may contribute to rebound effects in residential properties.

8.2 Psychological Factors Contributing to Direct Rebound Effects

In Chap. 7 of this book, Soland and Santarius present a theoretical model incorporating a number of psychological and economic mechanisms that may contribute to direct rebound effects. They suggest that adopting energy efficient technologies results in a reappraisal of responsibility, a reappraisal of consequences and a reappraisal of behavioural control. This may then lead to three types of rebound effects (moral leaking, moral licensing and attenuated consequences) and two types of beneficial effects (increased responsibility and social learning).[1] For economic mechanisms, rebound (improved control effect or economic rebound effect) occurs without motivational processes being affected. This is similar to the economic rebound effect described in micro-economic literature on this subject.

The Soland and Santarius model is a useful theoretical framework for research, but there is currently limited empirical evidence for psychological mechanisms

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[1] Soland and Santarius define beneficial effects as changes in the use of an energy efficient technology that countervail potential rebounds. It is conceptually similar to negative rebound effects. The same motivational processes underlying beneficial effects may also contribute to behavioural changes in other domains, also known as behavioural spillover.

underlying the rebound effect. In the preceding Chap. 6, Peters and Dütschke begin to address this issue. Peters and Dütschke found evidence from focus groups supporting the notion that after purchasing energy efficiency products, behavioural patterns appear to change. Some respondents reported increased usage of the new energy efficient product, whilst others reported decreased usage. The reported behaviours in relation to purchasing home insulation (household heating) were found to be relatively stable. When exploring the psychological constructs that might affect these changes in behaviour, Peters and Dütschke found that re-evaluation of behaviour (attitude change) appears to take place. Personal and social norms were reported to be fulfilled, relaxed and enhanced after purchasing the energy efficiency product and mixed effects were also found for response efficacy. It could therefore be hypothesised that after energy efficiency improvements are installed, re-evaluation of attitudes is likely to occur. Mixed effects may be found for other psychological constructs such as subjective norms and perceived behavioural control.

Evidence from studies on behavioural spillover and response generalisation may improve our understanding in this area. Thøgersen (1999) suggests that a change in attitude or change in behaviour may subsequently spill over into other areas. This behavioural spillover can be both positive and negative. Positive spillover occurs when the "adoption of a particular behaviour increases the motivation for an individual to adopt other related behaviours" (Thøgersen and Crompton 2009: p 143). In contrast, negative spillover occurs when the individual's motivation for adopting other similar behaviours recedes (Thøgersen and Crompton 2009). Self-perception theory suggests that people form their attitudes by perceiving their own behaviours (Cornelissen et al. 2008). When applied to behavioural spillover, self-perception theory predicts that when a person behaves in an environmentally friendly way in one area, their attitudes, perceptions of themselves or general disposition may change in a way that will make them more likely to carry out environmentally friendly behaviours in other areas (Thøgersen and Ölander 2003; Thøgersen and Crompton 2009). The attitude change may also increase the likelihood that the person will repeat the initial behaviour (Thøgersen and Crompton 2009). In the present study, if the occupants have external wall insulation installed, their attitudes, perception of themselves or general disposition may change. This might make them more likely to carry out other environmentally friendly behaviours.

As well as re-evaluation of attitudes, there is evidence to support the idea that people's identities are re-evaluated after environmentally friendly behaviours are carried out (Poortinga et al. 2013). It is also suggested that identity and environmental self-identity (the extent to which an individual sees them self as a person whose actions are environmentally friendly) are important in determining behaviour (Crompton 2008; Stets and Biga 2003; Van der Werff et al. 2013). For example, people with a strong environmental identity will see themselves as an environmentally friendly person and will usually try to behave in line with this identity (Van der Werff et al. 2013). Whitmarsh and O'Neill (2010) found that self-identity was a better predictor for carbon offsetting behaviour than the variables from the Theory of Planned Behaviour (TPB). Both behaviour specific self-identity (a carbon off-setter) and generic pro-environmental self-identity influenced carbon offsetting intention. However, since their research was correlational and not experimental or longitudinal, it was not possible to say whether certain behaviours caused spillover to other behaviours. Additionally, the respondents reported their behavioural intentions rather than reporting their actual behaviours.

Van der Werff et al. (2013) carried out a study to explore this further and they questioned whether environmental self-identity is an important construct for explaining positive spillover. Participants were sent a questionnaire and they were then sent another questionnaire a year later. This first questionnaire asked them about their values and driving styles. The second questionnaire included items to measure environmental identity and asked the participants about their intention to reduce the amount of meat that they consumed. They found that biospheric values and past behaviour contributed to predicting environmental identity. They also found that this in turn promoted the intention to reduce meat consumption one year later. These findings suggest that environmental self-identity could also be an important factor in explaining why positive spillover or beneficial effects may occur (Van der Werff et al. 2013).

8.3 Aims of the Study

This chapter aims to contribute to research on rebound effects and psychological constructs that might contribute to rebound effects after energy efficiency improvements are installed. Using empirical evidence, actual energy use was monitored before and after energy efficiency improvements were made to calculate if rebound effects occur and to measure the size of the rebound. Changes in attitudes, subjective norms, perceived behavioural control and self-identity were also explored to find support for both the Soland and Santarius model and the qualitative findings by Peters and Dütschke.

Based on previous research on the size of rebounds, (Sorrell et al. 2009; Galvin 2015; Gavankar and Geyer 2010; Milne and Boardman 2000) it is hypothesised that after energy efficiency improvements are carried out a rebound effect of 20–60 % could occur. Since the occupants are predominantly low-income households, it is further hypothesised that the energy efficiency improvements carried out in low-income areas in Wales could have a rebound closer to 60 % (Gavankar and Geyer 2010).

It is also hypothesised that satisfaction with the initial temperature of the property is a factor contributing to the differences in the rebound effects that are found; occupants with lower levels of thermal satisfaction are likely to have a higher rebound than occupants with higher levels of thermal satisfaction. Additionally, it is hypothesised that attitudes, subjective norms, perceived behavioural control and self-identity might change after energy efficiency measures are installed. More specifically, in line with self-perception theory, re-evaluation of attitudes is likely to occur and environmental self-identity may become more prevalent.

8.4 Method

This chapter makes use of a controlled intervention study that took place over the two heating seasons of 2012–2013 and 2013–2014. The study aimed to examine potential rebound effects as a result of structural energy-performance investments under the Arbed programme (Arbed meaning 'save' in Welsh). The Arbed programme was set up to provide home energy efficiency and renewable micro-generation measures for low-income and fuel-poor households in Wales. It was co-funded by the Welsh Government and the European Regional Development Fund (ERDF). The energy efficiency improvements included measures such as external wall insulation, boiler and radiator upgrades, new ventilation systems and voltage optimisers.

The study consisted of two interlinked parts: (1) a household survey and (2) a household physical monitoring study. The initial household survey was conducted in the 2012–2013 heating season (December 2012 to February 2013). Postal questionnaires were sent to residents of three different communities (n = 1199) that were due to receive Arbed energy efficiency improvements (see Fig. 8.1). The same questionnaire was also sent to residents of three similarly sized communities in the same geographical area where no such improvements were planned (n = 1199). These communities served as a control for the study. The response rate for the questionnaires sent in December 2012 for the Arbed group was 9.2 % (n = 110) and 9.3 % for the control group (n = 112). Participants of the first questionnaire who gave consent to be recontacted (n = 154) were then sent the same questionnaire in the 2013–2014 heating season after energy efficiency improvements had been carried out in the three Arbed communities. The second post-intervention survey took place between December 2013 and February 2014. In total, 41 residents living in the Arbed areas filled out both the 'before' and 'after' questionnaires, while 52 residents from the control areas completed the questionnaire. The attrition rate between the two waves was 45.4 % for the Arbed group and 34.2 % for the control group. The majority of the respondents were aged 55 and over, did not have children living with them, and were owner-occupiers. More than half of the occupants were either retired or unemployed, and about half of the respondents reported household incomes of less than £20,000 per annum. There were no major socio-demographic differences between the Arbed and control groups

The questionnaire was conducted as part of the first author's PhD research. It contained 40 questions on the respondents' houses, pro-environmental household behaviours, thermal satisfaction, attitudes (towards environmental behaviour and towards the environment), subjective norms, perceived behavioural control (self-efficacy and controllability), self-identity, and socio-demographic background information. Scale analyses (Cronbach's alpha) were carried out to establish the internal consistency of the scales to measure the different constructs. The data was then analysed using repeated measures factorial Analysis of Variance (ANOVA). The repeated measures ANOVA estimated the effects of both the between subjects variables (intervention versus control) and the within subjects variables (before

Fig. 8.1 Geographic locations of the Arbed and control properties

versus after the energy efficiency improvements). The questionnaire also asked the occupants which energy efficiency measures they had installed during the last 12 months. Some of the Arbed occupants who were initially due to have the Arbed energy efficiency measures did not end up having them and this was due to the structure of the property and the scheme requirements, and some of the control group installed some of these measures themselves. For the analysis of this research, the respondents were then categorised into those who had energy efficiency improvements installed (energy efficiency improvement group) in comparison with those who had not (no energy efficiency improvement group).

Respondents to the initial household survey who consented to be recontacted were sent a letter asking if they would also be willing to take part in a household physical monitoring study. This involved the installation of four small data loggers in the main living area, hallway, main bedroom and second bedroom. The data loggers recorded the indoor air temperature at ten-minute intervals. The data loggers were installed in January 2013 and left in the properties until April 2014; covering parts of the 2012–2013 and 2013–2014 heating seasons. Gas and electricity meter readings were taken during the monitoring periods of January 2013 to April 2013, and January 2014 to April 2014. In total, 40 households were monitored over the whole period, of which 21 were located in the Arbed intervention areas and 19 in the control areas. The indoor air temperatures between Monday, January 21st and Sunday, March 24th 2013 were compared with the temperatures recorded between Monday, January 20th and Sunday, March 23rd 2014. Heating degree days were used to take into account the differences in external temperatures between the two years.

8.5 Results

The findings from the physical monitoring are initially presented. This includes the mean, minimum and maximum temperatures for the different rooms in the properties that took part in the study. Temperatures at set points in the day are presented and heating degree days are taken into consideration. The gas consumption used by the occupants is also presented to explore the difference in actual energy use after energy efficiency improvements are carried out. The potential and actual energy saving for a sub-sample of the occupants provides evidence of suggested rebound.

Following the changes in behaviour, the psychological constructs (attitudes, subjective norms, perceived behavioural control and self-identity) that may contribute to these behavioural changes are analysed.

8.5.1 Indoor Air Temperature

The mean, minimum and maximum temperature for the living room, main bedroom and second bedroom for the properties which had energy efficiency improvements and the properties which did not have these improvements is presented in Table 8.1.

Between 2013 and 2014, the range in temperature reduced by 2.1, 3.4, 2.9 and 4.1 °C for the living room, hallway, main bedroom and second bedroom, respectively, for the properties which had energy efficiency improvements. In comparison, the properties without energy efficiency improvements had a 0.3, 0.8 and 4 °C

Table 8.1 Mean, minimum and maximum internal air temperatures (°C) for properties with energy efficiency improvements ($n = 25$) and properties without ($n = 15$), both before and after energy efficiency measures were installed

	2013 (Before)				2014 (After)			
	Living room	Hallway	Main bedroom	2nd bedroom	Living room	Hallway	Main bedroom	2nd bedroom
Energy efficiency improvement								
Mean	18.5	16.2	17.6	18.0	18.9	17.3	17.9	17.6
Min	10.6	6.2	9.1	4.3	11.8	10.7	11.3	8.6
Max	26.0	22.4	25.7	26.0	25.1	23.5	25.0	26.2
No energy efficiency improvement								
Mean	17.4	16.6	16.1	16.2	17.9	17.7	17.0	17.2
Min	10.2	8.4	6.7	5.9	12.1	11.8	10.2	7.0
Max	21.9	21.8	21.2	21.6	24.1	26.0	22.3	26.7

increase in the ranges in temperature for the living room, hallway and second bedroom and a 2.4 °C decrease in range of temperature for the main bedroom. These findings suggest that more uniform temperatures were found for the energy efficiency improvement group after the measures were installed. There were however large variations in temperatures throughout the day as well as between different households. For this reason, the temperature at set points in the day was used for further analysis. Temperature recordings at 6 am, midday, 6 pm and midnight were taken for each of the four rooms for each property. These time points were selected to represent indoor air temperature at different times in the day. Peak electricity demand in the UK occurs at around 6 pm in the winter and demand is lowest between midnight and 6 am (Boardman et al. 2005). High electricity demand at 6 pm occurs when people return home from work and when it starts getting dark in the winter. It is assumed that they would also have their heating turned on at this time. Between midnight and 6 am, they might have their heating turned off or at a lower temperature. This is supported by Fig. 8.2.

Figure 8.2 shows the mean temperatures (for the four times during the day) for the living area, hallway, main bedroom and second bedroom for the properties with energy efficiency improvements and for the properties without. The graphs show the temperatures before and after the energy efficiency improvements were installed. It is noticeable for both the properties that had the energy efficiency improvements and those that did not that the indoor air temperature in the different rooms was lower in 2014 than it was in 2013. This could be due to climatic differences between the two years.

In order to take into account the climatic differences during the two monitoring periods, the heating degree days (HDD) for each of the days during the monitoring

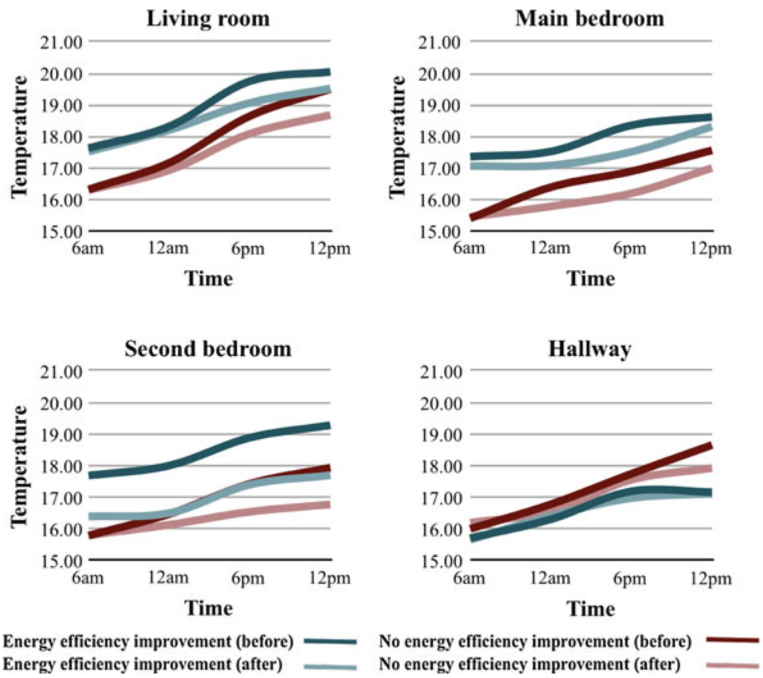

Fig. 8.2 Mean internal air temperatures (°C) for properties with energy efficiency improvements (*n* = 25) and properties with no energy efficiency improvements (*n* = 15) before and after measures installed

period were calculated. The HDDs ranged from 5 to 16 during the monitoring period, with five HDDs being warmer (around 10 °C) than 16 HDDs (around −1 °C). The HDD degree days were categorised into three groups: 5–8 HDDs; 9–12 HDDs and 13–16 HDDs. The heating degree day categories were then used when comparing the two groups' indoor air temperature for the different rooms before and after the energy efficiency improvements were carried out (see Table 8.2).

When heating degree days were taken into account (see Table 8.2), the properties with measures installed and the properties without measures installed had an increase in temperature after the measures were installed for nearly all of the rooms and for all degree days. Significant differences were found between the two groups for the second bedroom for all heating degree day categories; for all degree day categories, except 5–8 heating degree days, for the main bedroom; and significant differences were found for 13–16 heating degree days for the living area. There was little difference between the two groups for the temperatures in the rooms.

Table 8.2 Mean internal air temperatures (°C) controlled for heating degree days (HDDs) for properties with (n = 25) and properties without (n = 15) energy efficiency improvements, before and after measures were installed

	Living room		Hallway		Main bedroom		2nd bedroom	
	Before (temp °C)	After (temp °C)	Before (temp °C)	After (temp °C)	Before (temp °C)	After (temp °C)	Before (temp °C)	After (temp C)
All data								
Energy efficiency improvements	18.5	18.9	16.2	17.3	17.6	17.9	18.0	17.6
No energy efficiency improvements	17.4	17.9	16.6	17.7	16.1	17.0	16.2	17.2
HDD 5–8								
Energy efficiency improvements	18.97	18.78	16.9	17.1	18.2	17.7	18.5	17.4
No energy efficiency improvements	17.90	17.75	17.3	17.6	17.0	16.8	16.9	17.0
HDD 8–12								
Energy efficiency improvements	18.54	18.88	16.3	17.3	17.7	17.9	18.1	17.7
No energy efficiency improvements	17.45	17.83	16.8	17.6	16.3	17.0	16.4	17.2
HDD 13–16								
Energy efficiency improvements	18.24	18.88	15.7	17.4	17.2	18.0	17.6	17.7
No energy efficiency improvements	16.99	17.93	16.1	17.9	15.4	17.1	15.6	17.5

8.5.2 Gas Consumption

Since there was little difference found between the two groups for the indoor air temperature, we expected to find some variation between the two groups for the amount of energy used to heat the properties. When the gas consumption for the monitoring periods was compared, the properties that had the energy efficiency measures installed appeared to use less energy than the properties without the measures installed. Suggesting that although the properties with energy efficiency measures had similar indoor air temperatures to the properties without energy efficiency improvements, they appeared to use less energy to achieve this temperature. This suggests that the measures installed were effective in regards to reducing energy demand (Fig. 8.3).

The predicted energy saving and actual energy saved were compared for the Arbed occupants who had new external wall insulation, new boilers and new radiators. This data was only available for the Arbed occupants since the predicted energy saving was calculated by the Arbed energy assessors. Ten properties were

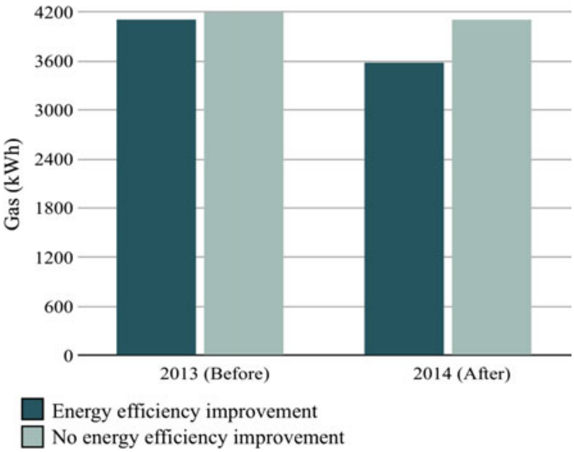

Fig. 8.3 Mean gas consumption (kWh) for properties with energy efficiency improvements (n = 15) and properties without energy efficiency improvements (n = 11) for the monitoring period in 2013 (before) and for the monitoring period in 2014 (after)

Table 8.3 Potential and actual energy savings in the monitored properties (n = 10)

House	Potential saving (%)	Actual saving (%)	(Potential saving—actual saving)/Potential saving (%) suggested rebound effect (%)
1	22	8	61
2	28	29	−1
3	25	11	56
4	38	21	44
5	28	21	26
6	30	−2	106
7	51	11	79
8	25	−13	153
9	31	18	42
10	39	50	−29
Mean	32	15	54

used for this analysis. The calculations for the predicted energy savings were based on the specific energy-saving measures for the individual properties. The actual energy saved was calculated by comparing the kWh of gas used before (2013) and kWh of gas used after (2014) the energy efficiency improvements were carried out. A percentage of the actual energy saved was calculated. Using the formula suggested by Druckman et al. (2010, 2011) (see Sect. 8.1), comparisons were then made between the predicted and actual energy saved to provide a suggested rebound for each of the households (see Table 8.3).[2]

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[2] The external weather conditions were not taken into consideration for this analysis. There were 718 heating degree days for the monitoring period in 2013 and 564 heating degree days for the monitoring period in 2014 and so the difference in temperature between the two years may have had a large impact on the amount of energy used.

Most of the properties had some (actual) energy saving, with the exception of those living in property numbers 6 and 8. These two properties were found to use *more* energy after the energy efficiency measures were installed, suggesting backfire occurred. Of the houses that did save energy, the actual energy saved ranged from 8 to 50 % in comparison with the previous year. House 2 and house 10s actual energy savings were higher than the predicted energy saving, suggesting a direct negative rebound or as suggested in Chap. 7 by Soland and Santarius, a beneficial effect occurred. Eight out of the ten properties saved less energy than expected, suggesting a rebound effect for all of these properties. This may have been due to the price effect, technical factors described in the introduction of this chapter (Galvin 2015) or due to changes in psychological constructs and consequently changes in behaviour. An overall rebound effect of 54 % was found for all of these properties.

8.5.3 Thermal Satisfaction

The 10 properties above were asked how satisfied they were with the temperature in their home both before and after the energy efficiency improvements were installed. Mixed responses were found for satisfaction prior to the energy efficiency measures being installed. Most occupants were fairly satisfied, but one was very satisfied and one was fairly dissatisfied. Eighty percent were very satisfied (20 % fairly satisfied) after the energy efficiency improvements were carried out.

When all of the occupants were asked about their satisfaction with the temperature in their home a significant difference was found between the before and after samples, $F(1, 89) = 12.26$, $p = 0.001$, but not between the energy efficiency improvement group and the no energy efficiency improvements group $F(1, 89) = 2.69$, $p = 0.105$. A significant time x group interaction effect was also (see Sect. 8.1) found, $F(1, 89) = 13.97$, $p = 0.000$. As would be expected, the energy efficiency improvement group in comparison with the no energy efficiency improvements group reported being more satisfied with the temperature of their home after the energy efficiency measures were installed in comparison with before (see Fig. 8.4).

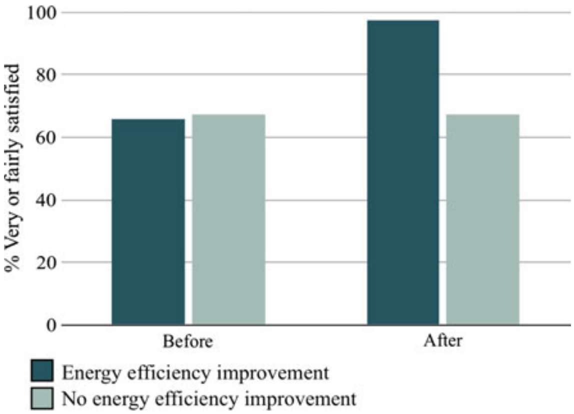


Fig. 8.4 Thermal satisfaction before and after energy efficiency measures installed for the energy efficiency improvement group ($n = 37$) and no energy efficiency improvement group ($n = 54$) (very or fairly satisfied)

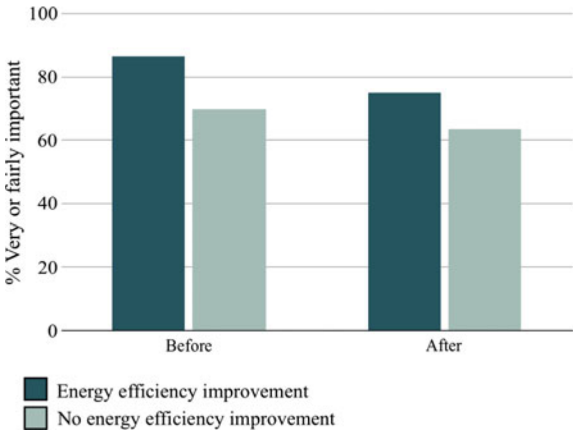
8.5.4 Attitudes Towards Environmental Behaviour

Analysis was run to compare the two groups' attitudes towards heating used in their home. A significant difference was found between the before and after samples, $F(1, 84) = 4.000$, $p = 0.049$ and in line with our hypothesis, a significant difference was also found between the energy efficiency improvement and no energy efficiency improvement group, $F(1, 84) = 5.805$, $p = 0.018$. Although the importance of reducing heating used in the home was higher for the energy efficiency improvement group, the importance of reducing heating used in the home declined for both groups over the two time periods. The time *x* group interaction effect was non-significant $F(1, 84) = 0.033$, $p = 0.856$ (see Fig. 8.5).

8.5.5 Attitudes Towards the Environment (Environmental Concern)

A repeated measures factorial ANOVA was carried out to assess whether attitudes towards the environment as measured by the single item 'How concerned are you about climate change?' was statistically different between the energy efficiency improvement and no energy efficiency improvement group before and after the Arbed measures were carried out. A significant difference was not found between the before and after (time) samples, $F(1, 87) = 0.613$, $p = 0.436$ or between the energy efficiency improvement and no energy efficiency improvement group, $F(1, 87) = 1.540$, $p = 0.218$. The time *x* group interaction effect was not significant $F(1, 87) = 0.613$, $p = 0.436$. Eighty-one percent of the energy efficiency improvement occupants and 63 % of the no energy efficiency improvement group reported that they were very or quite concerned about climate change before the measures were installed. This dropped to 76 and 61 % (respectively) the following year.

Fig. 8.5 Attitudes towards reducing amount of heating used in home before and after energy efficiency measures installed for the energy efficiency improvement group ($n = 35$) and no energy efficiency improvement group ($n = 51$) (very or fairly important)



8.5.6 Subjective Norms

The two subjective norm items ("I would be embarrassed to be seen as having an environmentally friendly lifestyle" and "I would not want my family or friends to think of me as someone who is concerned about the environment") were combined into a single scale. The subjective norm sub-scale had very high reliability both for the before (Cronbach's $\alpha = 0.91$) and after (Cronbach's $\alpha = 0.93$) responses. A subjective norm variable was created using the mean of the two items and a repeated measures factorial ANOVA was carried out. No significant difference was found between the before and after samples, $F(1, 88) = 0.41$, $p = 0.840$, but a significant difference was found between the energy efficiency improvement and no energy efficiency improvement group, $F(1, 88) = 7.409$, $p = 0.008$. Although the energy efficiency improvement group disagreed more with these statements in comparison with the no energy efficiency improvement group, there was a non-significant time *x* group interaction effect, $F(1, 88) = 0.041$, $p = 0.630$.

8.5.7 Perceived Behavioural Control (Self-efficacy)

When asked how easy or difficult it would be to turn off heating when it is not in use, a significant difference was not found between either the before and after samples, $F(1, 88) = 1.028$, $p = 0.313$ or between the two groups, F(1, 88) = 0.040, p = 0.842. There was also a non-significant time *x* group interaction effect, $F(1, 88) = 0.326$, $p = 0.569$.

The four self-efficacy items (ease of turning off heating when not in use; turn off taps when brushing teeth; turn off lights when not in use; and recycling waste) were combined to form a single scale. The scale had high reliability for both the before (Cronbach's $\alpha = 0.75$) and after responses (Cronbach's $\alpha = 0.87$). A significant difference was not found between the before and after samples, $F(1, 88) = 2.059$, $p = 0.155$, but a significant difference was found between the two groups, $F(1, 88) = 2.949$, $p = 0.032$. The energy efficiency improvement group reported that making these changes was easier in comparison to the no energy efficiency improvement group. There was a non-significant time *x* group interaction effect, $F(1, 88) = 0.391$, $p = 0.533$.

8.5.8 Perceived Behavioural Control (Controllability)

The occupants were asked whether they agreed with the statement "I can personally help reduce climate change by changing my behaviour" and whether they feel that they can make a difference with regard to climate change. The two controllability items were then combined into single scale (the sub-scale had high reliability for both the before; Cronbach's $\alpha = 0.76$ and after; Cronbach's $\alpha = 0.85$ responses) and a repeated measures factorial ANOVA was carried out. A significant difference was not found between the before and after samples, $F(1, 86) = 0.287$, $p = 0.593$, between the energy efficiency improvement and no energy efficiency improvement groups, $F(1, 86) = 2.278$, $p = 0.135$, and there was a non-significant time *x* group interaction effect, $F(1, 86) = 0.002$, $p = 0.965$.

8.5.9 Self-identity

The following three environmental self-identity items were combined into a single reliable scale: 'I think of myself as someone who is concerned about Climate Change'; 'I think of myself as someone who is concerned about environmental issues'; and 'I think of myself as an energy conscious person'. An environmental self-identity sub-scale was created using the mean of the three items. The environmental self-identity sub-scale had high reliability for responses both before (Cronbach's $\alpha = 0.86$) and after (Cronbach's $\alpha = 0.87$) the energy efficiency improvements were installed. A significant difference was not found between the before and after samples, $F(1, 89) = 0.031$, $p = 0.860$ and a significant difference was also not found between the two groups, $F(1, 89) = 3.16$, $p = 0.068$. However, a near significant time *x* group interaction effect was found, $F(1, 89) = 3.688$, $p = 0.058$. Supporting our hypothesis, the energy efficiency improvement group was found to agree more with the environmental self-identity items after the energy efficiency improvements in comparison with before.

8.6 Discussion

Psychological analysis of rebound effects has only recently begun and empirical research exploring this is scarce. This chapter aimed to contribute to empirical research on rebound effects and psychological constructs after energy efficiency improvements are installed.

The research used the Arbed case study in Wales. Questionnaires and physical monitoring of indoor air temperature and energy use were collected before and after energy efficiency measures were carried out. The questionnaires enabled quantitative analysis to be carried out, whilst the physical monitoring provided an insight into actual behaviour as opposed to self-reported behaviours. Although this was a useful case study for recruiting occupants from similar socio-demographic backgrounds, in similar geographic areas, and who had certain energy efficiency improvements installed, there were limitations to using this case study. Although all of the Arbed occupants (around 1000 properties) and a similar number of properties who did not have these measures installed were contacted to take part in the research, and different methods were used to try and increase the response rate, only a few occupants responded and fewer still took part in both questionnaires over the two heating seasons ($n = 93$). With a sample size of 100, the margin of error is 10 %. Additionally, since there were even fewer properties that had physical monitoring ($n = 10$), the margin of error for this is roughly 32 %. Since some of the 'Arbed' occupants did not actually have the energy efficiency measures installed, the occupants were then separated into those who had energy efficiency improvements (external wall insulation, new boilers and/or new radiators) in comparison with those who did not. Ideally the Arbed sample would have all had measures installed and the 'control' group would not have had the measures installed and these two groups would have been compared. Differences in the materials and/or systems installed for the different measures would then be minimised. With a larger sample, it would have also been preferable to carry out separate analysis on the individual energy efficiency measures, such as comparing properties that only had external wall insulation. Additionally, it would have been beneficial to have a control group for the physical monitoring data on suggested rebound.

The present study does however, provide some interesting contributions about rebound effects and psychological constructs, but due to the relatively small sample sizes, caution needs to be taken when interpreting these results and applying the findings to the general population.

Three hypotheses were included in this research: (1) The rebound effect would be between 20 and 60 %; larger rebound being found in properties with occupants who are not satisfied with the temperature of their home. (2) Re-evaluation of attitudes is likely to occur after the installation of energy efficiency improvements and mixed effects would be found for subjective norms and perceived behavioural control. (3) The occupants will have a more prevalent environmental self-identity after the energy efficiency measures are installed.

In line with our first hypothesis, an overall rebound of 54 % was found. Although 80 % of the properties were found to save energy after the energy efficiency improvements were installed, 20 % of the properties used more energy. Two out of the 10 properties saved more energy than initially predicted, but eight of the properties saved less energy than predicted. Although based on a very small sample, these findings highlight the need for further research to be made on the factors that might contribute to these large rebound effects being found. Identifying these factors and finding ways to minimise them is crucial for policies aimed at improving the energy efficiency in the residential sector. As mentioned in the introductory paragraphs of this chapter, the price and technical effects were not separated when calculating this rebound (Galvin 2015). The 54 % rebound effect that was found could therefore be due to price effects, physical effects, user interface effects, socio-technical mismatch effects and technological failures. However, these findings could also be due to factors such as moral leaking and moral licensing as suggested by Soland and Santarius. Additionally, the rebound is calculated using a formula that relies on potential savings and these potential savings might not have been calculated accurately. Although it is difficult to ascertain which of the above factors might contribute to the rebound found in this study, additional empirical research that disaggregates all of the above is necessary to contribute to our understanding of the specific causes of the rebound effects.

The rebound found in this study does however give us some indication that after energy efficiency improvements are carried out, occupants might take-back some, and sometimes quite a considerable amount, of the potential energy savings to increase their thermal comfort.

When the thermal satisfaction of the occupants in these properties was taken into consideration, in contrast to our hypothesis, there was no indication that larger rebound effects were found for occupants who were not satisfied with the indoor temperature. This may be due to other factors contributing to the rebound, but may also have been due to the very small sample size for this physical monitoring. Additional research with much larger sample sizes would be needed to explore this further.

When all of the occupants were asked about their thermal satisfaction, although significant differences were not found between the energy efficiency improvement and no energy efficiency improvement group, the energy efficiency improvement group reported being more satisfied with the temperature of their property after the measures were installed in comparison with before. From a fuel-poverty and health and well-being perspective, these findings are very positive.

This chapter also explored which behavioural constructs may change after the installation of energy efficiency improvements. In Chap. 6 of this book, Peters and Dütschke found evidence from their focus groups to suggest that re-evaluation of attitudes takes place. When attitudes towards heating (thematically similar to the energy efficiency improvement measures installed) were analysed in the present study, in line with our second hypothesis, significant differences were found between the energy efficiency improvement and no energy efficiency improvement group. Although the importance of reducing heating was higher for the energy efficiency improvement group, this importance declined for both groups between the two time periods. The fact that the importance declined for both groups could have occurred because 2014 was a milder winter in the UK in comparison with 2013. The occupants may not have been as concerned about reducing their heating use, since they had used less heating in comparison with the previous year. The positive change in attitude for the energy efficiency improvement group may contribute in explaining 'beneficial' effects and as suggested by Soland and Santarius, this may have been due to increased responsibility and social learning. Additional research would need to be conducted to support this.

Although a large majority of the occupants reported that they were very or quite concerned about climate change, in contrast to our hypothesis, significant differences were not found between the two groups for attitudes towards the environment (environmental concern). These findings suggest that attitudes that are thematically similar to the energy efficiency improvement may change, but re-evaluation of broader, more global attitudes, such as attitudes towards Climate change remain unchanged.

In regards to subjective norms, in comparison with the no energy efficiency improvement group, the energy efficiency improvement occupants disagreed more with the statements “I would be embarrassed to be seen as having an environmentally friendly lifestyle” and “I would not want my family or friends to think of me as someone who is concerned about the environment”. These results are not surprising, since the majority of the energy efficiency improvements were external wall insulation. This measure was quite disruptive, the insulation was also on the front facade of the houses and it was therefore quite apparent that the occupants had energy efficiency measures carried out. Similar to the findings on norms by Peters and Dütschke, the energy efficiency improvements may have strengthened the occupant’s subjective norms.

Significant differences were not found between the two groups for controllability. When asked how easy or difficult it would be to turn off heating when not in use (self-efficacy for heating use), significant differences were also not found. However, when all four of the self-efficacy items were combined into a single scale, the energy efficiency improvement group reported that making energy efficient behavioural changes would be easier in comparison to the group who did not have measures installed.

Our final hypothesis was also in line with self-perception theory which suggests that people infer their attitudes from their behaviour. After having energy efficiency improvements installed they may identify themselves as an energy conscious person. This was supported in part by our results. The energy efficiency improvement group was found to agree more with the environmental self-identity items after the energy efficiency improvements in comparison with before and a near significant time *x* group interaction effect was found.

In summary, rebound effects were found in this research, but the attitudinal changes, changes in subjective norms and changes in reported self-identity for the energy efficiency improvement group were all in a ‘positive’ direction. They therefore contribute to our understanding of beneficial effects, but do not necessarily explain the causes for the rebound found. Further research with larger samples, more detailed physical monitoring and desegregating the technical reasons are crucial for increasing our understanding of rebound effects and the technical and psychological factors which contribute to it.

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Chapter 9
Energy Efficiency and Social Acceleration: Macro-level Rebounds from a Sociological Perspective

Tilman Santarius

Abstract This chapter investigates macro-level rebounds from a sociological angle. Macro-level rebound effects have already been researched in economics. Yet macroeconomic rebound analysis vastly depend on the parameters and the kind of production functions applied. This chapter discusses whether currently used production functions adequately consider broader changes in the structural (economic and societal) framework conditions that might be brought about by energy efficiency improvements (EEI). It draws on a large body of sociological literature on ‘social acceleration’, which shows how technological efficiency improvements and innovation increase the pace of production and consumption and, hence, accelerate the ‘speed of life’ and the rate of social change. In an attempt to merge this sociological discourse with macroeconomic rebound considerations, the chapter finally discusses whether the ‘velocity of money’ (*V*) could serve as an additional parameter that explains an increase in economic output due to an improvement in energy efficiency.

Keywords Social acceleration · Time and society · Economics of time · Macro-level rebound effect · Velocity of money · Economic growth

Throughout past rebound research, economics has already investigated how energy efficiency improvements (EEI) impact a nation’s overall economy. Macroeconomic rebound research investigates how EEI increase the overall output of the economy, change its composition, i.e. the share of sectors in the overall output, and in effect impact on the aggregate energy demand of the economy. Most briefly, a ‘macroeconomic rebound effect’ can be defined as ‘(energy) efficiency-induced economic growth.’ It was Jevons in 1865 (see Jevons 1906) who first discovered that EEI in

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T. Santarius (✉)
Institute of Vocational Education and Work Studies,
Technical University of Berlin, Marchstr. 23, 10587 Berlin, Germany
e-mail: santarius@tu-berlin.de

T. Santarius
Institute for Ecological Economy Research, Potsdamer Str. 105, 10785 Berlin, Germany

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blast-furnaces would increase overall economic production and coal consumption in Great Britain (see also Alcott 2005). Since the late 1970s, the link between EEI and economic growth has been reformulated by Brookes (1978, 1990, etc.) and was mainly theorized by Saunders (e.g. Saunders 1992, 2000). In recent years, the debate on macroeconomic rebound effects has been structured by Sorrell and others (e.g. Sorrell 2007, 2009; Broadstock et al. 2007). But macroeconomic rebound research has not yet considered how EEI may structurally change the economy, let alone how they impact social institutions.

In Sect. 9.1, this chapter begins with briefly summarizing macroeconomic rebound research and reflecting its potential shortcomings and blind spots. The following sections then approach the issue of macro-level rebounds from an interdisciplinary angle, bridging macroeconomic with sociological theories. In particular, the discourse on 'social acceleration' (e.g. Harvey 1989; Virilio 1986; Rosa 2013) seems well suited to grasp 'transformational rebound effects'; namely, as Greening et al. (2000) have stated, '*how changes in technology have the potential to alter social institutions and rearrange the organization of production*' (full quote above in the introduction to part II of this volume). In a historical fashion, Sect. 9.2 highlights how EEI have shaped transportation and communication technologies, and thus have mainly contributed to an acceleration of human movement and interaction. However, Sect. 9.3 makes sure that such a 'social acceleration' has not been brought about by mere technological determinism. It rather shows how technological accelerations in transportation and communication have changed social institutions and imaginations, namely the apprehension of the key categories of space and time. Against this background, Sect. 9.4 then sketches out the complex interrelationship between energy efficiency and technological acceleration, social acceleration and the acceleration of production and consumption.

The two final sections try to present some outlooks for future economic and sociological research. With a view to economics, Sect. 9.5 makes the point that examining the link between energy efficiency and the velocity of money (V) can be worthwhile, as such a link would contribute a new mosaic stone in the challenging quest to understanding economic growth. Section 9.6 presents this chapter's key message, i.e. the definition of 'structural rebound effects', and postulates that such rebounds are one of the drivers behind the seemingly ever-accelerating, restless modernity. In addition to these sociological findings, Sect. 9.6 draws some conclusions for energy and climate policy decision-makers.

9.1 Deficiencies of Macroeconomic Rebound Research

In economic terms, EEI can be understood as the substitution of energy through capital (and knowledge). For example, the production of low-energy homes usually is more costly than of conventional homes, but the former require less energy for heating the same amount of square metres than the latter; hence fuel demand can be substituted through capital investments. On the macroeconomic level, the question arises: To what extent do the production factors of capital and energy relate like ‘substitutes’, so that capital actually replaces energy? Or do energy and capital rather relate as ‘complements’, so that increased investments in/spending of capital—e.g. for EEI—bring about an increased demand for energy?

Saunders (2000) as well as Birol and Keppler (2000) postulate the following theorem: “*…the ease with which fuel can substitute for other factors of production (such as capital and labour) has a strong influence on how much rebound will be experienced. Apparently, the greater this ease of substitution, the greater will be the rebound*” (Saunders 2000, p. 443; see also econometrically: Sancho/Guerra 2010). From this theorem, one could derive a somewhat counter-intuitive conclusion: The easier energy can be replaced by capital—and that is what is actually going to happen when investments in energy efficiency replace demand for energy carriers across all sectors of the economy—the larger will macroeconomic rebound effects potentially be. An elasticity of 1 describes full substitutability of energy through capital.

However, Howarth (1997) argues that the elasticity of substitution between energy and capital usually be moderate ($0 < e < 1$) rather than high ($e > 1$). According to him, therefore, backfire is rather unlikely. Yet regrettably, the empirical literature is far from uniform on this question and cannot even agree on a range of the elasticity in question. After several decades of research, no reliable figures exists that could clarify this issue empirically (see Broadstock et al. 2007, p. 51). Moreover, as Berndt and Would (1975) have shown, the elasticity of substitution between capital and energy cannot be determined in isolation, but depends on the elasticities of substitution between capital and other factors of production, most notably labour.

Furthermore, it appears reductionist to isolate the discussion of substitution elasticities—the scope of substitutability between factors of production—from the discussion of output elasticities—the impact from factor productivity on overall economic output, i.e. gross domestic product (GDP). For the energy elasticity of substitution partly depends on how strong an improvement in the productivity of the production of certain goods or services impacts on the overall demand for those goods and services—and hence, the overall level of production in the economy. And in turn, the sum of overall economic growth in production will influence the overall demand for energy services. This suggests another theorem: The greater the output elasticities of the production factor of energy, the greater are the potential rebound effects (Saunders 2000; Grepperud/Rasmussen 2004).

Again, different estimates of the actual scope of the output elasticity of energy can be found in the literature. In the tradition of the early macroeconomic growth theorists Solow and Swan, most neoclassical economists assume that output elasticities of factors of production correspond to their factor cost shares of GDP (Solow 1956). Since the factor cost share of energy usually only amounts to 5–10 %, neoclassical economists assign a low output elasticity to energy (see also Kümmel 2011). Accordingly, under neoclassical assumptions, EEI will generate rather small macroeconomic rebound effects. On the other hand, ecological economists often assume that energy as a production factor has a much higher output elasticity, which cannot be attributed to its low cost share of GDP (Sorrell/Dimitropoulos 2007). According to the laws of thermodynamics, ecological economists attribute energy a key role in the growth process of industrial economies (e.g. Stern/Cleveland 2004; Kümmel 2011). Given ecological economists' assumptions, improvements in energy efficiency will cause high rebound effects and hence, will significantly stimulate economic growth (Fouquet 2008; Ayres/Warr 2009). However, neither theoretically nor empirically it seems possible to verify or falsify these very general neoclassical or ecological economics' assumptions, let alone to bridge these contradictory paradigms.

Given all these uncertainties, econometric calculations of macroeconomic rebound effects are highly arbitrarily or at least 'user-defined': they strongly depend on the production functions and parameters that make up the models (Santarius 2014).

Yet what is more important for the argument of this chapter: Even if reliable answers could be found to the question of substitution and output elasticities, macroeconomic models do not consider *structural* effects of (energy) efficiency improvements on the overall economy. Macroeconomic models work with the kind of 'ceteris paribus' condition, which assumes that EEI may change the composition or level of output of the economy, but not its very constitution. This chapter will argue that EEI can change the time, i.e. the speed of capital and goods turnover.

While the aspect of 'time' has already been introduced to microeconomic rebound research by Binswanger (2001) and Jalas (2002) (see Chap. 10 of this volume), macroeconomic rebound models have so far been blind to structural and temporal impacts of EEI. This deficit can be illustrated when reconsidering the theorem from Birol/Keppler (2000) and Saunders (2000) that '*the ease of fuel substitution has a strong influence on rebound*' (see full quote above). Now question the word 'ease': If this—as usually in economics—refers to the *material* dimension of substitution, it means the quantitative extent to which energy can be replaced by capital (or other factors of production). For example, energy input can be greatly reduced through the conversion of non-insulated buildings to low-energy houses thanks to increased capital investment in insulation.

However, if the word 'ease' refers to the *structural* dimension of substitution, it could mean in which time frame, i.e. *how fast* a substitution can take place. To stay with the example: How quickly can conventional buildings be insulated or replaced by low-energy houses? An elasticity of substitution of 1—that is: the complete substitutability of energy by capital—would mean that all buildings can be replaced by passive or zero-energy buildings. Apart from the share of embodied energy, which is required for the production of insulation materials, this appears theoretically possible. But how long does it take to realize full substitution in practice? Does full substitutability suggest that this can be realized within a short period of time, such as the model-theoretic observation period of one year? Or what kind of validity does a substitution value of 1 have if the renewal of existing buildings requires a long period of time—in an extreme case, if the complete substitution can be realized only after the average life span of the building stock of around 100 years?

Up to now, macroeconomic rebound research has not considered the factor of time. In terms of structural economic effects, the factor of time could characterize economic exchange relationships; i.e. the pace of the circulation of money, goods and services. For instance, in an economy whose goods and capital circulation is relatively rapid, can the investment in low-energy houses be realized more quickly than in an economy which is marked by slow transaction times and relatively little movement in the markets? And conversely: Can the improvement of the energy efficiency of an economy accelerate the rate of goods and capital circulation? These are the questions of the following sections of this chapter.

9.2 Efficiency and Technological Acceleration

The relationship between technical energy efficiency, time/speed and energy demand can be studied from the history of transportation and communication. As of transportation, it has been extensively documented how the improvement of technical efficiencies in motors, automotive engineering and transport infrastructures was undoubtedly key in enabling faster and long-distance travels (e.g. Schivelbusch 1986; Fouquet 2008). Take for example the energy efficiency of steam engines: in 1840, about 1700 tonne-kilometres could be travelled with one tonne of coal; in 1920, this figure rose to 3400 tonne-kilometres (Fouquet 2008). Slowly, diesel engines replaced coal-fired railways, and again efficiency had been improved massively. The thermal efficiency of a diesel engine in 1920 amounted to 10 %, but this figure rose to 35 % in 1970 (Summers 1971). From nineteenth century, invention of the railway until about the 1980s, EEI could be translated into higher travel speed at low costs. While speed still rose for certain high-speed lines, average travel speed has not much improved since the 1980s (Obermayer 1994).

Similar waves of acceleration of transportation have been unleashed by the introduction of the automobile and the airplane. The car—although average travel speed has always been slower compared to railways—has enabled the acceleration of rural, ‘off-track’ areas as well as of everyday, short-distance transportation. EEI in motor and automotive engineering have resulted in far more often usage of the car, which eventually advanced to become the ‘no. 1 means of transportation.’ Airplanes instead have enabled long-distance transportation, at first mainly between continents and within the USA. And as energy efficiency of jet engines improved 24-fold between 1952 and 2000 (Fouquet 2008), air travel became increasingly affordable and now much penetrates business- and leisure-life. Certain examples like the Concorde airplane, which races from New York to Paris in only 3 h, did not triumph further acceleration as they turned out too costly, and such greater time efficiency in the air was countervailed by ‘lost time’ in increasingly jammed roads from airports into city centres (Gleick 1999). Yet in any way, throughout 200 years, energy efficiency of transportation technologies magnified time efficiency of travelling.

The history of energy efficiency in communication—from conventional mail through telegraph, telephone and fax, and nowadays electronic and virtual communication—appears even more impressive. Take the rise of digital computing, the innovation of computers would not have been possible without massive increases in energy efficiency. After early experiments with mechanical calculators since the seventeenth century and the development of electromechanical computing machines since the nineteenth century, the invention of electron tubes rang the development of the modern computer in 1943. While electron tubes tremendously increased computing power, they were still be very energy intensive. E.g. for the operation of its 55,000 electron tubes, the 1958 built SAGE calculator used legendary three megawatts—enough to power around 2000 households (Matis 2002). With the invention of the transistor in 1948 began a second wave of energy efficiency and computing productivity. Transistors consumed about 80 % less electricity than electron tubes and multiplied switching speeds. Finally, in 1971 the introduction of the microprocessor heralded a further stage in the efficiency revolution of communications technologies.

Energy efficiency in communication technologies describes the conversion efficiency of energy sources not into physical work, but into computational capacity; this is called 'performance per watt efficiency'. It has increased extraordinarily over the decades (see also Todorovic/Kim 2014). For example, the 1950-year UNIVAC I computer, which was equipped with 5200 electron tubes, performed approximately 0.015 operations per second (OPS). In contrast, a 2005-year Fujitsu FR-V VLIW vector processor with a 4FR550 processor already whopped 17 billion OPS (Matis 2002; Suga/Imai 2006). More recent comparisons between microprocessors still exhibit considerable energy efficiency gains, which can be illustrated by the introduction of multi-core processors: An AMD Opteron dual-core processor consumes about 41 % less energy than its predecessor, the AMD Opteron single-core processor (Williams 2006). Overall, the figures suggest that from the mid-twentieth century until today, energy efficiency of computing performance has increased by more than one trillion percent (*sic*!). And the time to transfer a message shrank close to zero—first from stationary computers, then even from mobile devices. Overall, energy efficiency of computational technologies magnified time efficiency of communication.

Most commonly, the history of technological revolution is told as a history of inventions (e.g. Landes 1972; Lipsey et al. 2005). While in economics, there is a vital debate whether economic, that is to say, cost-efficiency improvements or product inventions are the more important driver behind economic growth (see, e.g. Schumpeter 1942; Baumol 2002; Hämäläinen 2003), at least as of EEI, inventions are hard to distinguish from efficiency improvements. Did James Watt invent 'his' version of the steam engine, or was the invention actually Thomas Newcomens' previous achievement and Watt only significantly improved the efficiency of that technology? Another example: The first transistor by Shockley, Bardeen and Brattain of 1947 still had dimensions of a shoebox and was even larger than an electron tube. But through incremental efficiency improvements, transistors and diodes could be shrunk to the size of salt grains, greatly reducing material and energy efficiency (Vorndran 1986). This chapter does not intend to make a point for efficiency improvements versus inventions. Rather, it focuses on how EEI improved the features and the applicability of technologies and in its course, as we will see, changed the economy and the society—no matter if improvements have been inventions, innovations or mere incremental enhancements.

Both the efficiency revolutions in transportation as well as in communication enabled faster and more interaction. Yet these were not necessarily cheaper in the first place. For instance, it is noteworthy that the energy efficiency—calculated as the passenger kilometres (PKM) per tonne of oil equivalent (toe)—had attained its historically highest level in the mid-nineteenth century with then highly developed horse and stagecoach transportation. Fouquet (2008) calculates the estimated energy consumption for the production of hay and oats for horses and compares it with the coal, oil and electricity consumption for trains and cars. According to him, transport modes in 1770 could achieve about 14,000 PKM per toe and even 32,000 PKM/toe in 1830. However in 1900, with fossil fuel-based transportation technologies having out-dated traditional ones, this figure only amounted that 4000 PKM/toe could be achieved. Until 1960 efficiency somewhat increased to its highest value in the twentieth century, 17,000 PMK/toe, and since then has even decreased again (Fouquet 2008 Table A7, p. 423ff). These figures are highly relevant for rebound research as they show that income and substitution effects *as such* cannot explain the radical increase in the amount of traffic. Rather efficiency improvements in the first place have been used for an *acceleration of traffic*. Amongst other impacts, these time-savings for passengers and freight shipments then have decreased travel costs, e.g. because no mo accommodation is necessary on few-hour travels that used to take days, but also because opportunity costs of ‘lost time’ on enduring travels can be saved. Moreover, time-savings also have increased comfort, safety, prestige and foremost multiplied consumer options. These conclusions also seem plausible for communication technologies: computers have saved costs directly, e.g. as labour costs for secretaries or bank officers could be cut. Yet far more important is that they have allowed communication to be accelerated to almost light velocity, and has opened up whole new realms of economic and social transactions. This has highly improved capital productivity. But moreover, as the next section shows, it has also changed social institutions and modes of social and economic interactions.

9.3 Time-Space-Distanciation in Modern Societies

It would be reductionist to assume that technologies ‘themselves’ accelerate economic transactions or even social life. In fact, social and economic acceleration is a repetitive motive in sociological discourses, and various reasons have been brought forward to explain this trend. Weber (1985, 2013) as well as Marx (1980) analysed how ‘tireless’ machines in factories compel an acceleration of work, while they force labourers to become ever more time-oriented. Simmel (1989, 1992) instead identified the introduction of money as the main reason for the extension of money-based (market) economies; money would make all things commensurable and exchangeable and hence would much widen the ‘spheres’ as well as the tempo of life. Elias (1984, 1997), for his part, makes the internalization of time discipline responsible for a change in time-space categories. By formally regulated school schedules, clearly timed lessons, work certificates per unit of time (performance audits) and so on, already at school individuals would internalize a tight temporal organization of work and everyday life. Civilized people who could control their emotions would therefore align their lives largely to the clock.

This chapter does not intend to provide an exhaustive analysis of sociological classics. Yet two conclusions seem to hold water while they refrain from a reductionist ‘technocism’. First, social acceleration obviously goes back to a variety of factors. After all it is a truism that modernization is a complex process in which technological progress interacts with psychological, social, political, cultural, economic, legal and other dimensions. Secondly, however, the process of modernization in general and social acceleration in particular was much interwoven with the technological acceleration by machines. Neither industrial production as Weber and Marx highlighted nor the extension of the social spheres highlighted by Simmel, could have taken place without the relevant technical efficiency improvements in transportations and communications technologies. Would transnational production chains be possible if goods continued to be transported with coal-fired steam locomotives? Would social relations have delinked from their local bond if sporadic personal visits were not complemented by efficient media technologies, which ensure regular communication despite geographical distances? Technology does not *determine* social acceleration, but unequivocally *enables* it. Technological innovations and improvements in efficiency so can be summed up for the rebound discussion, represent a necessary, albeit not sufficient condition of the *exceptional degree* of social acceleration that has been achieved by modern societies.

Now the following paragraphs of this section briefly consider how technology-powered social acceleration has ‘*altered social institutions*’, while the next section then analyses how it has ‘*rearranged the organization of production*’ (see quote from Greening et al. above). In the course of the technological acceleration of transportation and communication, social categories of time and space have been fundamentally transformed. It is well analysed how the introduction of the railroad changed both individual perceptions as well as social discourses—the ‘common sense’—of space and time. The travelogue of the maiden voyage of the Charleston Courier, which marked the first regular and scheduled train service in the United States on December 25, 1830, metaphorically brings this to the point: “*We flew on the wings of the wind at the varied speed of fifteen to twenty-five miles an hour, annihilating time and space, leaving all the world behind*” (Wikipedia.org 2014: Best_Friend_of_Charleston). Yet the much-quoted saying of the ‘annihilation of space and time’ is, strictly speaking, not correct; it is rather the annihilation of the hitherto historical perception of a ‘time-space continuum:’ The locus—e.g. the ecosystem, village, place of life, etc.—lost its disposition as a seemingly incontrovertible fact, while life became more and more governed by time as the dominant social orientation force (Rosa 2013). That is why Marx rather spoke of the “*annihilation of space through time*” (Marx 1974, p. 438), and Harvey later observed an increasing "*time-space compression*" (Harvey 1989, p. 240ff). For the change in spatial and temporal perceptions and understandings expresses itself primarily in the detachment of the perception of time from space, which is well expressed by Giddens' terminological proposal that every society has its own special form of "*time-space distanciation*" (Giddens 1981, p. 90ff).

With high-speed technologies available and institutional time-space compression at work, everyday life accelerated at a continuous pace. With reference to Rosa, the pace of life can be defined as an increase in action and/or experience episodes per unit of time (Rosa 2013). It is as easily conceivable as it has been documented through qualitative and quantitative empirical data, how efficient transportation and communication technologies enable the acceleration of pace of life. Many time budget studies actually empirically prove that individuals perform more actions/activities per unit of time, while they also perceive time as increasingly scarce, resulting in time pressure, hectic, restlessness and stress as widespread feelings of modern life (see e.g. Robinson/Godbey 1997; Levine 1997). Short trips, fast food restaurants, speed dating, Short Message Sending (SMS), Twitter and many other terms reveal not only the rich vocabulary that describes the acceleration of the pace of life, but also indicate today's normality of these activities.

While the acceleration of the pace of life is largely undisputed, debate exists whether social acceleration also applies to the pace of social change. For instance, Harvey states that the sequence of styles in visual arts, literature and architecture have increasingly compacted and started to overlap (Harvey 1989, p. 260ff). Likewise, publications about the evolution of management concepts suggest that dominant forms of work organization would replace in ever shorter periods. For example, time periods continuously shortened from the classic (early) capitalist factory, which lasted from the seventeenth to the nineteenth centuries, through Fordism mass production, which rose in the late nineteenth and prevailed to mid-twentieth century, before it was replaced by the concept of 'Lean Management' in the second half of the twentieth century, which today gets questioned by new concepts like 'Smart Factory' (see for example Lipsey et al. 2005; Böhler 2012). What is more, also social and scientific paradigms (Kuhn 1962) seem to follow each other more rapidly and, as Appadurai states, increasingly soften into more fluid *social imageneries* (Appadurai 1996; likewise Castells 1996). Rosa generalizes that the pace of social change "*has accelerated from an intergenerational pace in early modern society to a generational pace in 'classical' modernity to an intra-generational pace in late modernity*" (Rosa 2009, p. 84). Where that is the case, Rosa concludes, it should be called an acceleration of society itself.

9.4 High-Speed Economy and Throw-Away Society

The following section will discuss how both technological and social acceleration speed up economic production and consumption, and how this has been reflected in the theorization of 'time economy.' In four ways, technological acceleration has stoked an acceleration of production. First, the acceleration of freight traffic allows an increase in the distribution of raw materials and goods. The more rapidly raw materials and intermediate products get transported to production sites, and final products to the place of sale, the more goods can be distributed and consumed in a given period of time. This boosts the output of the production. Transportation is also driven by the acceleration of communication flows, as warehousing and other transaction times of freight traffic can be reduced by an optimized logistics.

Secondly, technological acceleration speeds up production processes. For example, more energy-efficient furnaces shorten melting processes of ores; conveyor belts reduce delays between individual production steps; etc. In general, it may be assumed, the faster production machines run, the faster raw materials and intermediates may be assembled into final products. Likewise, the quicker information on status of raw materials and intermediates or on sudden problems in the process are received by the management, the smoother and faster production processes can run.

Improved communicative links between production and consumption, such as through barcodes on supermarket checkouts, thirdly speeds up whole production cycles. IT-based feedback about consumer trends enables product marketing—from design to manufacturing, warehousing and distribution—to quickly adapt production cycles. Vice versa, fast communication technologies also serve producers to influence the desires and 'needs' of their consumers more quickly and more directly. For instance, the analysis of buying behaviour of consumers on the internet promises to adjust production cycles to consumer preferences and trends in real time.

Fourth, the technological acceleration of transport and communications indirectly accelerates production, because it heats up the competition between companies. The faster products can move between geographically dispersed locations, and the easier it is to communicate over large geographical distances, the more do local and regional markets merge into large national and transcontinental markets. The number of competitors grows with the size of the market, and increased competition in turn forces producers to accelerate production processes and delivery times. On the world market, the comparative advantage in time turns out as a condition of the comparative advantage in costs.

This explains why Marx postulated that all economy would eventually dissolve into the 'economy of time'. "*Economy of time, as well as the distribution of work on the various branches of production, thus remains the first economic law…*" (Marx 1974, p. 89; translation by TS). Among other things, Marx based his theorem on the following equation: "*A turnover of capital = production time + circulation time*" (ibid., p. 521). Marx thereby explains why both production time as well as circulation time are constantly under pressure to be accelerated, because the sum of corporate profits directly depends on the value of a given product or service multiplied by the number of sales in a given time period. The more often production processes can be repeated in a given time period, the more often can capital reproduce itself, and the more effectively can this capital generate added value (profit)—and hence, make the economy grow as a whole. Rinderspacher postulates that time as a resource had achieved an '*economic use imperative*' (Rinderspacher

1985, p. 60). And because the 'saving of time', i.e. the most rational use of time in the economic process, can be improved infinitesimally, it can be understood as a complementary phenomenon to the accumulation of capital.

Yet if delivery times, production processes and even production cycles are accelerated, consumption must keep pace accordingly; otherwise a chronic over-supply is created, which sooner or later brings production to a standstill. Consumption increases either by shortening the amount of time per unit consumed (acceleration) or by more consumption per unit of time (intensification). Consumer trends and fashions alter in ever-shorter stretches of time, while the overall product portfolio immensely diversified from early to late capitalism. The lifetime of products contracts, either because they break down earlier—no matter if due to cheap quality or 'planned obsolescence'—or because they loose their symbolic value for conspicuous consumption. In addition, the shift from goods to services consumption further accelerates consumption, as "*the ‚lifetime' of such services (a visit to the museum, going to a rock concert or movie, attending lectures or health clubs), though hard to estimate, is far shorter then that of an automobile or washing machine.*" (Harvey 1989, p. 285).

The discourse(s) on consumerism in affluent societies, i.e. on the so-called 'throw-away society' (Lindner 1970; Toffler 1970; also Galbraith 1969; Schor 1998; Cross 2000; Princen et al. 2002; and others) has well described how the acceleration of consumption changes its character and quality: By way of the continued obsolescence of products and because of the economic rationality of discarding and replacing instead of repairing, individuals stop personally appropriating products, stop 'growing together' with beloved items and hence, acquire an increasingly transitory and contingent relationship to their belongings. In short, the 'ex and hop'-mentality fundamentally alters the relationship between subjects and objects. This constantly downgrades the personal value of goods and services, which in turn often triggers the need for more consumption in order to maintain any given level of satisfaction. This spiral of accelerated consumption well latches with the spiral of accelerated production; it firmly locks capitalist societies in the ‚iron cage of consumerism' (Weber 2013).

9.5 Energy Efficiency, the Velocity of Money and Economic Growth

Against the background of the foregoing sociological considerations, let us now reconsider its meaning for macroeconomics. The link that Marx drew between the speed of production, consumption, transport and overall capital turnover can be matched with a more modern economic debate about economic growth and the velocity of money (V). The question arises: do EEI indirectly accelerate the velocity of money? Or asked in another way: may V as an indicator serve to signify structural rebound effects?

The velocity of money (V) describes the frequency at which an average unit of currency is used to purchase domestically produced goods and services within a given time period; in other words, how many times each Euro, Yen or Rubles is spent each year. For the different types of money (cash, liquid deposits, large institutional deposits, etc.; $M0$–$M3$), V can be considered separately. Economist Fisher (2007) established a relationship between V and money supply (M) on the one hand and price level (P) and economic growth (Y) on the other. He postulates: $M \times V = P \times Y$. In its simplest form, this 'Fisher equation' or Quantity Equation states that an expansion of the money supply (M) or an increase in the velocity of money (V) results in an inflation that raises the price level, or may otherwise increase economic output (Y).

It would go beyond the scope of this article to reflect the widespread discussion about the value and legitimacy of the Fisher equation (for an introduction, see Keynes 1924; Laidler 1991; Friedmann 2006). Yet for sure, linking the discourse of social acceleration and structural rebound effects to monetary growth would be innovative. Because when it comes to the analysis of causes for alternations in V, so far monetary arguments dominate (Ireland 1993). For example, a correlation between the degree of monetization of the economy and its velocity of money has been made (see Bordo/Jonung 1987). As reasons for the long-term increase of V, arguments usually refer to innovations and efficiency improvements in payment transactions as well as to financial policy (e.g. Goldsmith 1969; Shaw 1973). Kuznets (1971) more generally claims a relationship between V and the increasing share of the financial industry in the GDP.

While technical efficiencies in the monetary and credit system are considered engines of increasing V, the impact of accelerated communication technologies have only indirectly been considered, and impacts of EEI on the accelerations of traffic, production, consumption and the pace of life in general have so far not caught any attention. If future research wants to follow this approach, it should not treat V as independent variable in the Fisher equation; traditionally, V is often calculated simply by multiplying the domestic product (Y) times its price index (P) divided by the money supply (M). In contrast, V would need to be treated as the dependent variable of either an independent theoretical analysis or an empirical investigation (as suggested by Veit 1966; Eichmann 2002). In any case, the influence of social and economic acceleration as a factor should be taken into consideration.

As a first approximation, a graphical approach should be provided here. Figure 9.1 illustrates alternations of V in the US in connection to the development of the US energy efficiency. Energy efficiency here is calculated as the sum of all utilized energy sources divided by the physical work, which has been derived from the use of those energy sources multiplied by their thermodynamic conversion efficiencies (for details of the calculation method, see Ayres/Warr 2009, p. 89ff and p. 311ff). This means that efficiency improvements in communication technologies (for example, performance per watt efficiencies) are not yet reflected. Figure 9.1 shows that basically and in the long run a positive correlation between energy efficiency and V exists. Interestingly, it also shows that falling energy efficiencies *precede* declining circulation velocities in the early 1980s and early 2000s,

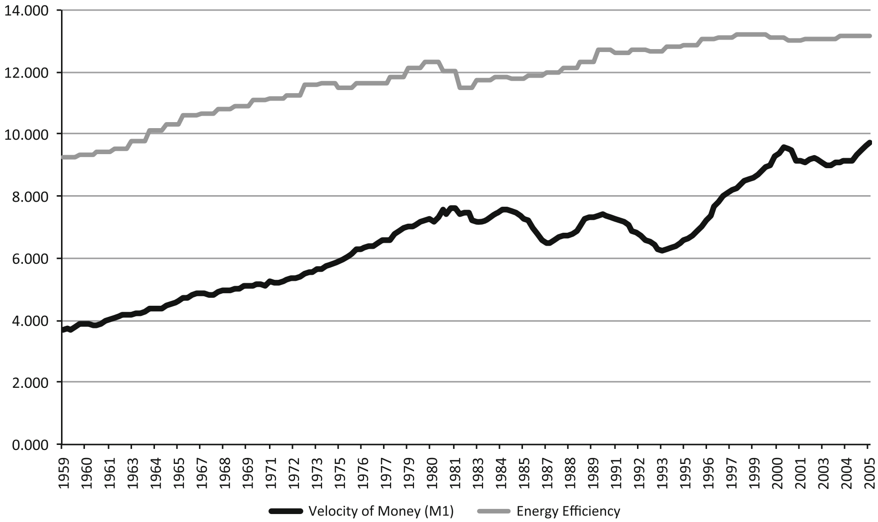

Fig. 9.1 Improvement of energy efficiency and acceleration of velocity of money in the USA (1959–2005). Source velocity of money: US Federal Reserve Bank (2014); source energy efficiency: Ayres and Warr (2009, p. 334). *Black line* velocity of money: nominal GDP/average $M1$. *Grey line* energy efficiency: Exergy exajoules/useful work exajoules

respectively. At the same time, however, in the mid-1980s a contrary behaviour of the curves can be observed, with declining V and increasing efficiency. Overall, the figure must not be used to draw hasty conclusions. Future research should dive into deeper regression analyses to reveal a statistically significant correlation.

9.6 Outlook: Rebound as a Motor of Restless Modernity

No matter whether the mammoth task of measuring the impact of social acceleration on turnover of capital and velocity of money can be accomplished or not, it has become clear that a complex relationship exists between technological, social and economic acceleration. This is partly driven by technical (energy) efficiency improvements, but also reinforces itself. In fact, energy efficiency, energy inputs, technological, social and economic acceleration form a ‘self-accelerating spiral’ (Rosa 2013). Within this spiral, EEI serve as one of the driving forces: they allow mobility and interaction with less energy demand and less time, but because this enables social and economic acceleration, energy demand in sum increases. Then the next round of EEI again reduces the relative demand for energy, i.e. the energy per experience episode of social interaction or per unit of value added, but this once more accelerates social and economic interactions and demand for energy services further increases, and so forth.

Note however, as has already been argued in Sect. 9.3 above, that EEI do not *determine* social and economic acceleration. As in most social phenomenon that do neither conform to Newton mechanics nor to laboratory conditions, a "*cause-effect-relativity*" (Santarius 2015) has to be taken into account. EEI *enable* technological acceleration, technological acceleration *enables* social and economic acceleration, but all three eventually *entail* an increased demand for energy services (see Fig. 9.2). Still a rebound effect emerges that ultimately stems from the causal interrelationship between energy efficiency and technological, social and economic acceleration; this effect therefore can be termed a 'structural rebound effect' and be defined as follows: A structural rebound effect refers to an increased demand for energy services that rests on the acceleration of economic and/or social processes, which were enabled by an increase in energy efficiency. Note that the increased demand for energy services can, but does not necessarily entail backfire; it can also describe a higher level of energy service demand compared to the situation before the EEI took place. In remains open to what extent absolute decoupling of energy demand from social acceleration is possible.

Section 9.5 has portrayed a link between social acceleration and economic growth in a rather technical approach, along the concept of the velocity of money (V). In addition, two more general conclusions can be drawn for macroeconomics, which refer back to Sect. 9.1 and existing research on macro rebound effects. On the microeconomic level, Jalas (2002) has stated that the analysis of "*time-use rebound effects* [...] *combines the constraints of time and money and treats them as interchangeable*" (Jalas 2002, p. 112). Now an analogous conclusion can be drawn for

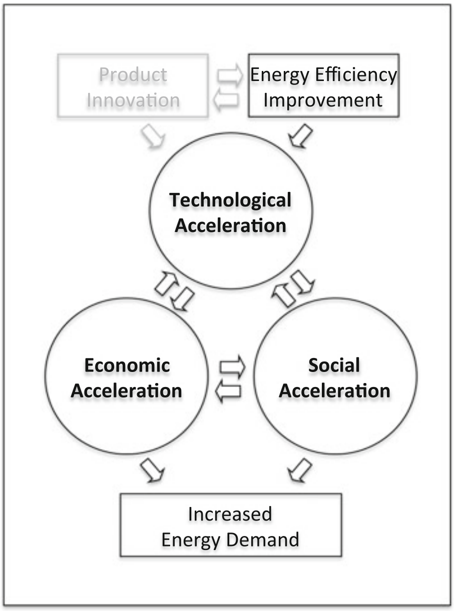

Fig. 9.2 Causal loop of the structural rebound effect. *Source* Author's own design

the macro-level. Yet, the point of reference here is not saved time in individual consumption acts, but accelerated production and consumption processes: First, the output elasticity of the production factor of energy as such might be less important to determine macroeconomic rebound effects. Rather, EEI structurally transform the economy and the society, which much improves capital productivity. Hence output elasticities of both capital *and* energy productivity co-determine the size of macroeconomic rebound effects. And a second conclusion: if energy and time are substitutes and time and capital are substitutes, then also energy and capital will figure as substitutes. This corollary makes an important contribution to the debate on the energy elasticity of substitution: Technological, social and economic acceleration apparently increase the elasticity of substitution between energy and capital. With regard to the theorem by Saunders (2000) and Birol/Keppler (2000)—'*the easier it is to substitute labor and capital through energy, the higher the rebound effects*' (original quote see above)—it can thus be postulated: The more EEI spur social and economic acceleration, the higher will be their associated (macro-level) rebound effects.

Besides those conclusions for macroeconomics, the following policy conclusions can be derived: EEI of technologies and products that have little or no impact on social or economic acceleration will have *comparatively* lower rebound effects. These include, for example, measures of building insulation or some efficient appliances, such as refrigerators and washing machines. Note that the latter can indeed generate the well-known microeconomic rebound effects (e.g. see Davis et al. 2012), as they may generate income and substitution effects. But they will not be prone to generate additional (macro-level) structural rebound effects.

In contrast, EEI that lead to a further wave of acceleration may generate structural rebounds in addition to economic and psychological rebounds. In the transport sector, further acceleration is conceivable in air traffic or when entirely new technologies emerge—for instance, by technologies such as a Hyperloop, which has been suggested for the connection between San Francisco and Los Angelos and would travel those 560 km in about 30 min (see Space X/Tesla Motors 2014). As of communication, electronic communication at light velocity has not yet penetrated all areas of economic and social life. EEI that enable a further acceleration of human-to-human, human-to-machine and machine-to-machine communications, i.e. through the Internet of Things or increased robotics in manufacturing, therefore run the risk to generate significant structural rebound effects.

It has already been concluded that as long as the economy keeps growing will there be considerable macro- and microeconomic rebound effects (Jackson 2009; Sorrell 2010; Santarius 2012). In the meantime, it remains open, to what extent EEI themselves perpetuate economic growth. Now it can be added, as long as the life and society accelerates will there be structural rebound effects. And this chapter presented new arguments that EEI may themselves not only grow output, but also accelerate the pace of life. Hence, both *degrowth* and *deceleration* appear as important prerequisites for a sustainable future.

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Part III
Policy Cases: Rebounds in Action

Parts I and II of this volume have asked the question: How can we understand, explain and define rebound effects, namely the specific mechanisms that generate an increase in demand after an energy or resource efficiency or sufficiency improvement has put into place? As the reader has seen, different scientific disciplines, theories and methodologies can provide different answers to this question. We assume the more inter- and multidisciplinary is the approach to investigate rebound effects, the more comprehensive will be the overall answer. Yet we believe that rebound research faces another challenge: Research usually tries to *isolate* rebound effects from other phenomena in order to make their functioning most transparent and clearly calculate their magnitude. This can be illuminating but also blinding—like car headlamps on full beam: Within the light cone the road appears clear; but outside it the blackness of the night remains to be discovered. Most of past rebound research as well as the chapters in Part I and II of this volume have a somewhat similar effect. They focus the view as part of the exercise to maximize scientific preciseness and reliability of the (empirical) results and conclusions drawn. At the same time, they exclude aspects outside their categories, explanatory variables, theories or data sets—but which nevertheless exist in the real world. Part III of this volume takes the endeavour to broaden the view and sprinkle some light on the interconnectedness of rebound effects in a complex world. After all, when putting rebounds into practice and when trying to design policies and measures that can mitigate these effects, the relationship between rebounds and other effects and phenomena needs to be considered in order to avoid second- or third-order feedback or countervailing effects.

Hence, Part III of this volume tries to put rebounds into praxis. It exposes the concept of these effects to practical energy and climate policies and relates it to the wider debate on sustainable development through a number of selected cases studies, i.e. in the fields of labour markets, urban planning, tourism, freight transportation and cloud computing. It also contextualizes rebound research in the 'big picture debate' and paradigmatic question whether 'green growth' or 'degrowth' is the more appropriate strategy to achieve long-term sustainability. The chapters combine various scientific disciplines as well as methods but focus on problem-oriented research; their main aim is to pave the way for research to go beyond disciplinary and interdisciplinary approaches and discuss rebound effects in a practical and—potentially—transdisciplinary manner.

Chapter 10 address the environmental implications of voluntarily reduction of work when time-use rebound effects are taken into consideration. Chapter 11 addresses the hypothesis whether inner-city dwellers make more frequent and longer leisure trips than suburban and outer-city dwellers in order to escape dissatisfactory residential environments. Chapter 12 looks at behavioural and systemic relationships within and between the two policy fields of climate change adaptation and mitigation. Chapter 13 discusses how new digital services associated with cloud computing impact energy use. Chapter 14 discusses rebound effects connected to policy measures taken to curb GHG emissions and energy use in road freight transport. Finally, Chap. 15 investigates the relationship between rebound effects and the issue of decoupling economic growth from resource use, energy use and related GHG emissions.

Chapter 10
Labour Markets: Time and Income Effects from Reducing Working Hours in Germany

Johannes Buhl and José Acosta

Abstract A reduction in working hours is being considered to tackle issues associated with ecological sustainability, social equity and enhanced life satisfaction—a so-called triple dividend. With respect to an environmental dividend, we analyse the time-use rebound effects of reducing working time. We explore how an increase in leisure time triggers a rearrangement of time and expenditure budgets, and thus the use of resources in private households. Does it hold true that time-intensive activities replace resource-intensive consumption when people have more free time at their disposal? In order to give an answer to the question, we estimate the marginal propensity to consume and the marginal propensity to time use in Germany. The findings from national surveys on time use and expenditure show composition effects of gains in leisure time and income loss. The results show that time savings due to a reduction in working time trigger relevant rebound effects in terms of resource use. However, the authors put the rebound effects following a reduction in working time into perspective. Time-use rebound effects lead to increased voluntary social engagement and greater life satisfaction, the second and third dividends.

Keywords Rebound effect · Time use · Resource use · Consumption

A significant reduction in working time in rich industrialised countries is being considered to tackle issues associated with ecological sustainability, social justice and individual quality of life (Schor 2005; Jackson and Victor 2011; Coote et al. 2013; Kallis et al. 2013; Pullinger 2014). However, as Kallis et al. (2013: 1564) recently noted, advocates of working time reductions in the degrowth discourse fail

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J. Buhl (✉) · J. Acosta
Wuppertal Institute for Climate, Environment, Energy, Doeppersberg 19, 42103 Wuppertal, Germany
e-mail: johannes.buhl@wupperinst.org

J. Buhl
Faculty for Social Sciences, Economics and Business Administration, University of Bamberg, Bamberg, Germany

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to take into account potential counterproductive “secondary and third level effects” of working time reductions—such as rebound effects.

The comprehension of rebound effects has evolved over time. More comprehensively, Sorrell (2010, p. 8) refers to rebound effects as “the unintended consequences of actions by households to reduce their energy consumption and/or greenhouse gas (GHG) emissions”. Every *action* that aims at promoting savings in resources is prone to rebound effects. With respect to time, Greening et al. (2000, p. 391) noted that “…many technological advances, in addition to fuel efficiency improvement, have resulted in changes in the allocation of time. This is reflected in a change in labour force participation rates and occupational structure”. Greening et al. (2000) paved the way for an introduction of time-use rebound effects such that later Jalas (2006, p. 51) classified the notion of time-use rebound effects as transformational rebound effects as well. They both argue that transformational effects respond to changes in consumer preferences, social institutions and in the organisation of labour—e.g. a reduction in working hours. In this regard, time-use rebound effects state that re-invested time savings may compensate for productivity gains in a similar way that re-invested monetary savings due to efficiency gains do. It would therefore be important to determine to what extent a reduction in working time is prone to time-use rebound effects.

Generally, Linder (1970) already stated that in modern industrialised societies, free time[1] decreases as productivity and wealth increase. More recently, Rosa (2013, p. 152f) corroborates Linder’s axiom by offering a more comprehensive understanding of social and technical acceleration and its implications for energy and resource requirements.

> Wherever it is possible to save time through improved techniques—even in administrative processes, in legislation, in education, indeed in recreation or entertainment—there is great social pressure to develop and implement them in order to have newly available freed-up time resources. In addition to this, the holding open of future opportunities to accelerate, e.g., by acquiring more powerful hardware, wider streets, greater energy storage […] likewise becomes an imperative of social action. The expectation of technical acceleration (and the corresponding quantitative growth of transportation, information processing, energy demand, etc.) is thus, as it were, always already “built in” to the social and material infrastructure. Technical acceleration is therefore a direct consequence of the scarcity of time resources and hence of the heightening of the pace of life.

Above all, technical acceleration is characterised by technological acceleration. However, technical acceleration is simultaneously characterised by an acceleration

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[1] Free time is usually seen “as the time resources that are not bound up in obligatory activities, and over which one may therefore dispose more or less at will.” As such, free time is “the time that remains left over after subtracting work time and housework (child care, errands, housework), and personal care time (eating, sleeping, body care)” (Rosa 2013, p. 133). However, free time is a deliberately subjective notion of the time people *consider* to have freely available after they have been at to work or have taken care of their children. Time use for eating, sleeping, resting or even time at voluntary work or time with children is often stressed as free time as well. Eventually, we distinguish between time at formal, paid work (labour) and time outside labour for the estimation of potential rebound effects after working time reduction.

of organisation, decision, administration, and control, i.e., the intentional acceleration of goal-directed processes through innovative techniques (Rosa 2013, p. 74). As such, we consider labour productivity gains, i.e. the increase in output (e.g. GDP) per (e.g. total) working hours a part of technical acceleration. With respect to an accelerating pace of life we follow Rosa's (2013, p. 121) definition of the same as the "increase of episodes of action and/or experience per unit of time as a result of a scarcity of time resources". Potential opportunities in terms of experiences (like trips, travels, going out, going to the movies, cooking, sports and so on) coming with technical acceleration emerge at an increasing pace. Likewise, the opportunity costs[2] of consumer decisions increase and the quest to decrease those by condensing actions and experiences over time (by means of increased energy and resource use) accelerates the pace of life in an experience-oriented society (Rosa 2013; Schulze 2013).

For instance, the analysis of changing leisure time conducted by Aall et al. (2011, p. 453) showed that "leisure activities are to increasing extent based on material consumption". And when it comes to the re-allocation of working and leisure time Druckman et al. (2012) explained "that a simple transfer of time from paid work to the household may be employed in more or less carbon intensive ways". Knight et al. (2013) describe a time-use rebound effect due to the reduction in working as a compositional effect that may be triggered by a change in how households allocate their time spent and expenditure, also taking into account monetary and temporary budget constraints. They wonder (on p. 694) if "[h] ouseholds with more free time might take more vacations by auto or air, they may travel outside the home more, or have greater involvement in extra-mural community activities, leisure or shopping, as well as other energy consuming activities". Their results suggest that "the compositional effect of work hours on consumption patterns may be more consequential for non-energy resources" and noted that "this is an issue that could benefit from further study". In this respect, we investigate whether it holds true that significant time savings following a reduction in working hours lead to resource-intensive consumption being replaced by time-intensive, but low-resource activities—taking into account time-use rebound effects.

To this end, we adapt a model of time-use rebound effects from the literature in the next section. The fourth section contains a presentation of the findings gained from the statistical analysis. In the fifth section, we discuss the methodological issues mainly caused by mixing data. In the final section, we summarise the findings and briefly draw conclusions with respect to potential increase in voluntary engagement and an increase in life satisfaction—the second and third dividends of working time reductions.

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[2] Opportunity costs is a basic concept in micro economics. It basically refers to the fact that a choice between opportunities leaves the foregone alternative as a cost, as an option that has not been realised. The more options foregone, the higher the opportunity costs. When it comes to working time reductions, opportunity costs are often given as the forgone wages. In this regard, opportunity costs are high in high-wage countries.

10.1 Method and Data

There are two main approaches for estimating time-use rebound effects in the literature. The first, explicitly referring to time-use rebound, was provided by Jalas (2002). He focused on how the use of resources is distributed between different activities besides working hours, leaving income effects aside. The second one and in line with Knight et al. (2013), Nässén and Larsson (2015) argue that consumers take decisions about their temporal and monetary budget constraints, taking into account both time and income effects of a reduction in working hours. The time-use rebound effect is then a composition or net effect of time gains and income loss due to a reduction in working hours. A composition effect takes into account the fact that people rearrange their time budgets and expenditure following a reduction in working hours. Nässén and Larsson (2015) conducted a marginal analysis of expenditure and time use in order to estimate a marginal net effect.

Our approach in this text adapts the second one from Nässén and Larsson (2015) in order to estimate the propensity to time use versus the marginal propensity to consume. Nässén and Larsson (2015) fit cross-sectional regressions on expenditure and time use. However, Gershuny (2003, p. 32) was right in stating that "[t]here is really only one way to see effects of change: to take repeated measures of the behaviour patterns of the same individuals. We can only ultimately identify change, by measuring changes". We calculate the marginal propensity to time use by applying a regression analysis of time use. Data was taken from the longitudinal German Socio-Economic Panel[3] (GSOEP) between 2008 and 2009. In order to derive a concise and equally differentiated picture of the substitution of expenditure, expenditure is estimated by a marginal analysis of the National Survey on Income and Expenditures in Germany for 2008. The data on resource use relies on calculations in an environmentally extended input output analysis of the total material requirements induced by the consumption of private households in Germany in 2005 (see Moll and Acosta 2006; Watson et al. 2013).

We start by defining the rebound effect according to Chitnis et al. (2014) as the percentage of offsetting actions ΔA in relation to expected savings ΔE.

$$\text{Rebound Effect} = \frac{\Delta E - \Delta A}{\Delta E} * 100 \tag{10.1}$$

For the estimation of potential rebound effects, we are in particular interested in the offsetting action ΔA. Simplifying, this could be expressed as the sum of the time effects ΔT and income effects ΔI. This means, more specifically, the total effect in

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[3] The data used in this publication were made available to us by the German Socio-Economic Panel Study (GSOEP) at the German Institute for Economic Research (DIW), Berlin. Socio-Economic Panel (SOEP), data for years 1984–2012, version 29, SOEP, 2013, 10.5684/soep.v29 (see Wagner et al. 2007). We used the Panel Whiz-Addon for Stata v13.1 to compile and prepare the data (see Haisken-DeNew and Han 2010 for a documentation on Panel Whiz).

terms of resource use results from a new mix of activities and consumption patterns due to a changing disposability of time and income.

$$\Delta A = \Delta T + \Delta I \tag{10.2}$$

The income effect is defined as the product of marginal propensities to consume (MPC) and resource intensity r of consumption category k (in terms of kg/€).

$$\Delta I = \sum_{k=1}^{n} \mathrm{MPC}_{ik} r_k \tag{10.3}$$

While the time effect results from the multiplication of the marginal propensities to time use MPT (in terms of h) with the resource intensity of time use category j (in terms of kg/h).

$$\Delta T = \sum_{j=1}^{n} \mathrm{MPT}_{ij} r_j \tag{10.4}$$

In microeconomic terms, we derive Engel curves showing the relationship between a consumer's income and the goods bought.

$$\mathrm{MPC}_{ik} = \frac{\partial c_{ik}}{\partial y_i} \tag{10.5}$$

The same propensities are defined for time use h along harmonised time use categories j depending on a marginal change of working hours l.

$$\mathrm{MPT}_{ij} = \frac{\partial h_{ij}}{\partial l_i} \tag{10.6}$$

The resource intensities of consumption are defined as the ratio of total material requirement (TMR) per total expenditure C along Classification of Individual Consumption According to Purpose (COICOP) in Germany. The total material requirement induced by the German household consumption was calculated using the Environmentally Extended Input Output Analysis. For that a model that is based on the Leontief production function was applied. The applied model consists in the re-attribution of all materials globally extracted from the environment due to the global production for final consumption in Germany. By doing so the total direct and indirect material required along the whole production chain of each consumed product has been taken into account. Thus, each calculated value represents the resource footprint of the corresponding product group consumed by the households in Germany. The data on expenditure of the German households were extracted from the Eurostat database. For a detailed rationale of calculations of the total material requirement, please refer to Watson et al. (2013, annex A) and Moll and Acosta (2006) or Buhl (2014).

$$r_k = \frac{\mathrm{TMR}_k}{C_k} \tag{10.7}$$

The definition of total material requirement per time use is more sophisticated. The total material requirement of time use is a re-allocation of the total material requirement of consumption along those harmonised time use categories. And the total time use H in category j is the average load of time use in Germany according to the National Survey on Time Use in Germany (see Buhl and Acosta 2016 for a more detailed description and Minx and Baiocchi (2010) for similiar results on material intensities of activities).

$$r_j = \frac{\mathrm{TMR}_j}{H_j} \tag{10.8}$$

The marginal propensity to consume in Eq. (10.5) is estimated using multivariate OLS (ordinary least squares) regressions of expenditures c per category k on disposable income (as total expenditure budget) y and a vector of covariates X and an error term ϵ.

$$c_{ik} = y_i \beta_y + \boldsymbol{X}_i \beta_{\boldsymbol{X}} + \epsilon_i \tag{10.9}$$

The marginal propensity to time use in Eq. (10.6) is estimated using a panel regression according to Hausman-Taylor (1981) of time use h in category j on vector of time use $\boldsymbol{X}_1$, a vector of endogenous time-varying covariates $\boldsymbol{X}_2$, a vector of exogenous time-unvarying covariates $\boldsymbol{Z}_1$ and a vector of endogenous, time-unvarying variables $\boldsymbol{Z}_2$. We follow Hausman and Taylors (1981) research rationale for defining the four subgroups of variables.

- $\boldsymbol{X}_{1it}$ exogenous, time-varying variables and potentially uncorrelated with μ_i such as time use for job, education, sleep etc.
- $\boldsymbol{X}_{2it}$ endogenous, time-varying variables and potentially uncorrelated with μ_i such as socio-economic characteristics like schooling years etc.
- $\boldsymbol{Z}_{1i}$ exogenous, time-unvarying variables and potentially uncorrelated with μ_i such as gender and birth cohorts
- $\boldsymbol{Z}_{2i}$ endogenous time-unvarying variables und potentially uncorrelated with μ_i are not identified.

Such an estimation fits well when benefits of instrumental variables and a within estimator (as in fixed effects models) are used, while time invariant characteristics are of interest. Theoretically, gender is crucial from a household production theory perspective. Druckman et al. (2012) considered time use and potential time-use rebound effects as a gender issue that is potentially disadvantageous to those who take care of potentially resource- and carbon-intensive reproduction activities.

The result is an Hausman-Taylor estimator (HT estimator) of marginal propensities to time use as a function of working hours l, exogenous time use $\boldsymbol{X}_1$, endogenous, time-varying socio-economics $\boldsymbol{X}_{2it}$ and time-unvarying, exogenous socio-demographics $\boldsymbol{Z}_i$.

$$h_{it} = l_{it}\beta_l + \boldsymbol{X}_{1it}\beta_1 + \boldsymbol{X}_{2it}\beta_2 + \boldsymbol{Z}_i\delta_i + \epsilon_{it} + \mu_i \tag{10.10}$$

The unknown parameters β_y and β_l are estimates of MPC and MPT. By substituting MPC and MPT in (10.3) and (10.4) with β_y and β_l in Eqs. (10.9) and (10.10), as well as substituting r_k and r_j from Eqs. (10.7) and (10.8) in Eqs. (10.3) and (10.4), we derive

$$\Delta I = \sum_{k=1}^{n} \beta_y \frac{\mathrm{tmr}_k}{C_k} / \sum_{k=1}^{n} \frac{x_{ik}}{y_i} \frac{\mathrm{tmr}_k}{C_k} \tag{10.11}$$

And for ΔT

$$\Delta T = \sum_{j=1}^{n} \beta_l \frac{\mathrm{tmr}_j}{H_j} / \sum_{j=1}^{n} \frac{h_{ij}}{H_i} \frac{\mathrm{tmr}_j}{H_j} \tag{10.12}$$

With average budget shares defined as the ratio of expenditures x_i in consumption category k and time use h_i in time use category j with respect to total expenditures C_i and total time H_i, respectively.

Replacing ΔI and ΔT in Eq. (10.2) of the offsetting action ΔA with Eq. (10.11) and (10.12) as well as substituting the expected savings ΔE with income effect ΔI and offsetting action ΔA, the rebound effect in Eq. (10.1) is thus

$$\text{Rebound Effect} = \frac{\sum_{k=1}^{n} \beta_y \frac{\mathrm{tmr}_k}{C_k} / \sum_{k=1}^{n} \frac{x_{ik}}{y_i} \frac{\mathrm{tmr}_k}{C_k}}{\sum_{j=1}^{n} \beta_l \frac{\mathrm{tmr}_j}{H_j} / \sum_{j=1}^{n} \frac{h_{ij}}{H_i} \frac{\mathrm{tmr}_j}{H_j}} * 100 \tag{10.13}$$

In this sense, the estimation considering time-use rebound effects does not differ from conventional rebound studies on energy efficiency rebound effects. For the latter, it is assumed that gains in energy efficiency lead to monetary savings by consumers, who then rearrange their expenditure due to income and substitution effects. Depending on the energy or greenhouse gas intensities of the new expenditure, rebound effects occur (see Sorrell 2010). For time-use rebound effects, it is assumed that gains in (labour) productivity may just as well be translated into time savings in terms of increased free time via a reduction in working time.

10.2 Results

First, the effect of a change in working hours on the allocation of time use is analysed (time effects). Second, the effect of a change in working hours on income and consumption patterns is analysed (income effects). Both time and income effects are then integrated in order to derive the net effect. The net effect of time and income effects constitutes the time-use rebound effect.

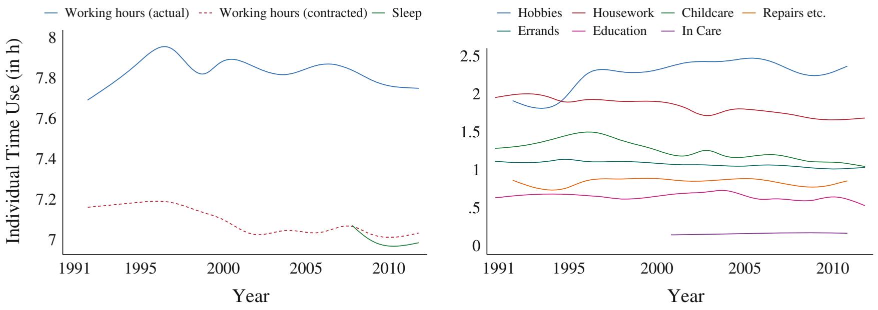

Fig. 10.1 Working hours and sleep (*left* trends) and other unpaid time use (*right* trends) in Germany between 1991 and 2012. *Data* German Socio-Economic Panel, v29

10.2.1 Time Effects

For the statistical description of time use we expand the analysis of time use in the German Socio-Economic Panel from 1991 to 2012. This enables us to show historical patterns of time use. In the following estimation of time and income effects, we focus on the years 2008 and 2009 in order to provide a consistent estimation of time and income effects alike.

But before, the descriptive statistics show that working hours (contracted as well as actual working hours) decreased during the past two decades. The same accounts for informal work and household production such as housework or child care. At the same time, time use for hobbies increased (Fig. 10.1). The historical trend thus suggests a shift from working hours in favour of hobbies.

Then, the question arises how those gains in free time are re-allocated and to what extent does this mean a shift from resource intensive to resource light time use. Based on the descriptive analysis (see Fig. 10.1), we hypothesise that time-use rebound effects play a major role when explaining (an observed increase in) intensive resource use in daily life despite relevant gains in free time. The following results from the stochastic estimations test the hypotheses at stake following the method described in 10.2 to estimate the marginal propensities to time use.

The coefficients in Table 10.1 show the marginal propensity for spending time in eight time use categories depending on working hours and socio-economic covariates that improve the fit of the model. All of the models derived demonstrate negatively correlated and highly significant effects of working hours on the time use categories. This result supports the predicted relationship between working hours and time use. A marginal increase in working hours leads to a reduction in all other time use categories outside labour, suggesting a potential for time-use rebound effects. Free time following a reduction in working hours is re-invested in the major time use categories. The greatest effects of re-allocation are visible in hobbies and child care, followed by housework, educational activities and sleep. A higher household net income leads to a significant reduction in time spent on child care

Table 10.1 Marginal propensity to time use in Germany from 2008 to 2009

	Sleep	Hobbies	Housework	Errands	Childcare	Repairs etc.	Education	In care
Job	−0.052*** (0.004)	−0.131*** (0.006)	−0.078*** (0.004)	−0.012*** (0.003)	−0.105*** (0.008)	−0.019*** (0.004)	−0.066*** (0.004)	−0.013*** (0.002)
Household net income	−0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)	−0.000 (0.000)	−0.000* (0.000)	−0.000** (0.000)	0.000 (0.000)	0.000 (0.000)
Household size	0.013 (0.028)	−0.096** (0.042)	0.007 (0.026)	−0.004 (0.020)	0.078 (0.054)	0.064** (0.025)	−0.029 (0.021)	0.029 (0.018)
With partner in hh	−0.074 (0.070)	−0.423*** (0.104)	0.008 (0.066)	−0.000 (0.051)	0.174 (0.136)	0.001 (0.062)	−0.082 (0.053)	−0.038 (0.044)
Children under 16 in hh	−0.062 (0.054)	−0.216*** (0.082)	0.104** (0.052)	−0.012 (0.040)	1.306*** (0.108)	0.018 (0.049)	−0.166*** (0.043)	−0.022 (0.035)
Schooling (in years)	0.039 (0.027)	0.087* (0.047)	−0.124*** (0.027)	−0.059*** (0.019)	−0.028 (0.057)	0.021 (0.024)	−0.505*** (0.026)	−0.005 (0.017)
Year of birth	0.001 (0.004)	−0.006 (0.007)	−0.012*** (0.004)	0.001 (0.003)	−0.040*** (0.011)	−0.029*** (0.004)	0.057*** (0.006)	−0.003 (0.003)
Male	−0.073*** (0.024)	0.303*** (0.034)	−0.890*** (0.020)	−0.139*** (0.015)	−0.695*** (0.056)	0.372*** (0.020)	0.105** (0.045)	−0.031** (0.014)
n	16,590	16,590	16,590	16,590	16,590	16,590	16,590	16,590

$^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

Note Hausman-Taylor estimates, constant suppressed, standard errors in parentheses

Data German Socio-Economic Panel v29 (waves 2008 and 2009)

Reading examples

A marginal increase of the time use for the job (one actual working hour) decreases the time use for hobbies by 0.13 (hour)

Males spend 0.3 h more for hobbies than females on an average and repairs (see negative sign of effects), suggesting that higher income levels tend to outsource these household services. Once again, family status has a major influence. In particular, if children are still living in households, the parents have less time for hobbies and leisure activities, but more time for household production, such as household chores and child care. Gender exhibits highly significant effects in all of the time use categories, suggesting a major influence of gender on time use patterns. Females spend more time on household production such as errands, household chores and child care, whereas males spend more time on leisure, doing repairs and pursuing hobbies. The roles still tend to be traditionally distributed between men and women in Germany when it comes to household production. However, this finding is consistent with Druckman et al. (2012), who reported significant differences in resource implications between men and women for the United Kingdom.

As the aggregation of time use in main time use categories like hobbies does not indicate, time savings following a reduction in working time are diversely re-invested in leisure activities. It makes sense to take a closer look at the kind of hobbies for which time is spent. People spend more time with their friends and neighbours, followed by time spent for media, TV, radio and going out, eating and sports. It is worth mentioning that spending more time on hobbies does not lead to more trips being undertaken or family and relatives being visited more often.[4]

10.2.2 Income Effects

According to both Nässén and Larsson (2015) and Knight et al. (2013), account has to be taken not only of potential time effects, but also of potential income effects following a reduction in working time. The assumption that a reduction in working time only results in a re-allocation of time use does not hold true when the reduction in working time is accompanied by a loss of income. More realistically, a relevant and voluntary reduction in working time is associated with income loss, which potentially alters the consumption patterns of such households. Households re-allocate both monetary and temporal savings. Income and time effects are most probably correlated, i.e. the change in income affects the way time is spent. In our analysis of time effects, we control for income effects, meaning that a change in time use refers exclusively to a change in working hours, and explicitly not to an associated change in income. However, we do not know exactly how consumption patterns change due to a change in income.

The cross-sectional analysis shows that a marginal rise in income is associated with greater expenditure in all consumption categories along the internationally

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[4] Since no time units are given for differentiated leisure activities in the data (GSOEP), the coefficients help us to differentiate and deal with the heterogeneous leisure activities of respondents and thus resource implications of time use (see Buhl and Acosta (2015) for a full presentation of the estimation results and respective coefficients).

harmonised Classification of Individual Consumption According to Purpose (COICOP) (see Table 10.2). Most income gains are spent on transport goods and services, followed by consumption in recreation and culture (including leisure and entertainment).

10.2.3 Time-Use Rebound Effect

The net effect of time savings and income loss following a reduction in working hours constitutes the rebound effect as described in Sect. 10.3 and noted in formula (10.13). The time-use rebound effect is basically the relation of the change in time use to the change in expenditures after a reduction in working hours. The bottom row in Fig. 10.2 shows Engel curves, presenting the relationship between a consumer's income and the goods bought. The slope of the Engel curve at any point is known as the marginal propensity to consume, and measures for a marginal change in income the ratio of the resulting change in the consumption of goods. The very same is calculated for a change in daily working hours (see top row in Fig. 10.2 and method in Sect. 10.3). Based on the concept of Engel curves and the corresponding marginal propensity to consume, we call the effect of a marginal change in working hours on time use the marginal propensity to time use. Fellner (2014) suggests to name the depiction of interdependent changes in time use T-Curves, referring to Engel curves as well.

We assume that a reduction in working hours is accompanied by a proportional drop in income. The drop in income then suggests a drop in expenditure. In contrast, a reduction in working hours leads to an increase in time use. Basically, a marginal decrease in the propensity to consume due to a loss of income is then cancelled out by a marginal increase in the propensity to time use due to time savings.

Finally, we add the triggered resource use of the marginal propensity to consume to the triggered resource use of the marginal propensity to time use. A marginal increase in time use due to a marginal decrease in working hours is responsible for a rise of 1.37 kg of resources used per hour. A marginal decrease in expenditure due to a marginal decrease in working hours is responsible for a decrease of 1.67 kg of resources used per Euro spent. In relative terms, this equals a marginal increase of 0.48 of resource use in relation to average time shares and a marginal reduction of 0.80 of resource use in relation to average expenditure shares. In other words, a marginal reduction in working hours is accompanied by a rebound effect of 59 %. Ultimately, a reduction in working hours is associated with relevant rebound effects, but still environmentally beneficial compositional effects, i.e. no backfire.

Table 10.2 Marginal propensity to consume along COICOP in Germany for 2008

	Food	Housing etc.	Transport	Clothing	Furnishing etc.	Health	Communi cation	Education	Recreation and culture	Restaurants and hotels	Miscellaneous
Income	0.030*** (41.23)	0.125*** (36.17)	0.425*** (40.18)	0.036*** (40.85)	0.081*** (19.50)	0.074*** (24.51)	0.008*** (36.62)	0.006*** (8.89)	0.120*** (24.99)	0.048*** (39.65)	0.039*** (22.61)
HH size	247.155*** (118.19)	239.581*** (36.34)	−422.542*** (23.11)	54.413*** (27.30)	−44.987*** (5.81)	−93.651*** (16.34)	26.828*** (39.57)	41.977*** (27.52)	−23.680*** (2.77)	−30.010*** (10.93)	−1.729 (0.49)
Schooling	−3.189*** (7.15)	16.069*** (12.35)	−21.346*** (8.06)	7.011*** (16.73)	−3.644*** (2.96)	−18.644*** (16.48)	9.092*** (54.79)	1.973*** (5.70)	0.870 (0.65)	7.887*** (13.27)	2.017*** (3.06)
Age	3.451*** (38.67)	12.401*** (48.40)	−15.758*** (29.90)	−1.779*** (21.65)	−1.242*** (5.54)	4.312*** (20.75)	−0.525*** (17.24)	−1.624*** (27.06)	0.767*** (3.11)	−0.928*** (7.46)	0.562*** (3.84)
Male	34.128*** (9.35)	70.001*** (6.57)	−147.478*** (7.40)	−24.972*** (7.35)	−15.950* (1.88)	14.499* (1.85)	−4.292*** (3.21)	−14.347*** (5.78)	−0.910 (0.08)	91.386*** (19.44)	−28.838*** (5.56)
R^2	0.89	0.87	0.58	0.63	0.28	0.25	0.76	0.15	0.56	0.49	0.38
n	44,088	44,088	44,088	44,088	44,088	44,088	44,088	44,088	44,088	44,088	44,088

$^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

Note OLS estimator, robust standard errors in parentheses

Data National Survey on Income and Expenditures 2008

Reading example A marginal increase in income (one Euro) increases spending on transport by 0.43 (Euro)

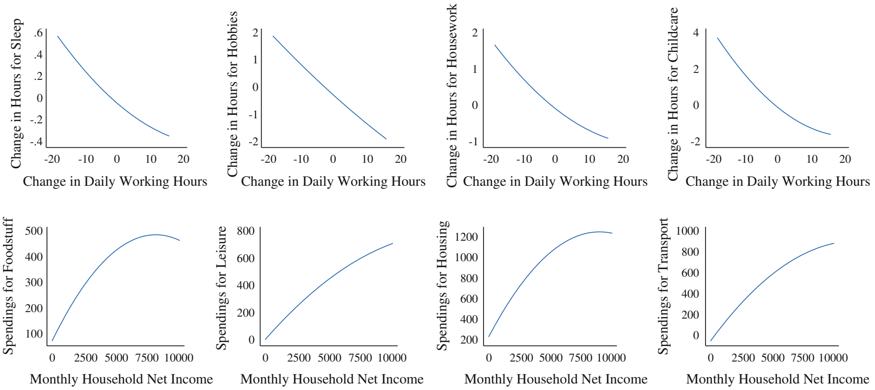

Fig. 10.2 Selection of predictions of the marginal propensity to time use (*top row*) and the marginal propensity to consume (*bottom row*). *Note* Quadratic prediction plots without confidence intervals. *Data* German Socio-Economic Panel v29, National Survey on Income and Expenditures 2008

10.3 Discussion

A comprehensive analysis across dimensions in terms of time use, expenditures and resource use naturally involves compromises and limitations. In order to integrate income and time effects, we had to rely on different data sets. In order to introduce leisure activities such as voluntary work in the stochastic analysis, we had to deal with different types of information, from ordinal to cardinal data. Leisure activities are only differentiated by frequency, not by time use. The analysis of time use is again restricted to 9 aggregated time use categories. Data on resource use is restricted to 12 main consumption categories along COICOP. For future research, consistent resource use and time use data with differentiated information, particularly about leisure activities, should be favoured. With respect to time use, we focus on everyday time use like hobbies. The national time budget surveys in Germany do not take irregular time use like vacations and longer holiday trips into account. But with respect to resource use, we take the complete resource use induced by private consumption into account and differentiate between main consumption categories like transport or leisure and recreation. On the one hand, this leads to overestimated resource use of the specific everyday time use due to overestimated resource intensities of the same. On the other hand, the unspecific data on resource use includes the rather irregular but environmentally relevant consumption like holiday trips and as such balances out the missing time use data to some extent. Still, information on both, regular, everyday time use and irregular time use would thus yield more consistent and differentiated estimates of time-use rebound effects. Furthermore, the estimation of the marginal propensity to consume relied on a cross-sectional analysis. However, a panel analysis would result in more efficient estimates of income effects, and event history data would yield more accurate results of the effects of a reduction in working time on time budget reallocations. Moreover, the identification of resource intensities is static. In the wake of relevant shifts in time use patterns, a dynamic identification of the relationship between resource use and time use to corresponding intensities would result in an appropriate dynamic interpretation of time use shifts. Changing time use for practices that merely rely on durables (such as outdoor sports) is unlikely to exhibit a proportional increase in resource use.

It is worth mentioning that the time composition effect does not take into account the overall scale effect of working time reductions as a policy. A comprehensive reduction in working time may affect overall production and resource use in addition to domestic consumption. Knight et al. (2013) argue that a combination of scale and composition effects may result in more beneficial effects of reduced working hours.

We did not differentiate between a voluntary and forced reduction in working hours, e.g. as a result of a corporate policy dealing with demand shocks. As a result, we assumed mixed motives for reducing working hours in the sample. For the analysis of rebound effects, a differentiation of motives is not essential. Working less in favour of the environment is therefore not a condition for analysing rebound effects after a reduction in working time. People opt to reduce their working time in order to gain free time, just as consumers opt for energy-efficient (product) solutions to save money (among other motives). However, an interesting strand of future research would be to differentiate rebound effects according to motives. Ultimately, the findings fail to fully provide a deeper understanding of working time reduction as an extensive policy. The findings rely on individual and rather voluntary reductions in working hours. Moreover, we assumed a proportional drop in income due to the reduction in working hours. In a progressive wage taxation system, a reduction in working hours would reduce income loss disproportionally.

Considering the shortcomings, our analysis overestimates the magnitude of time-use rebound effects. Nevertheless, the analysis suggests that time-use rebound needs to be taken into account when evaluating environmentally driven policies involving a change in the working hours regime.

10.4 Summary and Conclusions

In our study, we analysed the widely promoted benefits of reducing working time in terms of environmental aspects. The literature on working hours within the scope of degrowth policies suggests reducing working hours to tackle environmentally unfriendly consumption patterns and job-related stress, and to achieve a satisfactory work-life balance. Hence, a reduction in working hours is expected to enhance social equity by redistributing working hours to informal social engagement. We opted to analyse micro data from national surveys on income, expenditure and time use. An analysis of micro data is suitable for comprehensively understanding potential substitutions of daily practices and activities following a reduction in working hours.

We primarily analysed whether it holds true that—for the case of a rich industrialised country like Germany—a reduction in working hours leads to more low-resource activities in everyday life by applying an integrated model of time-use rebound effects. In this respect, the aim of the study was to account for both time and income effects. It is hypothesised that a gain in free time fosters a change in consumption patterns, in time use and expenditure towards more time-intensive but low-resource daily life.

A marginal estimation of the propensity to time use and to consume supports the findings that time effects may compensate for income effects to a relevant extent due to a reduction in working hours. The composition effect reveals relevant time-use rebound effects. The respondents reported shifts in time use in favour of hobbies, media consumption, going out as well as active sports. In addition and more strikingly, time use is re-allocated in favour of caring activities and household production, supporting the hypotheses that hours of paid work were substituted by informal work. The analysis revealed that a reduction in working hours leads to more informal work, care and intensified social relationships with friends and neighbours. However, taking leisure substitutions into account, the substitutions are in sum rather ambiguous from an environmental point of view. Substitutions in favour of resource-intensive hobbies and sports may lead to relevant time-use rebound effects in terms of the use of resources. Overall, the analysis showed that the environmental implications are not as clearly beneficial as expected when time-use rebound effects are taken into consideration. The analysis revealed environmentally ambiguous effects due to time-use rebound effects. Shifts in time use are still associated with resource-intensive consumption patterns. Nonetheless, in spite of non-trivial rebound effects, substitutions result in environmentally beneficial net effects due to reduced working hours.

The analysis shows that a reduction in working time could have positive effects on the environment. More time is typically spent pursuing leisure activities and in favour of informal work and social engagement, which is indeed associated with a triple dividend–low-resource, socially beneficial and individually satisfying activities. The effects suggested that a "smart" recomposition of time use may be associated with greater life satisfaction (see Knabe et al. 2010; Dunn and Norton 2013 on the subject and Buhl and Acosta 2016 for a detailed analysis). The co-benefits of rebound effects are an increase in life satisfaction since people have more time for their hobbies and leisure activities. More importantly, a reduction in working hours results in increasing social engagement (again, the detailed analysis can be found in Buhl and Acosta 2016). In this regard, the paper found evidence suggesting that it led to a more "amateur economy" (Nørgård 2013). Time-use rebound effects show that even amateurs are unlikely to live idly.

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revised according to helpful suggestions from the editors. The theoretical background on social acceleration and time-use rebound effects has been largely extended. The method and model to estimate time and income effects is given in full detail in the text. The empirical results have been extended by presenting historical trends of time use in Germany. The discussion of strengths and weaknesses of the underlying method and data has been elaborated to great extent as well.

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Chapter 11
Urban Planning: Residential Location and Compensatory Behaviour in Three Scandinavian Cities

Petter Næss

Abstract Within the literature on sustainable urban development, the dominant view is that dense and concentrated cities produce lower environmental strain than do sprawling and land-consuming cities. But is there a danger that environmentally favourable urban planning solutions will be counteracted by oppositely working mechanisms? In the literature, two partly related main types of such effects have been particularly discussed: (1) A greater amount of leisure travel (including flights) when people save money and time from living in an urban context that does not require much daily-life travel; and (2) increased vacation home ownership and use as a compensation for dense daily living environments. These counteracting mechanisms include genuine rebound effects as well as compensatory effects resulting from perceived unsatisfactory characteristics of ‘eco-efficient’ residential environments. In practice, the demarcation between rebound effects and compensatory mechanisms resulting from ecological modernization strategies in urban planning is often blurred. This chapter draws on research carried out by the author in Norwegian and Danish cities and compares this against international literature on the topic. The paper concludes that rebound effects exist, counteracting to some extent the effects of resource-saving principles in urban planning. Avoiding such effects seems impossible unless the purchasing power decreases. The existence of rebound effects should, however, not prevent us from seeking to develop our cities in as environmentally friendly ways as possible.

Keywords Residential location · Daily travel · Long leisure trips · Compensatory travel · Compact city · Rebound

Since the concept of sustainable development entered the international political agenda with the UN publication ‘Our Common Future’ in 1987, a large amount of research has been addressing the topic of sustainable urban development. The currently dominant understanding of urban sustainability as well as sustainable

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P. Næss (✉)
Norwegian University of Life Sciences, Ås, Oslo, Norway
e-mail: petter.nass@nmbu.no

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development in general is confined within the paradigm of ecological modernization, according to which environmental sustainability can (and should) be achieved without abstaining from continual economic growth. The key to making this possible is an assumed decoupling of growth in production and consumption from negative environmental consequences through more efficient resource use and cleaner technologies (often referred to as increasing eco-efficiency).

For urban development, the challenge of decoupling lies in finding ways to accommodate growth in the building stock and ensuring accessibility to facilities while reducing negative environmental impacts resulting from the construction and use of buildings and infrastructure. Within the literature on urban sustainability, dense and concentrated cities are predominantly considered to produce lower environmental strain than do sprawling and land-consuming cities (CEC 1990; Jenks et al. 1996; Newman and Kenworthy 1999; Næss 2001).

However, critics have argued that environmentally favourable urban planning solutions run the risk of being counteracted by oppositely working mechanisms resulting from the same solutions. In the literature on sustainable urban development, such effects are often referred to as compensatory behaviour (e.g. Kennedy 1995; Holden and Norland 2005), referring to a wish to compensate for perceived negative side effects of the new eco-efficient solutions. The term ‘rebound effects’ is less frequently used about such counteracting mechanisms, although some of the mechanisms referred to might actually belong to this category (Vilhelmson 1990). Here, rebound effects are understood as reductions in expected gains from new technologies that increase the efficiency of resource use, cf. earlier chapters in this volume. In practice, the demarcation between rebound effects and compensatory mechanisms resulting from ecological modernization strategies in urban planning is often blurred. This chapter will therefore deal with both rebound effects and compensatory mechanisms, yet with the main emphasis on the former.

In the literature on urban sustainability, rebound effects and compensatory mechanisms have mainly been discussed in terms of environmentally undesirable effects of residential location strategies otherwise considered to minimize energy use, greenhouse gas emissions and land consumption. The purpose of this chapter is to illuminate the extent to which such effects can actually be found in a Scandinavian urban context.

The main hypothesized rebound effect is a greater amount of leisure travel (including flights) when people save money and time from living in an urban context that does not require much daily-life travel (Vilhelmson 1990; Schafer and Victor 1997). The assumed mechanism is that the time and money people save by travelling shorter distances to daily and weekly, ‘bounded’ destinations result in an accumulated ‘surplus’ of time and money providing an opportunity for longer leisure trips.

In addition comes a plausible indirect rebound effect resulting from lower public and private expenses on infrastructure and buildings in dense cities due to more resource-efficient spatial organization. The surplus thus saved can be spent on environmentally harmful consumption and investments. This latter type of rebound effect will not be addressed empirically in this chapter.

The main compensatory mechanisms mentioned in the urban sustainability literature stem from a wish to escape from the eco-efficient urban environment because of perceived negative side effects of these environments. People who are dissatisfied with their dwelling and its surroundings will, it is assumed, spend a large proportion of their leisure time elsewhere. Notably, residents of dense urban areas are believed to be, so to speak, ‘forced’ for psychological reasons to make leisure trips in order to compensate for lack of nature in their residential environments. Increased use and ownership of second homes may be also part of this effect. (Kaiser 1993; Kennedy 1995; Berg 1996; Holden and Norland 2005).

As mentioned above, the demarcation between rebound and compensatory effects is blurred. In debates about ways to ‘decouple’ economic growth from environmental degradation, eco-efficiency increase and substitution are often referred to as the main strategies. While the former concept means ‘getting more from less’, i.e. reducing the resource input and environmental impact per unit produced, substitution refers to a change of consumption pattern from environmentally harmful to less environmentally harmful product categories (e.g. spending money on culture instead of material consumption). Whereas an inner-city apartment is clearly a more eco-efficient type of residence than a detached single-family house in a car-dependent suburb, many people would say that a flat in an apartment building is a completely different ‘product’ from a detached house. A sustainability strategy of replacing the building of detached suburban houses with the erection of inner-city apartment buildings could thus be seen as a form of substitution rather than as a technological eco-efficiency improvement. Increased consumption on other items resulting from such substitution (which could in some sense also be considered as a ‘sufficiency’ practice’) would then not be rebound effects in a strict sense. Moreover, the effects themselves may be difficult to categorize distinctly as either compensatory or rebound. For example, increased leisure travel among inner-city apartment dwellers might result from money saved due to low need for car ownership and daily-life motorized travel, but it could alternatively be due to a wish to escape from a daily neighbourhood with little greenery. In practice, the effect could be a combination, where a rebound effect made the increased leisure travel possible while a compensatory effect accounted for its motivation.

Some previous research has attempted to illuminate the above-mentioned possible mechanisms. Comparing families with children living in the downtown area of the Swedish city of Gävle (68,000 inhabitants), a small urban settlement (3000 inhabitants) and a rural village in the same region, Tillberg (2001) found the longest leisure trips by car during the weekend among the inner-city residents and the shortest ones in the small urban settlement. However, over the whole week, the distance travelled by car on leisure trips was practically the same in inner-city Gävle and the small urban settlement, and the rural village residents travelled consider ably further. Total travel distances were considerably longer in the rural village and shortest in the inner city, with the small urban settlement in-between. Schlich and Axhausen (2002) have compared travel behaviour between residents of inner-city Zurich and two peripheral suburbs. They found more frequent trips to leisure activities away from home both among downtown dwellers and among the inhabitants of a traffic-exposed suburb, compared with those in a suburb not exposed to traffic nuisances. However, the overall distance travelled in connection with leisure activities was shortest when living in the inner city. Some other studies have found the frequency of flights to be higher among respondents living close to the city centre, also when demographic, socioeconomic and attitudinal variables are taken into account. Such a tendency was found in the metropolitan areas of Copenhagen (Næss 2006a), Oslo (Holden and Norland 2005) and the Danish city of Aalborg (Nielsen 2002), but not in the little Danish town of Frederikshavn (Næss and Jensen 2004).

This chapter focuses on the possible counteracting effects of living in dense inner-city urban settings in terms of leisure travel and second home ownership and use. Will inner-city residents carry out more and longer leisure trips reducing or counteracting the environmental gains of low daily-life motorized travel? And will they increase their ownership and use of second homes, with the additional land consumption and transportation resulting from a multi-home lifestyle? The chapter draws on research carried out by the author in Norwegian and Danish cities, especially two studies of residential location and travel in the metropolitan areas of Copenhagen (Næss 2006a) and Oslo and Stavanger (the latter an on-going study, cf. Næss 2015a).

Copenhagen and Oslo (with populations within their continuous urban areas of 1.3 million and 0.96 million, respectively) are interesting cases as both cities and city regions have expressed high sustainability ambitions and have for a long time had a focus on land use planning that can reduce the need for car travel. Especially Oslo has for several decades pursued (and is still pursuing) a quite consistent urban containment policy, with a population density increase within the continuous urbanized land of 29 % over the period 1985–2011 (Næss et al. 2011a, b; Næss 2014). Copenhagen metropolitan area has for several decades pursued a policy of channelling urban development to areas adjacent to urban rail stations and has since a decade ago revitalized its famous Finger Plan in order to prevent urban development outside the main public transport corridors (Næss et al. 2011a, b), combined with considerable recent densification in the central parts of Copenhagen. Distinct from Copenhagen and Oslo, Stavanger metropolitan area is a population-wise smaller and more polycentric urban region consisting of the two previously separate cities of Stavanger and Sandnes and with a large employment centre developed in the 1980s and 1990s situated in-between. The continuous urban area of Stavanger-Sandnes has about 210,000 inhabitants. The historical centre of Stavanger is still the dominant centre of the region.

In the next section, the methods of the studies will be briefly outlined. Thereupon, the ‘baseline’ eco-efficient urban spatial characteristics that might give rise to rebound effects will be presented, with a focus on impacts of residential location on weekday travel and land consumption in each of the three cases. In the subsequent sections, the occurrence and importance of the following potential rebound effects will be discussed: Travel by car in the weekend, long-distance non-work trips, private flights, and second-home access and use. After a discussion of the empirical findings, some brief concluding remarks round off the chapter.

11.1 Methods of the Three Case Studies

The two research studies providing the main empirical input of this paper show clear methodological similarities, following a mixed methods research design sometimes referred to as ‘The Explanatory Qualitative-Quantitative Method’ (Næss 2015b). So far, this approach has been applied and gradually developed further in studies of residential location and travel in the cities/urban regions of Frederikshavn, Copenhagen, Hangzhou, Oporto and most lately Oslo and Stavanger. Distinct from mainstream rebound studies, which tend to concentrate on aggregated data, our approach focuses on the individual actions underlying any aggregate-scale patterns characterized as rebound effects. An important strength of this research design is its better ability to identify causal mechanisms than in studies relying on the comparison of macro data at a national or regional scale. This is especially so because the qualitative interviews provide insight into the backgrounds, motivations and justifications that agents draw on when they make transport-relevant decisions about their participation in activities, location of these activities, modes of transportation and the routes followed. These transport rationales make up important links in the mechanisms by which urban structures influence travel behaviour (Næss 2005, 2013).

The Copenhagen Metropolitan Area study included 17 qualitative interviews with residents living in five different (inner-city and suburban) neighbourhoods, a questionnaire survey comprising 1932 respondents from 29 selected residential neighbourhoods, and a travel diary follow-up survey completed by 273 of the respondents of the first survey. Since data collection in 2001, different aspects of the results have been published in journal articles and books over the subsequent years (see, for example, Næss 2005, 2006b, 2009), including one article addressing particularly the issue of ‘compensatory leisure travel’ (Næss 2006a). The data collection of the Oslo and Stavanger studies took place in the summer of 2015, and only parts of this material have so far been analysed. Altogether, 33 qualitative interviews were carried out, 17 of which in the Oslo area and 16 in the Stavanger area. Around 3400 persons fully or partially completed the common questionnaire for the two cases. The gross samples were drawn randomly among inhabitants living within broadly defined distance belts around the centres of Oslo, Stavanger and Sandnes, respectively, supplemented with inhabitants of new housing projects in each city region identified by main developers and realtors. Some respondents turned out to have moved away from the case regions and were therefore excluded. The samples used in the analyses consisted of 1992 persons in the Oslo case and 1373 in the Stavanger case, totalling 3365.

In each of the three city cases, the interviews, each lasting for 1–1.5 h, were audio recorded and transcribed. Due to missing answers to some questions, the survey material used in subsequent multivariate analyses includes a lower number of respondents than the number of returned questionnaires. More details about the methods of each study can be found in the publications cited above and in forthcoming articles on residential location and travel based on the Oslo and Stavanger studies. The purpose of the present paper is not to once again present the methodology and bring the main results of these studies, but instead to highlight some aspects that can help shedding light on any rebound effects of transport-reducing residential location.

11.2 Residential Location: Impacts on Daily-Life Travel Behaviour and Land Consumption

Apart from various environmental impacts of residential location in the form of travel (see below), land consumption is another important part of the ecological footprint of housing development. There are clear centre-periphery gradients in land consumption per capita in all the three city cases, with lower land consumption in the inner than in the outer parts (Table 11.1).

The smaller difference between inner city and suburb in Stavanger than in the two other city regions must be seen in the light of the smaller population size of the former city. Its dense inner city therefore covers only a part of the distance belt within the 5 km range from the centre.

A number of studies have found that energy consumption and CO_2 emissions from transportation decrease with higher density for the city as a whole (Newman and Kenworthy 1999; Næss 1993; Næss et al. 1996; Lefévre 2010). An even higher number of studies have found that suburbanites tend to travel longer distances for daily-life purposes than their inner-city counterparts and carry out a higher proportion of their travel by motorized modes, especially the private car (see Næss 2012 for an overview). This tendency is also evident in our three case cities. Focusing on travel by car over the weekdays from Monday to Friday, Fig. 11.1 shows that residents of the outer suburbs of each metropolitan area travel 2–3 times longer distances by car than those living close to the main city centre. In this figure as well as in the figures presented later in the paper, the respondents have been divided into groups according to the distance from their dwelling to the centre of each city region, with approximately similar numbers of respondents in each distance belt. Since there is considerable difference in car travel distances between those living in the innermost parts of the inner distance belt and those living four or five kilometres away from the city centre, the actual differences in car travel between central and peripheral locations are even larger than what can be seen in the graphs.

Table 11.1 Approximate[a] land consumption (m^2) per inhabitant in the local areas of respondents living within different distance belts from the city centres of Oslo and Copenhagen

Oslo, 2015				Stavanger, 2015				Copenhagen, 2001			
0–6 km	6–13 km	13–22 km	Over 22 km	0–5 km	5–9 km	9–15 km	Over 15 km	0–6 km	6–15 km	15–28 km	Over 28 km
62	154	190	247	147	194	204	230	58	131	286	317

[a] Land consumption in Oslo and Stavanger-Sandnes measured per inhabitant within the 100 × 100 m grid unit within which the residence is located; in Copenhagen within the demarcation of the specific residential area

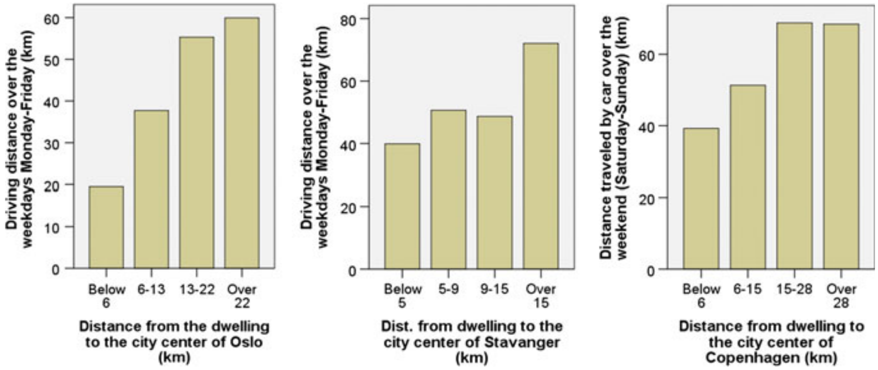

Fig. 11.1 Distances travelled as car driver (Great Oslo, to the *left*, and Stavanger, in the *middle*) and as car driver or passenger (Greater Copenhagen, to the *right*) over the five weekdays (Monday–Friday) among respondents living within different distance belts from the main city centre of each metropolitan area. $N = 1654$ (Oslo), 1132 (Stavanger) and 1798 (Copenhagen)

Needless to say, the amount of car travel on weekdays is influenced not only by the location of the dwelling. A number of individual characteristics also play a role (together with the general economic, social, political and cultural conditions of a society). However, after conducting statistical control for a range of socioeconomic and demographic factors,[1] residential location stands out with considerable influences on car travel. In all the three city regions, the distance from the dwelling to the main city centre is the residential location variable showing the strongest influence (Beta values of 0.324, 0.232 and 0.166, respectively, in the Oslo, Stavanger and Copenhagen case, $p = 0.000$ in all cases). In Oslo and Stavanger, these effects are also stronger than the effects of any of the demographic and socioeconomic variables. Like proximity to the main centre, living at a short distance from the closest second-order centre also contributes to reduce car driving, but with smaller effects than those of the distance to the main centre (Beta values for Oslo, Stavanger and Copenhagen of 0.059, 0.121 and 0.080, respectively). The stronger effect of the distance to second-order centre in Stavanger reflects the more polycentric structure of this urban region. The distance from the residence to the closest local centre shows generally weaker and more uncertain effects, especially in Stavanger (Beta values for the three respective city regions of 0.047, 0.017 and 0.065).

For most travel purposes, people do not necessarily choose the closest facility, but rather they travel a bit further if they can then find a better facility. This is especially true as regards workplaces. Travel distances therefore depend more on the location of the dwelling relative to large concentrations of facilities than on the distance to the closest facilities. People who live close to the city centre have a large

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[1] Age, gender, workforce participation, income, education level, and number of children in the household aged below 7 and 7–17.

number of facilities within a short distance from the dwelling and therefore do not have to travel long, even if they are very selective as to the quality of the facility. Since travel distances are often short, inner-city residents also carry out a higher proportion of trips by bike or on foot.

In all the city cases, similar patterns as for car travel were also found for total weekday travel distances and commuting distances. Travel by non-motorized modes showed the opposite tendency, with longer walking and biking distances travelled by inner-city residents than suburbanites, and a much higher share of the total travel distance accounted for by these modes. Furthermore, distances travelled for a number of non-work daily-life purposes tended to be considerably shorter when living in a central part of the metropolitan area. Both in Greater Oslo and in the Stavanger-Sandnes area, residents living in central areas tend to travel shorter distances than their more peripherally residing counterparts to reach places for entertainment and culture, restaurants or cafes, grocery stores, sites for physical exercise, private services such as banks or hairdressers, libraries and religious buildings. The same applies to the distances travelled to places where passengers are picked up or dropped off. Proximity to the main city centre, the closest second-order centre as well as to a local centre contributes to reduce the above-mentioned trip distances. Inner-city dwellers, who usually live close to the main city centre as well as several local centres, therefore tend to travel considerably less than suburban residents for intra-metropolitan leisure and other non-work activities.

As shown above, the direct environmental and climate benefits of dense urban development are evident—but what about counteracting rebound and compensatory effects?

11.3 Weekend Driving

The Copenhagen interviews conducted in 2001 showed some examples of mechanisms that might lead to less weekend travel when living in a low-density residential environment. These mechanisms must be considered ‘compensatory’ rather than rebound effects in a resource efficiency sense. The following statement by an interviewee who had moved from an apartment to a row house with garden is illustrative:

> When we lived in a flat, then we were much more out. Then we went to Klampenborg [an area with a park in a northern suburb] and to the seaside… after we have got a [row] house, … we aren’t so much out because we haven’t such a [need], the children can play out in the street and they have their playmates and they have grown bigger and we have the garden, haven’t we. … [When we lived in a flat,] we were almost out every weekend for some activity (female support educator, 47 years old, living in an old row house close to the city centre of Copenhagen).

This mechanism is, however, countered by other mechanisms. The quantitative material of the Copenhagen study indicates that inner-city dwellers travel longer

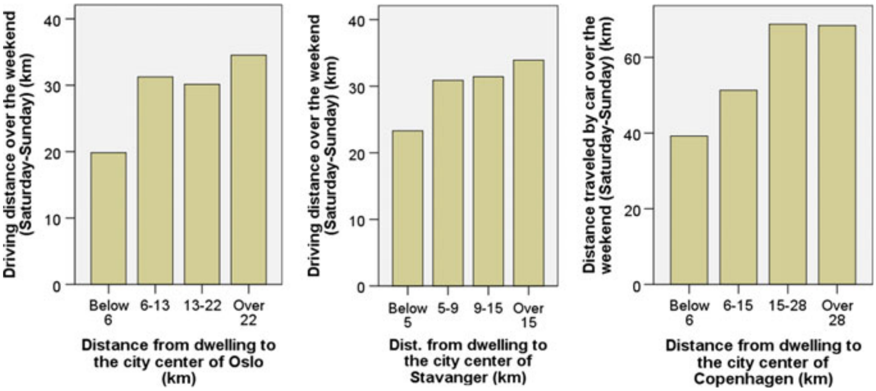

Fig. 11.2 Distances travelled as car driver (Greater Oslo, to the *left*, and Stavanger-Sandnes, in the *middle*) and as car driver or passenger (Greater Copenhagen, to the *right*) over the weekend (Saturday–Sunday) among respondents living within different distance belts from the main city centre of each metropolitan area. *N* = 1654 (Oslo), 1132 (Stavanger) and 1798 (Copenhagen)

distances to reach recreational forests and shores but visit such areas less often than their suburban counterparts. Moreover, trips to green areas are not the only, or dominant, part of leisure travel. Many of the out-of-home leisure activities that people engage in take place in typical urban settings, cf. above.

Total travelling distances during the weekend are therefore considerably longer among suburbanites than among those living close to the city centre. This is especially so for car travel, since suburbanites are more frequent car users than inner-city dwellers. In line with this, Fig. 11.2 shows how the distances travelled by car during the weekend are considerably longer among residents living in the peripheral than in the central parts of the metropolitan areas of Oslo, Stavanger as well as Copenhagen.

This holds true also when taking into consideration the influences of a number of socioeconomic and demographic characteristics of the respondents (Table 11.2). The absolute values of the standardized regression coefficients, shown in bold italics, indicate the relative strength of each variable. High income, being male, high age, small children in the household, a high education level and workforce participation all show effects in terms of increased weekend driving distances in one or more of the three case regions. The location of the dwelling relative to the main city centre is, however, the variable showing on average the strongest influence (measured by the standardized regression coefficients) across the three case regions, with strong and statistically significant effects in each city region. In Stavanger and Copenhagen, there are also tendencies of more weekend car travel when living far away from the closest second-order centre, but these effects are weaker and statistically significant only in Stavanger.

Table 11.2 Factors influencing the logarithm of the driving distance[a] over the weekend (Saturday–Sunday) among respondents in the metropolitan areas of Oslo and Copenhagen

	Unstandardized coefficients (above), standardized coefficients (below, bold italics)			Level of significance (p values), T values in parentheses		
Metropolitan area and year of investigation	Oslo 2015	Stavanger 2015	Copenhagen 2001	Oslo 2015	Stavanger 2015	Copenhagen 2001
Residential location variables						
Logarithm of the distance (in km) to the main city centre	0.836 ***0.280***	0.554 ***0.202***	0.357 ***0.179***	0.000 (10.63)	0.000 (5.96)	0.000 (5.00)
Logarithm of the distance (in km) to the closest second-order centre	0.063 ***0.024***	0.230 ***0.085***	0.153 ***0.064***	0.317 (1.00)	0.010 (2.57)	0.080 (1.75)
Logarithm of the distance (in km) from the dwelling to closest local centre[b]	0.089 ***0.027***	−0.002 **−0.001**	0.045 ***0.029***	0.275 (1.09)	0.985 (−0.02)	0.358 (0.92)
Control variables[c]						
Personal annual income (in Oslo and Stavanger measured in classes of income; in Copenhagen measured in 1000 DKK)	0.301 ***0.265***	0.234 ***0.256***	0.001 ***0.164***	0.000 (7.81)	0.000 (5.89)	0.000 (5.56)
Gender (female = 1, male = 0)	−0.532 ***−0.101***	−0.425 ***−0.098***	−0.280 ***−0.069***	0.000 (−4.26)	0.000 (−3.15)	0.007 (−2.68)
Age	0.025 ***0.158***	0.015 ***0.110***	0.004 ***0.027***	0.000 (5.61)	0.001 (3.30)	0.385 (0.868)
Number of household members below 7 years	0.394 ***0.086***	0.197 ***0.053***	0.281 ***0.078***	0.000 (3.62)	0.076 (1.78)	0.004 (2.90)
Workforce participation	0.291 ***0.051***	0.471 ***0.096***	0.248 ***0.052***	0.097 (1.66)	0.010 (2.58)	0.081 (1.74)
Education level (in Oslo and Stavanger 5-level scale; in Copenhagen 2-level scale)	−0.050 ***−0.024***	0.087 ***0.053***	0.056 ***0.012***	0.357 (−0.92)	0.112 (1.59)	0.424 (0.800)

(continued)

Table 11.2 (continued)

	Unstandardized coefficients (above), standardized coefficients (below, bold italics)			Level of significance (p values), T values in parentheses		
Metropolitan area and year of investigation	Oslo 2015	Stavanger 2015	Copenhagen 2001	Oslo 2015	Stavanger 2015	Copenhagen 2001
Number of household members aged 7–17	0.118 ***0.032***	0.015 ***0.006***	0.047 ***0.021***	0.501 (0.67)	0.843 (0.20)	0.670 (0.43)
Constant	48.53	28.25	−3.00	0.000 (5.40)	0.001 (3.22)	0.000 (-5.13)

Oslo: $N = 1516$, Adj. $R^2 = 0.258$; Stavanger: $N = 1000$, Adj. $R^2 = 0.193$; Copenhagen; $N = 1436$, Adj. $R^2 = 0.117$

[a] In the Oslo and Stavanger studies, the variable includes only travel as car driver. In the Copenhagen study, distance travelled as car driver as well as car passenger is included

[b] In the Copenhagen study defined as the closest S-train station

[c] In the original analyses, possession of driver's license for car, and whether or not the respondent has moved to the present dwelling less than 2 years ago (Oslo and Stavanger) or 5 years ago (Copenhagen) were included among the control variables. Since none of these variables showed significant effects while at the same time a considerable number of respondents had missing values for these variables, they were omitted in the final analyses in order to keep the number of respondents included in the analyses as high as possible

Table 11.3 Factors influencing the frequency of long-distance trips[a] over the last month among respondents in the metropolitan areas of Oslo, Stavanger and Copenhagen

	Unstandardized coefficients (above), standardized coefficients (below, bold italics)			Level of significance (p values), T values in parentheses		
Metropolitan area and year of investigation	Oslo 2015	Stavanger 2015	Copenhagen 2001	Oslo 2015	Stavanger 2015	Copenhagen 2001
Residential location variables						
Logarithm of the distance (in km) to the closest second-order centre	0.065 ***0.041***	0.076 ***0.040***	−0.070	0.130 (1.52)	0.254 (1.14)	0.563 (0.34)
Logarithm of the distance (in km) to the main city centre	0.019 ***0.010***	−0.001 ***-0.001***	−0.077	0.726 (0.35)	0.987 (−0.02)	0.425 (0.64)
Logarithm of the distance (in km) from the dwelling to closest local centre[b]	0.007 ***0.003***	0.001 ***0.001***	−0.024	0.904 (0.12)	0.984 (0.02)	0.732 (0.12)
Control variables[c]						
Personal annual income (in Copenhagen: measured in 1000 DKK, in Oslo measured in classes of income)	0.104 ***0.152***	0.115 ***0.182***	0.0015	0.000 (3.98)	0.000 (3.93)	0.000 (21.50)
Number of household members below 7 years	−0.146 ***−0.053***	−0.249 ***−0.097***	0.094	0.050 (−1.96)	0.003 (−3.02)	0.467 (0.53)
Number of household members aged 7–17	0.014 ***0.006***	0.031 ***0.017***	−0.296	0.813 (−0.24)	0.580 (0.55)	0.008 (7.05)
Education level (in Oslo and Stavanger 5-level scale; in Copenhagen 2-level scale)	0.000 ***0.000***	0.010 ***0.008***	0.329	0.996 (0.01)	0.812 (0.24)	0.032 (4.63)
Age	−0.005 ***−0.052***	−0.009 ***−0.098***	0.013	0.102 (1.64)	0.007 (2.70)	0.043 (4.09)
Gender (female = 1, male = 0)	−0.005 ***−0.001***	−0.019 ***−0.006***	−0.249	0.957 (−0.05)	0.849 (−0.19)	0.087 (2.93)

(continued)

Table 11.3 (continued)

	Unstandardized coefficients (above), standardized coefficients (below, bold italics)			Level of significance (p values), T values in parentheses		
Metropolitan area and year of investigation	Oslo 2015	Stavanger 2015	Copenhagen 2001	Oslo 2015	Stavanger 2015	Copenhagen 2001
Workforce participation	−0.149 ***−0.043***	−0.157 ***−0.046***	0.257	0.211 (−1.25)	0.248 (−1.16)	0.216 (1.53)
Constant	−8.06	−16.12	−1.497	0.188 (−1.32)	0.015 (2.45)	0.113 (2.51)

Oslo: N = 1581, Adj. R^2 = 0.013; Stavanger: N = 1059, Adj. R^2 = 0.022; Copenhagen; N = 1531, Nagelkerke R^2 = 0.074

[a] In the Oslo and Stavanger study, the variable refers to the number of trips to destinations further than 100 km from the dwelling during the last month. In the Copenhagen study, the variable refers to whether or not the respondent made any trips to destinations outside the island of Zealand during the last week. Commuting trips and official trips are not included in any of the cases

[b] In the Copenhagen study defined as the closest S-train station

[c] In the original analyses, possession of driver's license for car, and whether or not the respondent has moved to the present dwelling less than 2 years ago (Oslo and Stavanger) or 5 years ago (Copenhagen) were included among the control variables. Since none of these variables showed significant effects while at the same time a considerable number of respondents had missing values for these variables, they were omitted in the final analyses in order to keep the number of respondents included in the analyses as high as possible

Table 11.4 Factors influencing the number of private flights (Oslo case) and flight-based holiday trips (Copenhagen case) over the last twelve months among respondents in the metropolitan areas of Oslo and Copenhagen

	Unstandardized coefficients (above), standardized coefficients (below, bold italics)			Level of significance (p values), T values in parentheses		
Metropolitan area and year of investigation	Oslo 2015	Stavanger 2015	Copenhagen 2001	Oslo 2015	Stavanger 2015	Copenhagen 2001
Residential location variables						
Logarithm of the distance (in km) to the main city centre	−0.289 ***−0.123***	−0.270 ***−0.099***	−0.118 ***−0.139***	0.000 (−4.01)	0.006 (−2.75)	0.000 (−3.82)
Housing type (single-family house = 1, other = 0)	0.104 ***0.024***	0.314 ***0.073***	0.061 ***0.035***	0.409 (0.83)	0.023 (2.28)	0.217 (1.24)
Logarithm of the distance (in km) to the closest second-order centre	−0.094 ***−0.046***	−0.088 ***−0.033***	0.034 ***0.033***	0.088 (−1.71)	0.344 (−0.95)	0.351 (0.93)
Logarithm of the distance (in km) to closest local centre[a]	−0.011 ***−0.004***	0.029 ***0.010***	0.019 ***0.028***	0.879 (−0.15)	0.742 (0.33)	0.355 (0.93)
Control variables[b]						
Personal annual income (in Oslo and Stavanger measured in classes of income; in Copenhagen measured in 1000 DKK)	0.225 ***0.250***	0.251 ***0.278***	0.001 ***0.245***	0.000 (6.69)	0.000 (6.08)	0.000 (8.54)
Number of household members below 7 years	−0.504 ***−0.140***	−0.535 ***−0.147***	−0.243 ***−0.159***	0.000 (−5.30)	0.000 (−4.64)	0.000 (−6.05)
Number of household members aged 7–17	−0.277 ***−0.097***	−0.278 ***−0.108***	−0.140 ***−0.120***	0.000 (−3.69)	0.001 (−3.40)	0.000 (−4.77)
Gender (female = 1, male = 0)	0.471 ***0.114***	0.435 ***0.102***	0.122 ***0.071***	0.000 (4.31)	0.002 (3.08)	0.005 (2.82)
Age	−0.024 ***−0.149***	−0.019 ***−0.143***	−0.003 ***−0.049***	0.000 (−6.18)	0.000 (3.98)	0.110 (−1.60)

(continued)

Table 11.4 (continued)

	Unstandardized coefficients (above), standardized coefficients (below, bold italics)			Level of significance (p values), T values in parentheses		
Metropolitan area and year of investigation	Oslo 2015	Stavanger 2015	Copenhagen 2001	Oslo 2015	Stavanger 2015	Copenhagen 2001
Education level (in Oslo and Stavanger 5-level scale; in Copenhagen 2-level scale)	0.050 ***0.031***	0.076 ***0.046***	0.161 ***0.093***	0.284 (1.07)	0.183 (1.33)	0.000 (3.52)
Workforce participation	−0.294 ***−0.065***	−0.062 ***−0.013***	0.038 ***0.019***	0.054 (−1.93)	0.747 (−0.32)	0.513 (0.66)
Constant	−45.16	−35.00	1.148	0.000 (−5.76)	0.000 (−3.71)	0.000 (4.47)

Oslo: $N = 1512$, Adj. $R^2 = 0.091$; Stavanger: $N = 1027$, Adj. $R^2 = 0.089$; Copenhagen; $N = 1542$, Adj. $R^2 = 0.112$

[a] In the Copenhagen study defined as the closest S-train station

[b] In the original analyses, possession of driver's license for car, and whether or not the respondent has moved to the present dwelling less than 2 years ago (Oslo and Stavanger) or 5 years ago (Copenhagen) were included among the control variables. Since none of these variables showed significant effects while at the same time a considerable number of respondents had missing values for these variables, they were omitted in the final analyses in order to keep the number of respondents included in the analyses as high as possible

Table 11.5 Factors influencing the number of visits to secondary home(s) over the last twelve months among respondents in the metropolitan areas of Oslo ($N = 1512$, Adj. $R^2 = 0.055$) and Stavanger ($N = 1027$, Adj. $R^2 = 0.073$)

	Unstandardized coefficients (above), standardized coefficients (below, bold italics)		Level of significance (*p* values), *T* values in parentheses	
Metropolitan area and year of investigation	Oslo 2015	Stavanger 2015	Oslo 2015	Stavanger 2015
Residential location variables				
Logarithm of the distance (in km) to the main city centre	−0.093 ***−0.007***	−2.414 ***−0.126***	0.830 (−0.22)	0.001 (−3.44)
Logarithm of the distance (in km) to the closest second-order centre	0.944 ***0.079***	−1.061 ***−0.056***	0.004 (2.89)	0.111 (−1.60)
Housing type (single-family house = 1, other = 0)	0.322 ***0.012***	2.653 ***0.088***	0.668 (0.43)	0.007 (2.70)
Logarithm of the distance (in km) from the dwelling to closest local centre	0.888 ***0.057***	−0.115 ***−0.006***	0.038 (2.07)	0.854 (−0.19)
Control variables[a]				
Age	0.088 ***0.118***	0.199 ***0.212***	0.000 (3.72)	0.000 (5.86)
Personal annual income (measured in classes of income)	0.899 ***0.171***	0.497 ***0.078***	0.000 (4.48)	0.092 (1.69)
Workforce participation	−2.327 ***−0.088***	−0.776 ***−0.022***	0.011 (−2.56)	0.569 (−0.57)
Number of household members below 7 years	−1.210 ***−0.057***	0.650 ***0.025***	0.033 (−2.13)	0.429 (0.79)
Gender (female = 1, male = 0)	1.325 ***0.055***	−1.245 ***−0.041***	0.042 (2.03)	0.217 (−1.24)
Education level (5-level scale)	−0.180 ***−0.019***	−0.708 ***−0.061***	0.520 (−0.64)	0.083 (−1.74)
Number of household members aged 7–17	−0.243 ***−0.015***	0.393 ***0.022***	0.587 (−0.54)	0.500 (0.68)
Constant	172.9	461.8	0.000 (3.69)	0.000 (5.99)

[a] In the original analyses, possession of driver's license for car, and whether or not the respondent has moved to the present dwelling less than 2 years ago were included among the control variables. Since none of these variables showed significant effects while at the same time a considerable number of respondents had missing values for these variables, they were omitted in the final analyses in order to keep the number of respondents included in the analyses as high as possible

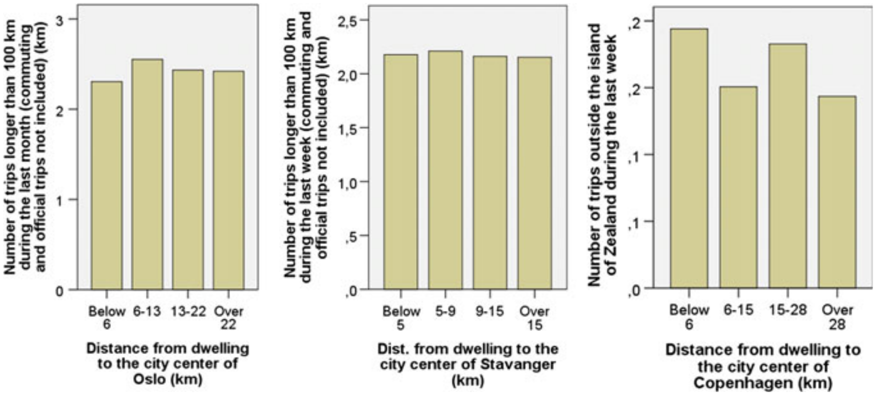

Fig. 11.3 Number of long-distance trips over the last month among respondents living within different distance belts from the city centres of Greater Oslo (to the *left*), Stavanger (in the *middle*) and Greater Copenhagen (to the *right*). Long-distance trips are defined as trips to destinations further than 100 km from the dwelling in the Oslo and Stavanger cases and as trips to destinations outside the island of Zealand in the Copenhagen case. Commuting trips and official trips are not included in any of the cases. $N = 1850$ (Oslo), 1132 (Stavanger) and 1914 (Copenhagen)

11.4 Long-Distance Trips

In neither of the three city regions, the frequency of long-distance non-work trips seems much affected by residential location. As can be seen in Fig. 11.3, there are very small differences in the average number of non-work trips longer than 100 km between the different distance belts in the Oslo and Stavanger cases. In Copenhagen, where the question posed was about trips outside the island on which the city is located, the frequency of such trips is higher among inner-city dwellers, but the pattern across distance belts is somewhat unclear. Controlling for socioeconomic and demographic characteristics, we find no significant effects of residential location (Table 11.3).

11.5 Flights

Some authors have found a higher frequency of flights among central-city residents (Holden and Norland 2005; Næss 2006a; Ornetzeder et al. 2008). Especially Holden and Norland have pointed at this correlation as a serious challenge to the sustainability of urban densification strategies. In my own study of Copenhagen metropolitan area, I also found such a correlation, but it was difficult to find any plausible causal explanation. I therefore concluded that the relationship was most likely produced by lifestyle factors disposing certain segments of the population both for preferring inner-city living and visits to large cities abroad (Næss 2006a).

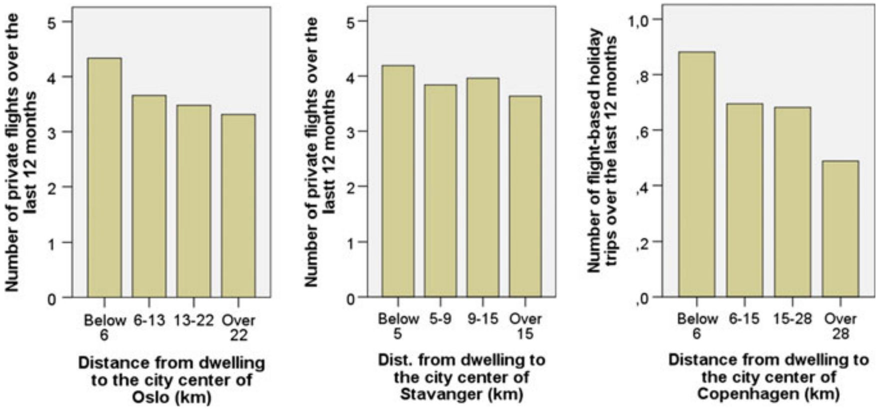

Fig. 11.4 Number of private flights (Oslo and Stavanger cases) and flight-based holiday trips (Copenhagen case) over the last twelve months among respondents living within different distance belts from the city centres of Greater Oslo (to the *left*), Stavanger-Sandnes (in the *middle*) and Greater Copenhagen (to the *right*). *N* = 1849 (Oslo), 1285 (Stavanger-Sandnes and 1932 (Copenhagen)

The new material from Oslo and Stavanger adds to the Copenhagen findings about the association between inner-city living and higher frequency of private flights. Distinct from the Copenhagen study, where the questions asked of the respondents were about the number of flight-based holiday trips, the Oslo and Stavanger questionnaire asked about the number of private (i.e. non-work) flights over the last twelve months. As can be seen in Fig. 11.4, the number of such flights is higher among respondents living close to the city centres of Oslo as well as Stavanger, yet with a less clear pattern in the latter case. The difference across distance belts is not directly comparable with the Copenhagen case, where only flights making up the main part of a holiday trip were included. There does seem, however, to have occurred a quite substantial increase from 2001 to 2015 in the overall amount of flights, regardless of residential location.

When taking into consideration the effects of socioeconomic and demographic variables (Table 11.4), a statistically significant effect of the distance from the dwelling to the main city centre remains in all three cases, with more flights the closer to downtown the respondents live. In the Stavanger case, we at the same time see a tendency of more frequent flights when living in a single-family house.

As might be expected, the number of flights is influenced by a number of socioeconomic and demographic factors. In all three cases, the number of flights tends to get higher if the respondent has high income, none or few children in the household, and/or is female. In the Oslo and Stavanger cases, we also find a tendency of more flights among younger persons and in Copenhagen among person with a long education.

One possible mechanism consistent with the hypothesis of compensatory travel could be that people living in urban settings where outdoor recreation opportunities are poor fly to tourist resorts in order to perform such activities. However, in all three city regions, the number of flights is very weakly related to the proximity of the dwelling to the closest green recreation area of 10 ha or more. Controlling only for socioeconomic and demographic variables, the effects of the distance to such a green area on flights are rather weak ($p = 0.034$ in Oslo, 0.066 in Stavanger and 0.064 in Copenhagen), and not at all statistically significant when comparing respondents living at similar distances from the main city centre, second-order centre and local centre in the Oslo and Stavanger cases. In Copenhagen, there is still a weak but uncertain effect ($p = 0.071$). A similar pattern is found for the statistical relationships between living in a single-family house and the number of flights. A very weak and uncertain flight-reducing effect can be found when controlling only for socioeconomic and demographic variables ($p = 0.139$) in the Oslo case. If also adjusting for the distance from the dwelling to the different categories of centres, the effect of single-family house on flights disappears. In Stavanger and Copenhagen no such effects can be seen, and in Stavanger there is even a weak tendency of increased flight frequency among single-family house dwellers ($p = 0.023$) when controlling for socioeconomic and demographic variables as well as for the location of the residence relative to urban centres.

The effects of inner-city dwelling on flights shown in Table 11.4 thus leave us with a conundrum. Let us therefore turn to the qualitative interviews to see if they can show any mechanisms plausibly having produced these effects.

11.5.1 Narratives About Flights by Interviewees Living in Different Geographical Contexts

A soon-to-be retired interviewee in Oslo living with his wife very close to the city centre (and the main railway station) pointed to easy access to the airport shuttle train as one of the benefits of their new residential location:

> We live close to everything here in Bjørvika – we just take the lift downstairs and then we are at the airport train platform. (Couple living in the Barcode downtown housing area, Oslo).

It is still hard to see that this opportunity would really be important to many inhabitants' decisions on whether or not to make flights, except maybe for a few very spontaneous trips.

A statement by one of the interviewees of the Copenhagen study may give another clue:

> And then we've also spent our vacation doing up our house. Last year it was the gutters, you know, and this year we dug up the entrance…. So the holiday is spent on that, you know…. Both money and holiday disappear. Sure, we take them from the same purse. (Male janitor, 55 years old, living in a single-family house in a suburb 27 km from the city centre of Copenhagen).

Conversely, a Stavanger interviewee who had moved from a relatively centrally located single-family house to a suburban apartment stated:

> …it had to be an apartment; this was why we moved from the house, because we have a cabin in the southernmost part of Norway, and we wanted to use it as much as we wish. And not feel that we should now be at home mowing the lawn or … oh, who's watering the flowers or … oh, now we need to stain the walls again this year, or…. And during the winter half year we fancy travelling, and if we just find out that now we find a cheap air ticket to that place; then we only lock the door here, and then this apartment manages itself" (female shopkeeper, 50 years old, living in an apartment 8 km from the city centre of Stavanger).

Apparently, living in a single-family house can tie up time and money preventing the residents from making at least some of the (often flight-based) holiday trips that they would otherwise have made. This is in line with the hypothesis of rebound flights, as the above-mentioned vacation-trip-reducing mechanism when living in a single-family house will not be present among inner-city dwellers.

A male civil engineer aged 60, living in a suburban apartment in Sandnes 13 km from the city centre of Stavanger, had moved with his wife from a single-family house not long ago. He said that they were finished with 'house with garden'. They had also more or less dropped going to restaurants in Norway, instead opting for extended weekends in metropolises abroad—or trips to mountain areas or bathing resorts in Austria and Greece. The question remains whether this international travelling was induced by their new status as apartment dwellers or the influence was the opposite: that they did no longer appreciate the private garden because their leisure interests had turned in a different direction.

Contrary to the hypothesis that inner-city living will cause more flights than when living in a suburban single-family house, the narratives of a number of interviewees living in single-family houses in the Copenhagen case as well as in the more recent Oslo and Stavanger cases display very extensive patterns of leisure flights. For example, a female translator, 46 years old, living in single-family house 10 km from the city centre of Stavanger told that the family made two to five annual flights to international destinations, mostly large cities combining opportunities for urban cultural experiences and bathing at the seashore. One of the really frequent flyers was a communication worker, 46 years old, living in a single-family house 6 km from the city centre of Stavanger. She and her husband were bound for leisure trips to Krakow next week, thereupon London, New York and Zanzibar in the course of the next few months. Her husband had a lot of flight bonus points that he had to burn—his job in the oil industry entailed a lot of point-producing official trips. She just laughed about the question of whether you would travel abroad on weekend trips more frequently if you lived centrally.

In the Norwegian contemporary context, going for several leisure trips to destinations abroad seems to be the more or less normal pattern, independently of residential location. A retired couple living in an apartment in the central part of a second-order town told that they went on several trips for bridge tournaments at tourist resorts at the Mediterranean Sea in the autumn and winter. There was, however, no indication that their motive for making this kind of trips had anything to do with their residential situation.

Many interviewees explicitly state that they do not consider their holiday locations and airplane travel to be influenced by where in the metropolitan area they live. For example, asked if she thought she would have spent the vacation differently if she had lived in a single-family house area in one of the suburbs of Oslo instead of in her actual apartment 4 km from the city centre of Oslo, a female 32-year-old engineer who had been flying to Budapest and Tallinn last year answered: “I think it might perhaps have been the same … yes, I do think we would have gone on the same kinds of holiday trips.” This statement was by no means uncommon. A female teacher, 35 years old, living in a single-family house 10 km from the city centre of Stavanger explicitly expressed that she would not have taken on more holiday trips if she had lived in the downtown area. Similarly, a male owner of newly established small freight business, 28 years old, living in apartment 2 km from the city centre of Stavanger stated that the location of the family’s dwelling was not important to their travel to destinations abroad. Likewise, a male engineer, 66 years old, living in apartment close to the city centre of Stavanger held that there was no relationship between the location of the residence and their amount of international travelling.

As can be seen above, many interviewees reject the notion that a centrally located dwelling induces more leisure flights. Our material shows a few statements that might be consistent with the hypothesis of rebound flights, where more opportunities for taking on flights arise when you need not do gardening or spend money on refurbishing a single-family house. However, the mechanisms indicated in these interviews seem rather weak and unlikely to produce strong aggregate-level correlations. It could still be that the influence of inner-city living on flights goes unnoticed by some of the interviewees, for example because they do not reflect on how their ability to afford making flights is affected by how much money they spend on daily-life travel. However, the statistical effect of inner-city living on flights might also, at least partly, be non-causal, generated by, for example, lifestyle preferences disposing some people for inner-city living as well as for visit to cities abroad. I will return to some of these issues in the Concluding Remarks section.

11.6 Secondary Homes

Several authors have hypothesized a compensatory effect of inner-city, high-density living in the form of increased secondary home ownership and usage (Dijst et al. 2005; Modenes and Lopez-Colas 2007; Norris and Winston 2010; Strandell and Hall 2015). In our Copenhagen study too, relationships between residential location and access to summerhouses were investigated. Taking socioeconomic and demographic characteristics into consideration, residents of high-density areas were found to own or in other ways have access to a summer house more frequently than people living in low-density areas. The results were, however, a bit contradictory, as people whose primary dwelling was a single-family house had access to summer houses much more frequently than the remaining respondents, especially in the

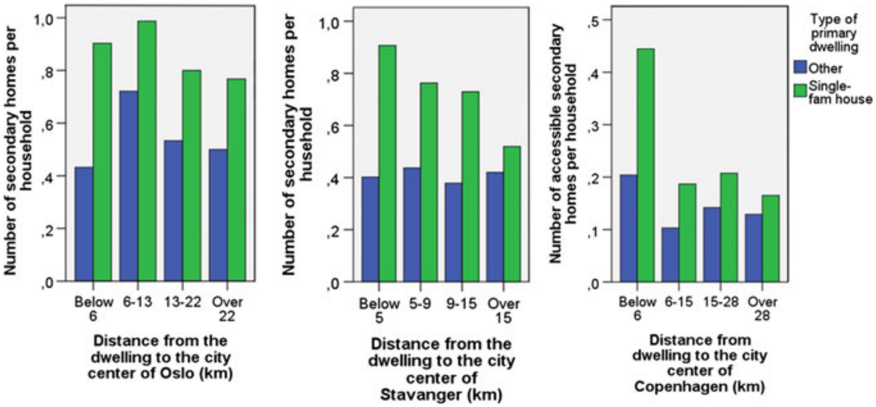

Fig. 11.5 Number of accessible secondary homes among respondents living within different distance belts from the city centres of Greater Oslo (to the *left*), Stavanger/Sandnes (in the *middle*) and Greater Copenhagen (to the *right*, and with different types of primary dwellings). *N* = 1826 (Oslo), 1132 (Stavanger) and 1932 (Copenhagen)

inner city but also within each of the other distance belts. The overall rate of summerhouse access was still clearly higher among those living close to the city centre.

In the new studies in Oslo and Stavanger, respondents were asked about their access to other dwellings than their primary residence, regardless of whether these dwellings were for summer or winter usage or the geographical situation (mountain, forest, shore, city, etc.) in which they were located. As can be seen in Fig. 11.5, people living in single-family homes in Oslo as well as Stavanger have access to secondary homes more frequently than residents of other housing types do. However, while the frequency of secondary home access among single-family house dwellers decreases with increasing distance from the residence to the city centre, there is a slight opposite tendency among those living in other housing types. A multivariate analysis including the same variables as in Tables 11.1, 11.2 and 11.3 showed no statistically significant effect of any of the three residential location variables in either Oslo or Stavanger.

Access to secondary homes does not necessary mean that these facilities are used to any great extent. People may, for example, have inherited a second home without being very enthusiastic users, or they may have inherited a less used second home in addition to the one they normally use. Sometimes such property may also function as an investment object. In the Oslo and Stavanger studies, we also asked about the annual number of visits to each secondary home to which the respondent had access. Among respondents from Oslo metropolitan area, the centre-periphery gradient found for access to secondary homes is reversed when the question is about frequency of use (Fig. 11.6). Respondents living close to the city centre of Oslo make on average considerably fewer trips to secondary homes than their counterparts living in the three outer distance belts. In Stavanger, the situation is

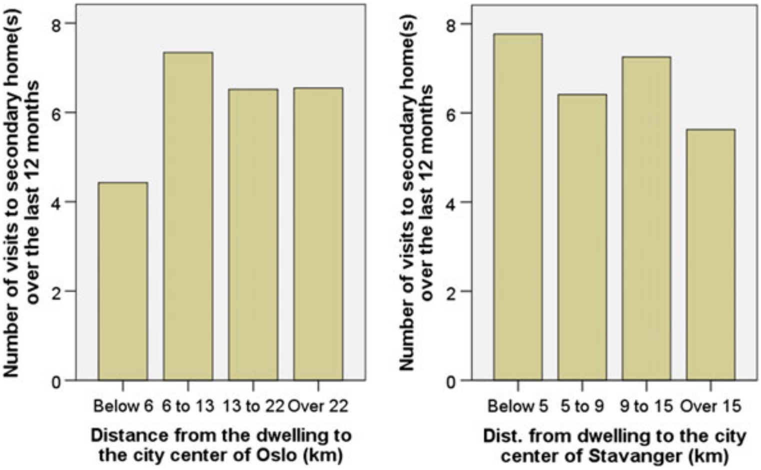

Fig. 11.6 Number of visits to secondary home(s) over the last twelve months among respondents living within different distance belts from the city centres of Oslo (*N* = 1911) and Stavanger (*N* = 1337)

different, with frequencies of use decreasing with increasing distance between the primary dwelling and the city centre.

Controlling for demographic and socioeconomic characteristics of the respondents (Table 11.5), the tendency among inner-city Stavanger residents of a higher frequency of visits to secondary homes persists, while the opposite tendency in the Oslo case is not any longer statistically significant. Instead, we find a tendency in the Oslo case of more frequent visits to secondary homes among respondents living far from the closest second-order centre, and a similar, but weaker effect of living far from the closest local centre. The frequency of visits to secondary homes appears to be influenced primarily by age (more frequent visits among older respondents), income (more visits with high income), workforce participation (fewer visits if you are a worker) and whether there are small children in the household (fewer visits if any of the household members is less than seven years old).

The qualitative interviews illustrate that the use of secondary homes can be quite extensive, especially among relatively affluent middle-class people whose children have moved out of home. The above-mentioned 60-year-old male civil engineer living in a suburban apartment in Sandnes told that he spent approximately 80 days annually in his mountain cabin in a snow-rich area suitable for skiing. Another male engineer, 66 years old had a cabin on an island twenty kilometres away from his apartment in the inner part of Stavanger. He stayed there with his wife during most of the period from spring to autumn, commuting from the cabin to his downtown workplace. However, there were no indications in the interviews underpinning the assumption of a causal relationship between inner-city living and increased usage of secondary homes. On the other hand, ownership and use of secondary home may create a need for car ownership among residents who would otherwise not feel any need for having a car. For example, a 71-year-old retired secretary who lived in apartment in the downtown area of Sandnes (a second-order centre in the Stavanger region) told that they 'had everything within walking distance'. She and her husband still had two cars. The reason for this was, she said, that they had a cabin 150 km down the coast where they lived each year during the time from March/April until September/October.

11.7 Concluding Remarks

Our investigations in the metropolitan areas of Oslo, Stavanger and Copenhagen show that certain individual-scale mechanisms exist, counteracting to some extent and among some residents the effects of resource-saving principles in urban planning. Most of these mechanisms could be characterized as real rebound effects, since the sorts of resource-consuming side effects of otherwise resource-saving residential locations are due to money and time saved from such residential locations. We find few, if any, of the compensatory mechanisms hypothesized in the literature, according to which inner-city dwellers make more frequent, long leisure trips in order to escape dissatisfactory residential environments.

Living in a neighbourhood where the need for car travel is low and you find that you do not need to own a car (or at least that you do not need more than one car in the household) may save you from a lot of expenses. What will this money be spent on? Indirect rebound effects due to money saved are probably hard to avoid. As long as the purchasing power remains the same or increases, resource efficiency improvement resulting in money-saving is like squeezing the balloon. Avoiding such effects seems impossible unless the purchasing power decreases. In a situation with economic growth, the metaphoric balloon is on top of that pumped up with more and more gas.

The identified rebound mechanisms in our three metropolitan cases are not very strong, and countervailing mechanisms exist. In some cases, the rebound mechanisms identified in qualitative interviews with individual persons do not manifest themselves at an aggregate metropolitan scale. For example, any rebound effects are not strong enough to change the environmentally favourable effects of inner-city living for weekend travel, where the effect of a central residential location in terms of reducing car travel is nearly as strong as on weekdays. Our material does not show any effects of residential location on the frequency of private long-distance trips either. The above results are in line with earlier findings in Greater Oslo (Næss et al. 1995) and the Danish small town of Frederikshavn (Næss and Jensen 2004).

Any counteracting effects of inner-city living on secondary home access do not manifest themselves in terms of statistically significant relationships. We find some modest effects of residential location on usage of secondary homes, but whereas living peripherally tends to decrease the frequency of visits to secondary homes in the Stavanger case, the effect of living peripherally is the opposite in the Oslo case.

We do find, however, a tendency of more frequent private flights among inner-city residents of all the three case cities. This tendency corresponds with results reported by Holden and Norland (2005). Although many interviewees reject the existence of any causal influence inducing residents of central-city neighbourhoods to make more flights, our interview material shows a few examples of mechanisms that might push in that direction. These mechanisms do not seem to be very strong or affecting the patterns of leisure travel among any great proportion of the population. Moreover, we find no correlation between the frequency of flights and the time spent on commuting, which should logically be expected if the hypothesis of a flight-hindering effect of time spent on barbeques, gardening and house maintenance among single-family house dwellers were true. Controlling for socioeconomic and demographic variables, the frequency of flights is also very weakly related to the proximity of the dwelling to the closest green outdoor recreation area above 10 ha, especially when comparing dwellings located at similar distances to the city centre.

Instead, a plausible mechanism, hinted at by Næss (2006a), might be that that an ‘urban’ and cosmopolitan lifestyle, prevalent in particular among young students and academics and among middle-class people whose children have moved out of home, contributes both to an increased propensity for flights and to a preference for inner-city living. This cosmopolitan lifestyle seems to be associated with a prioritization of ‘urban’ activity opportunities such as cinema, theatre, rock concerts, exhibitions, cafes and outdoor restaurants over the rural and secluded life behind the privet hedges of single-family houses. If these assumptions of a tangled urban-cosmopolitan lifestyle are correct, this lifestyle will be a background factor contributing both to an increased propensity for flights and to a preference for inner-city living. This is still a speculative explanation, since the empirical material of our three studies does not illuminate this issue.

In the contemporary Scandinavian context, inflated housing prices in inner-city districts counteracts the money-saving effect of living in an area where the dependence on car travel and car ownership for accessibility to daily activities is low. Partly, the high inner-city housing prices reflect the lower transportation costs associated with inner-city living: people can then afford to pay a higher price for the dwelling, thus pushing market prices upwards (Christaller 1966). Hence, the money released through lower transportation expenses is shifted on to the sellers and financiers of inner-city dwellings, with indirect rebound effects resulting from the investments made by these actors. However, in the central areas of Oslo and Copenhagen, and to some extent also Stavanger, dwellings are on average smaller than in the suburbs. So although the price per square metre of dwelling in Oslo’s inner eastern and inner western districts is currently 30–50 % higher than in the corresponding outer parts of the municipality, the actual purchasing prices per dwelling are likely to show a much less steep centre-periphery gradient. It therefore seems plausible that the combined expenses on (primary) housing and daily-life travel will be on average lower among inner-city residents, thus opening for rebound effects based on surplus of money.

Anyway, the existence of possible rebound effects should not prevent us from seeking to develop our cities in the most environmentally friendly ways possible. Creating car-dependent cities in order to, for example, reduce holiday travel is clearly not a viable strategy—taxes and regulations directly targeting the ‘rebound activities’ are much more efficient.

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Chapter 12
Tourism: Applying Rebound Theories and Mechanisms to Climate Change Mitigation and Adaptation

Carlo Aall, C. Michael Hall and Kyrre Groven

Abstract Little attention has been given to the rebound effects within climate change mitigation and adaptation literature. Still, a growing attention has been given to the need of integrating adaptation and mitigation policies in order to avoid negative feedback mechanisms to take place between the two. In this article, we investigate the potential of applying theories of rebound effects on the climate change mitigation and adaptation discourse. In doing so, we have developed a model for identifying inter- and intra rebound effects taking place within and between the two policy domains of climate change, and given examples of such effects from the case of tourism.

Keywords Climate change mitigation · Climate change adaptation and tourism

In Shakespeare's Macbeth, the three witches make their brew while singing the magic formula: "Double, double, toil and trouble. Fire burn and cauldron bobble". Their prophecy reflects the magnitude of Macbeth's toil and multitude of trouble. This also serves as a metaphor for the 'double trouble' of mitigating and adapting to climate change at the same time, and the 'toil' of having to do this at such haste and to such a large extent. This chapter presents a novel approach to address the double trouble and the toil. In this chapter, we discuss the potential of transferring rebound theory from the energy to the climate field of research and policymaking in order to gain a better understanding of how to avoid ineffectiveness in climate change adaptation and mitigation.

The latest report from the Intergovernmental Panel on Climate Change (IPCC) stresses the urgency of achieving radical cuts in greenhouse gas (GHG) emissions in order to achieve the goal of limiting global warming in the twenty-first century to

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C. Aall (✉) · K. Groven
Western Norway Research Institute, Sogndal, Norway
e-mail: caa@vestforsk.no

C. Michael Hall
Department of Management, Marketing and Entrepreneurship,
University of Canterbury, Christchurch, New Zealand

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be below 2 °C, and thus hopefully to prevent dangerous anthropogenic interference with the climate system (IPCC 2014a). At the same time, the IPCC states that no matter how fast GHG emissions are cut, society must adapt to severe effects of climate change in the years to come (IPCC 2014b). Taking this situation into account, it is of utmost importance to be sure that climate strategies and measures are effective in achieving the intended effect in time.

Although a growing number of studies in the climate change literature have documented the extent that situations of ineffectiveness occur (see Warren 2011, for an overview), few, if any, studies have offered an overarching theoretical framework that enables us to understand the mechanisms that create situations of ineffectiveness—and thus can guide us in avoiding these situations. The chapter commences by providing an overview of the literature on the need to integrate adaptation and mitigation policies and, in particular, the so far rather limited research done relating to the concepts of maladaptation and malmitigation. It then presents a generic model on how to identify different categories of mitigation and adaptation ineffectiveness followed by applying rebound theory in order to explain the possible mechanisms producing climate policy ineffectiveness. The chapter then presents an overview on how climate change mitigation and adaptation efforts currently manifest themselves in the tourism sector. It concludes by discussing to what extent our model can guide research in assisting policy-makers with new insights on how to avoid climate change mitigation and adaptation ineffectiveness.

12.1 Climate Change Mitigation and Adaptation: From Separation to Integration

Schipper (2006) describes the evolution of the relationship between the mitigation and adaptation concept taking place within the United Nations Framework Convention on Climate Change (UNFCCC) process. She shows that a dichotomy between mitigation and adaptation was already well-established by the early 1990s when the climate change response policy was framed. Schipper emphasized that adaptation was given a subordinate role, owing to the notion that mitigation was more important than adaptation. Hence, the UNFCCC objective, as stated in Article 2, is explicitly to stabilize atmospheric greenhouse gas concentrations in order to prevent dangerous climate change, whereas the convention only contains fragmented references to adaptation. After years of drafting, the UNFCCC negotiations were finalized at the Earth Summit in Rio in 1992, and came into force two years later. At the time, adaptation was primarily understood in terms of ecological limits, inspired by the Club of Rome's report *The Limits to Growth* (Meadows et al. 1972). One of the main questions of adaptation research was the extent to which adaptive capacity was able to offset mitigation needs. However, this approach did not trigger the framing of an adaptation policy regime because, as Schipper (2006: 88) puts it, "capacity to adapt was considered something inherent in ecosystems and society, therefore not requiring explicit policy".

The 1990s saw adaptation gradually become established as a viable and legitimate policy option. This slow progress has been explained in various ways: Negotiators from states with high emissions were reluctant to propose adaptation measures because this could be seen as an admission of responsibility, while some refused to discuss adaptation strategies because they did not acknowledge that climate change was actually taking place. Adaptation was also considered a 'defeatist' option, and a possible hindrance for establishing a mitigation framework, rendering climate policy a choice between mitigation and adaptation (Parry et al. 1998; Schipper 2006).

The Kyoto Protocol was agreed at the UNFCCC's third conference in 1997, as an achievement of long-lasting mitigation focus. The following year, Parry et al. (1998) argued that implementation of the Kyoto targets hardly would affect projected impacts of climate change, and the authors therefore urged the international society to embrace adaptation strategies to reduce impacts of inevitable climate change. They deemed ignoring adaptation as both 'unrealistic and perilous' (op cit.). Similar calls combined with delays in the implementation of the Kyoto Protocol prepared the ground for a dedicated adaptation policy, as it became clear that mitigation would not suffice and that adaptation was a necessity.

The advent of adaptation policy seems to have been accompanied with a considerable shift in the approach to the term. While adaptation initially was seen as "a spontaneous adjustment that would determine the limits of how much climate change could be tolerated, and hence how much mitigation was necessary", it was gradually transformed to a policy strategy for sustainable development (Schipper 2006: 91). Since COP-6 in 2000, adaptation has increasingly been associated with capacity building, technology transfer and equity. In 2001, adaptation received a more prominent role in the Third Assessment Report (TAR) of the IPCC compared to earlier assessment reports, and in 2004 an important step was made by COP-10 in Buenos Aires, when a work program for adaptation was adopted (UNFCCC 2005).

This appreciation of adaptation as a climate change policy on par with mitigation does not automatically imply that the strategies are treated in an integrated manner. Mitigation and adaptation are still to a large degree kept apart, as seen in the IPCC working group structure, which maintains a division between mitigation and adaptation responses (IPCC 2014a, b). However, there are calls for greater integration between the two policy fields (e.g. Wilbanks and Sathaye 2007; Biesbroek et al. 2009), and some achievements have been made in this respect.

An increasing number of studies suggest that mitigation and adaptation are complexly interrelated (Ayers and Hug 2009; Warren 2011), and thus advocate the need to handle the challenges of mitigating and adapting to climate change in context and not separately. Some argue that this is important in order to achieve a more cost effective climate policy (Kane and Shogren 2000). Others state the importance of such an integral approach in particular for the case of poor countries in order to avoid climate policies that undermine sustainable development goals (Laukkonena et al. 2009; Hall 2015). It has also been suggested that, if treated separately, there is a danger that adaptation policies may trigger increases in GHG emissions and mitigating policies may trigger increases in societal vulnerability to climate change (Klein et al. 2007; Bizikova et al. 2007; Corfee-Morlot et al. 2009; Warren 2011). These insights are highlighted in the summary for policy-makers by the IPCC (2014b: 89): "Significant co-benefits, synergies, and trade-offs exist between mitigation and adaptation and among different adaptation responses; interactions occur both within and across regions. Increasing efforts to mitigate and adapt to climate change imply an increasing complexity of interactions, but tools to understand and manage these interactions remain limited".

The prefix 'mal' has been linked in the literature to both 'adaptation' and 'mitigation' in order to coin a situation with less-then-anticipated effective adaptation or mitigation policies. In both cases this may also relate to the existence of co-benefits, synergies and trade-offs between mitigation and adaptation.

The term '*maladaptation*' has been given different interpretations (Juhola et al. 2016). It could mean less effective adaptation than anticipated, but most frequently it is used to describe a situation in which adaptation efforts leads to increased, rather than decreased, vulnerability (Smit 1993; Burton 1997; IPCC 2001). Scheraga and Grambsch (1998) provide an even broader definition and describe maladaptation as a situation whereby negative impacts of all sorts (not merely that of increasing climate vulnerabilities) are caused by adaptation decisions. Barnett and O'Neil (2010) elaborates on this perspective and identify five distinct types or pathways through which maladaptation arises. Namely actions that, relative to alternatives: Increase GHG emissions; disproportionately burden the most vulnerable; have high opportunity costs; reduce incentives to adapt; and set paths that limit the choices available to future generations. This latter pathway is similar to the concept of 'lock-in' in sustainable transitions research. According to Geels (2004), path dependence and lock-in occur because socio-technical systems, rules and actors and organizations provide stability through different mechanisms such as networks and mutual dependence. In seeking to synthesize the various approaches towards maladaptation Juhola et al. (2016) developed a typology of the outcomes of maladaptation: Rebounding vulnerability (i.e. adaptation action that increases current or future climate change vulnerability of the implementing actor or the targeted actor (s) if implemented by, e.g. a local government); shifting (or 'spill-over') vulnerability (i.e. adaption action at one specific location that may cause an increase in climate change vulnerability at a different location); and eroding sustainable development (i.e. adaptation action that increases GHG emissions, negatively impacts environmental conditions and/or social and economic values). The literature also discusses a number of sources for maladaptation, many of which focus on short-term profit maximization or institutional path dependency (Barnett and O'Neil 2010; Granberg and Glover 2012a, b). From this perspective maladaptation can be the results of how society organizes its adaptation governance and if and how this governance is coordinated and steered.

The term '*malmitigation*' is noted in international literature to a much lesser extent, but is given a similar meaning as its twin term—i.e. ineffective mitigation, mitigating leading to an increased vulnerability for climate change, or the wider definition that mitigation may lead to a large variety of negative environmental side-effects (Corfee-Morlot et al. 2009; Nurhadi et al. 2013; Scrieciua et al. 2013; Kongsager et al. 2015).

The task of *integrating* adaptation and mitigation seems to have gained most weight in a *local* policy context (Schreurs 2008). This is illustrated, for example, by a comprehensive Canadian handbook on local climate change adaptation from 2007 (Bizikova et al. 2008) and the Proceedings from the World Congress on Resilient Cities arranged by the International Council of Local Environmental Initiatives (Sidi 2012)—both of which present several concrete examples of (mostly) negative interactions between adaptation and mitigation. These interactions are structured in accordance with a two-axis model: Increasing/decreasing GHG emissions and increasing/decreasing climate change vulnerabilities (cf. Fig. 12.1). An example of an antagonistic relationship between adaptation and mitigation which is currently attaining increased attention in research is that of densifying versus diluting land-use patterns in urban areas. The densification strategy is developed in order to reduce GHG emissions from urban transportation and heating of residential houses, whereas the dilution strategy is developed in order to reduce vulnerability towards urban flooding by means of creating more 'space' for water (Groven 2015).

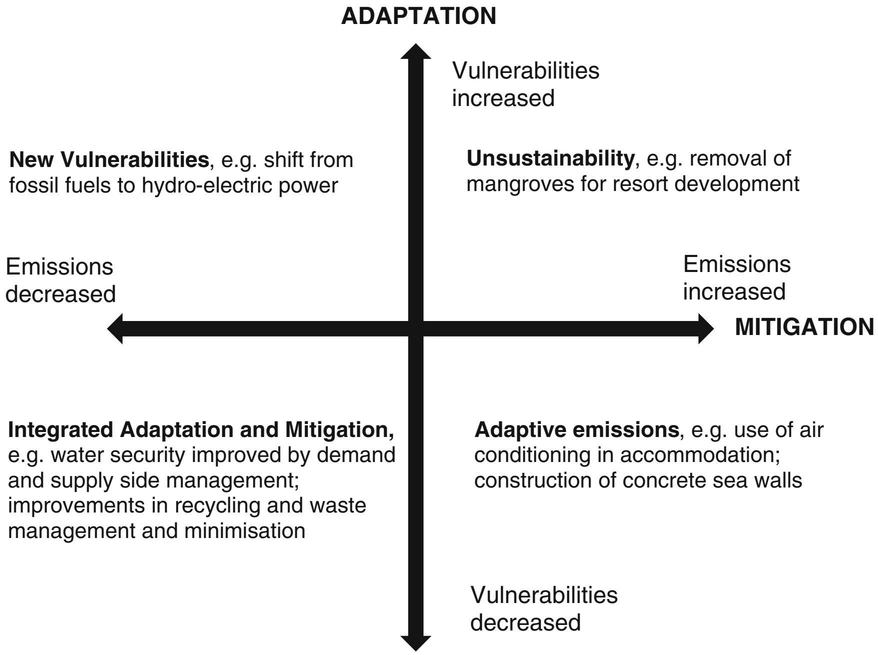

Fig. 12.1 Linkages between adaptation and mitigation (adapted from Cohen and Waddell 2009)

12.2 Modelling Malmitigation, Maladaptation and the Relationship Between the Two

Whilst the IPCC highlights the urgency of focusing on the negative consequences of adaptation, their definition of maladaptation does not go far in making it analytically distinct or to operationalize it for further research and practice to avoid negative outcomes (Juhola et al. 2016). The same seems to be the case for climate change mitigation. Thus, a comprehensive framework to understand why both mitigation and adaptation ineffectiveness occurs, which in turn can inform us on how to reduce such ineffectiveness, is missing. As illustrated in a number of articles in this book, the rebound effect is basically about that the actual effect of a specific effort proves to be less than expected due to counterproductive processes or actions —termed ‘rebound effects’—which are caused by carrying out the effort in question. Thus, the rebound concept may offer a framework for a comprehensive understanding of ineffectiveness traps embedded in the policy domain in question; be it ‘energy’ or (as for the case of this article) ‘climate’. In the figure below we have presented a model that aims at doing this. The model differentiates between three main categories of rebound effects, here illustrated with such effects taking place within the climate policy domain (see Fig. 12.2):

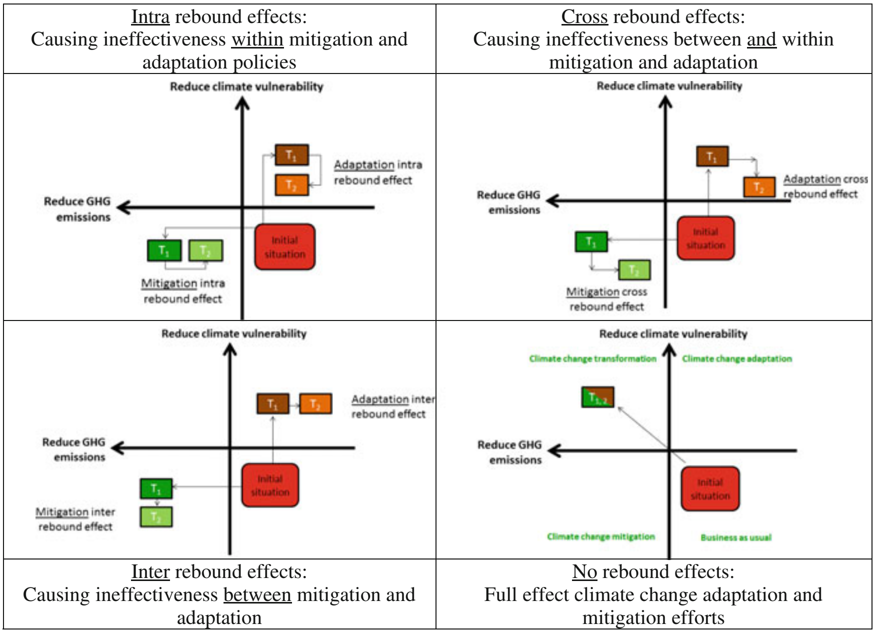

Fig. 12.2 A suggested model for identifying categories of climate change mitigation and adaptation rebound effects

- *Intra* rebound effects: The situation in which net GHG reduction is lower than anticipated, or the net effect of climate change adaptation is lower than anticipated.
- *Inter* rebound effects: The situation in which climate change mitigation efforts increases climate change vulnerabilities, or climate change adaptation increases GHG emissions.
- *Cross* rebound effects: The situation in which intra and inter rebound effects takes place *at the same time*.

The fourth alternative in Fig. 12.2 is the case in which none of these three categories of rebound effects come into action.

It is important to note that when expanding the application of the concept of rebound effects from the classical context (termed 'intra rebound effects' in Fig. 12.2) to a situation which involves two different resource categories (cf. the categories 'inter' and 'cross' rebound effects, involving the two resource categories 'GHG emissions' and 'climate vulnerability') we must face the challenge of to a certain degree comparing 'apples and oranges'. Although adaptation and mitigation could—and should—be noted as 'two sides of the same coin', it still remains a challenge to compare the two in the sense that adaptation actions are more of a 'qualitative' nature than mitigation actions. While mitigation can be measured in one quantitative dimension (e.g. kg of GHG emissions) there is no single yardstick that is widely accepted when discussing the outcomes of adaptation. Thus, it will be impossible to analyze intra rebound effects in the same quantitative way as for inter rebound effects within the energy policy domain, e.g. to assess in any meaningful way a percentage increase in climate change vulnerability due to the implementation of a specific mitigation effort. Instead we have to apply a combined quantitative and qualitative approach when describing the behavioural and systemic relationships between adaptation and mitigation efforts.

12.3 The Case of Tourism

We have selected tourism to illustrate the potential of applying the model presented above. We have selected tourism as an illustrative case because it is a particularly GHG-emission intensive economic sector (Gössling 2010); because it for the last decades has in fact and are (by representatives of the sector) expected to experiense for the coming years a particularly strong increase in GHG emissions (Gössling et al. 2013; Scott et al. 2016), and at the same time it is extremely susceptible to major adaptation challenges due to climate change (Scott et al. 2012). Below we will present examples of intra and inter rebound effects relating to climate policy efforts currently taking place within the tourism sector.

Although intra rebound effects have been recognized in relation to natural resource use since the 19th century, their implications have been not received much attention in tourism (Hall 2009, 2010). There have been significant concerns expressed about the extent of intra rebound effects in mitigating GHG emissions from aviation, which is the largest sectoral contributor to tourism emissions (Scott et al. 2016). Sorrell (2010) observed that increased consumption of air travel and tourism would potentially be driven by increases in macroeconomic efficiency gains as sustained increases in per-capita consumption outweigh efficiency gains. Indeed, in the highly competitive airline industry the efficiency gains may serve to fuel the low pricing that exists on some air routes. Barker et al. (2009) modelled the rebound effects resulting from the global energy efficiency measures incorporated into the IPCC's Fourth Assessment Report and estimated that for transport there would be a worldwide direct rebound of 9.1 % in 2020 and 9.1 % in 2030, and a macroeconomic rebound of 26.9 % in 2020 and 43.1 % in 2030. Therefore, leading to a total economy wide rebound of 36.0 % in 2020 and 52.2 % in 2030. This compares to an estimated rebound for all sectors of 31 % of the projected energy savings potential by 2020, rising to 52 % by 2030 (Barker et al. 2009). Hall et al. (2013) argue that if this scale of rebound was applied to World Tourism Organisation (UNWTO 2008) and World Economic Forum (2009) estimates of emissions then, even allowing for the estimated greater use of low-carbon fuels, the actual increase in emissions allowing for rebound effects would likely be over 200 % in absolute terms despite greater per tourist fuel efficiencies given the extent to which growth in tourist trips and speed and distance travelled outweighs increased efficiencies. This means that by 2030 the impacts of forecast energy efficiencies on proposed tourism emissions reduction will potentially be more than halved and that the reduction in the potential gain in energy efficiencies over the period to 2035 cut by more than 35 % (Gössling et al. 2013).

Installing artificial snow-making facilities is a commonly selected strategy for adapting to an anticipated reduction in snow reliability (Demiroglu et al. 2013) even though this is also frequently done as an economic measure to extend the skiing season under current climate conditions (Aall and Høyer 2005). Still, installing such facilities may all other factors alike introduce new climate change vulnerabilities in the way that the ski resort will become more dependent on an abundant supply of fresh water in order to produce snow (Gössling et al. 2012). Climate change may also lead to decreased water availability during periods when artificial snow is required (Matasci et al. 2014). Looking at this from the consumer-side, adapting to reduced snow reliability is to a large extent a question of 'chasing for snow'; i.e. to increase the level of transport involved in skiing. Also here we can in principle point at the possibility of this producing new climate change vulnerabilities, like increased exposure to climate-related natural hazard events on roads and railways.

Studies of possible inter rebound effect specifically aimed at the tourism sector are limited, and they mostly analyzes the extent to which adaptation together with mitigation takes place (see e.g. Becken 2005; Gössling et al. 2013) and to a very limited extent discusses the potential of antagonistic effects taking place between these two modes of climate policy-areas, nor say discusses the strategies required to avoid such effects.

According to Barnett and O'Neil (2010) the most often-cited example of maladaptation is that of the increased use of GHG-emission intensive air-conditioners in order to adapt to the increased rate of heat waves (Kovats et al. 2006), an issue of significance for many accommodation providers in tourism destinations. The growing use of water for pools and spas in water scarce regions, sometimes via energy intensive desalination plants (McEvoy and Wilder 2012) is another example that is frequently cited in tourism research (Gössling et al. 2015).

Tourism is a major economic user of alpine regions that are increasingly prone to the impacts of climate change, not just on snow availability but also on landscape geomorphology and slope stability. Although winter tourism lower altitude/lower latitude winter resorts are coming under increased pressure from climate change, growing consumer demand means that higher altitude/high-latitude resorts in alpine regions which can provide greater snow security can continue to expand. However, localized erosion may be promoted by construction of second homes, hotels and resorts, and ski areas and the roads needed to access them (Kurtaslan and Demirel 2011). Furthermore, the expansion of alpine areas formerly regarded as marginal for development can create new climate-related natural hazard risks. Snow can be stabilized with structures that retain or redirect it to avoid avalanches. However, as Walker and Shiels (2013, p. 10) point out, “physical structures lead to a false sense of security and additional development in landslide-prone terrain, [providing] … an illustration of Jevon’s paradox (increased efficiency in resource use leads to increased use)”.

Another example of inter rebound effects of climate change adaptation is that of desalination in the Canary Islands, a major tourism destination for which desalination is critical with respect to maintaining a sufficient level of water supply in the face of climate change and the danger of reduced levels of precipitation. Even today, the fresh water supply of the Island of Lanzarote is entirely dependent upon this technology (von Medeazza and Moreau 2007). First implemented in 1964, desalination provided the fresh water that enabled Lanzarote’s tourism industry to develop. Between 1986 and 2002 fresh water production grew by 425 %, while the resident population grew by 108 % and tourists by 250 %. In 2001 the net water consumption per permanent resident was 120 litres per person per day; while tourists consumed 460 litres, although luxurious hotels required over 1000 litres per tourist per day. As von Medeazza and Moreau (2007, p. 1030) commented, “it seems that increasing supplies will always be insufficient because they increase demands even faster and that ultimately, supplies will always be fully used up… Decreasing production energy costs seem indeed to trigger a rebound effect on water consumption”. Significantly, seawater desalination is the island’s greatest individual energy consumer so there is a close coupling between energy, water and emissions and the level of use of water in the tourism industry. As von Medeazza and Moreau (2007) conclude ‘hydraulic structuralism’ produced the perception from many stakeholders that water scarcity problems could be entirely solved by increasing supplies. However, the creation of additional supplies appears to have created a diffusion of responsibility effect “in which a ‘water squander’ culture—subsequently triggering socially constructed water calamities—increasingly emerge” (2007, p. 1030).

Another candidate of an inter rebound effect of climate change mitigation and adaptation is the process of making destinations more dependent of single climatic 'powered' renewable energy sources like hydro-power and wind—which, all other factors alike, may lead to some destinations being more vulnerable to climatic variability, e.g. less water availability for hydro-power generation or wind availability especially at times of peak seasonal demand (and thus, more vulnerable to climate change). One option for mitigating this kind of malmitigation would be to combine the change from fossil energy to renewable energy sources with that of reducing the total end-use of energy as part of a destination sustainable transition strategy. Also significant where appropriate is to ensure that there is a mix of renewable power sources rather than being reliant on a single source.

Still, the perhaps most obvious candidate for illustrating inter rebound effects involved in climate policy is that of adapting to an anticipated reduction in snow reliability. As already mentioned, a consumer adaptation strategy is that of 'chasing for snow' which obviously will lead to an increase in transport-related GHG emissions. A web-survey of 224 visitors to the three Norwegian alpine summer ski canters (Stryn, Folgefonna and Juvasshytta) showed that a large share of the skiers would choose long trips by air if the summer snow-conditions in Norway would be to poor. When asked on how the respondents would react, taking a realistic account of their time and budget limits, should negative perceptions on the effect of climate change hold, activity substitution in the form of top-touring came out to be the most favoured alternative (Demiroglu et al. 2015). On a scale of 1–5 for 'very little' to 'very much' this alternative had a mean score of 3.84, followed by temporal substitution to the same ski centre in summer (3.67), and medium tendency towards spatial substitution to the other two centres within Norway (2.98). The least favoured alternatives were spatial substitution to the summer centres in the Alps (2.45), North America (1.89), and Japan (1.66), the winter resorts in South America (2.44), Australia and New Zealand (2.21), and South Africa (1.72), and an activity substitution in the forms of skiing at dry (1.52) and indoor slopes (1.57) and replacing summer skiing for good with other leisure activities (2.23).

Examples of producer-related inter rebound effects in winter tourism are even more profound. Here, we may identify a 'ladder' of climate change adaptation ranging from adjustments to transformative efforts:

- Installation of artificial snow-making facilities at existing ski resorts
- Extension of existing ski slopes to higher altitudes
- Supplementation of existing ski resorts with new and more snow reliable ski resorts within the same ski destination
- Establishment of new ski destinations in more snow reliable areas.
- Construction of outdoor artificial (mostly snowflex) or hybrid (articificial + natural snow) ski slopes.
- Construction of 'roofs' over natural ski slopes making them a semi-indoor arena.
- Construction of a 100 % indoor skiing arenas with 100 % controlled climate conditions.

In all of these examples, although to a varying degree, we might experience inter rebound effects in the form of increased energy use (and accompanying GHG emissions) from constructing, maintaining and running of the different installations. For the case of moving skiing facilities or developing new facilities we may also experience increased energy use from transportation due to the fact that many traditional and old skiing locations are often located in connection with major public transportation hubs (in particular, railroad hubs), whereas new locations often are located farther away from such hubs—thus resulting in an increase in car use at the expense of public transportation.

12.4 How to Avoid Rebound Effects in Climate Change Adaptation and Mitigation: A Suggested Agenda for Policymaking and Further Research

Høyer (2010) claims that the contemporary discourse on climate change is dominated by what he calls *CO_2 reductionism*, in which complex phenomena interconnecting both nature and society are reduced to one singular issue: emissions of CO_2. This kind of misconception will, according to Høyer, inevitably lead to suboptimal and even contra productive policies—e.g. what we above have defined as intra rebound effects leading to mitigation ineffectiveness. The solution to this situation is according to Høyer to reunite CO_2 with the other factors from which it has become disconnected during the last two decades, namely that of greenhouse gases, fossil energy, energy, consumption, economic growth, sustainable development and the post-carbon society. For example, in urban design and planning, a great deal of attention has been given to encouraging compact and denser cities in order to reduce local mobility and encourage greater use of public transport without considering its effects on individual's broader mobility lifestyles (see also the contribution of Petter Næss, this volume). Strandell and Hall (2015) found that, even after controlling for demographic and socio-economic factors, the denser the residential area the more people use second homes. Similarly, and also in Finland, Ottelin et al. (2014) found that GHG emissions from flying can offset the gain from reduced private driving in dense urban areas. These findings are important because they emphasize that tourism, as well as emissions in general, need to be understood within the totality of individual lifestyles and consumption practices.

Similar to what Høyer (2010) describes regarding the mitigation part of the climate change discourse, it could be claimed that the contemporary discourse on climate change adaptation is dominated by what we could call *resilience-reductionism*, in which the complex options for society on how to respond to climate change is reduced to the one task: To protect society from the negative effects of climate in order to maintain society as it is today (Amundsen 2014). Even if climate change adaptation may include large-scale efforts and lead to at least some sort of societal change, it is not evident that such changes also may lead to the qualitative societal changes envisioned in the IPCC Special Report “Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation” and their definition of the concept of transformation (IPCC 2012: 2): “The altering of fundamental attributes of a system (including value systems; regulatory, legislative, or bureaucratic regimes; financial institutions; and technological or biological systems)”. This definition is contrasted to that of adaptation (op. cit): “The process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities”. So, for instance, instead of questioning the logic of letting air mobility continue to increase due to GHG mitigation concerns, a traditional approach to that of adapting to climate change would focus on how to protect new airports from, e.g. sea level rise—thus enabling aviation to continue to increase; whereas a transformative approach would combine the two ideas to ‘reduce GHG emissions’ and ‘protect society’—and therefore perhaps come up with the transformative solution to enable society simply to demand for less travelling. Thus, there is a danger that the traditional modus operandi for climate change adaptation may—through what we have denoted as inter rebound effects—lead to the continuation of those structures that initially are the causes of man-induced climate change and, therefore, also to obstruct the need for society to enter into a level of transformative changes (Pelling 2011; O’Brien 2012).

A static or equilibrium model of resilience in human-ecological systems dominates in disaster management, economics and engineering (Groven et al. 2012). In contrast, dynamic resilience predominates in studies related to complexity (Meerow and Newell 2015), e.g. ecological systems and socio-ecological systems. Such considerations are important in considering the pre and post states of a system following a major disturbance, such as climate change-related events or the challenge to transform into a post-carbon society, as they frame how resilience is understood. Hall (2016) suggests that a number of important considerations emerge from the original grounding of resilience thinking in ecological system dynamics as a means to understanding how complex socio-ecological systems, which would include the tourism system for example, self-organize and change over time. This includes a need to be better aware of the ontological and epistemological dimensions of systems, i.e. how systems are conceptualized, especially with respect to emergent properties, as more reductionist approaches may not be sufficient to explain such properties. A further issue is that if resilience is concerned with the dynamic relationships within a system, that is ‘adaptive renewal’, then the survival (sometimes termed resilience) of a particular organization or member of a specific species may not be particularly relevant. It is necessarily neither a positive nor a negative to the system per se. Instead, what is significant is transformation and self-organization in the system as it moves between states (Hall 2016). For example, in commenting on the relationship between resilience and disturbance, including in relation to post-disaster management, Hall (2016) argued that there is no intrinsic relationship between organizational survival and improving the resilience of a community per se. Instead, at the community level, the issues for resilience becomes more which organizations need to survive and what organizations will be born with what characteristics and values to replace those that have died in order to maintain or enhance system properties. Something that undoubtedly includes ensuring is that the system is able to respond to the needs of the most vulnerable (Cutter et al. 2014). As Armitage and Johnson (2006) observe, from a community perspective and also with respect to overcoming resilience-reductionism, the question of 'resilience for whom and for what' needs to be asked. This is not, of course, to suggest that organizational survival is unimportant, but from the functioning of the system within which the organization is embedded, different sets of questions must be asked other than those *just* concerned with organizational survival and the maintenance of what was there before. For each level of a system different concerns arise, and so the emergent nature of a system means that different questions need to be asked at each level and of the system as a whole (Hall 2016).

Both these approaches—the CO_2-reductionism to that of climate change mitigation and the resilience-reductionism to that of adapting to climate change—are examples of how complex phenomena in nature and society are reduced to a limited number of issues which in addition mostly involves numerical mechanisms (Schneider et al. 2000; Orlov 2009). Bhaskar et al. (2010) argues that in order to address properly the complex issues of both creating a sustainable development and avoiding climate change, policy-makers needs to take into account the very important non-reductionistic and complex relationships within and between nature and society. Thus, there is a need to 'open up' the climate change discourse into a more holistic one (Hall 2013). Acknowledging the relevance and importance of different rebound effects and rebound mechanisms that can come into play in climate change adaptation and mitigation efforts may help in achieving this. However, such ecological thinking does not transfer very well to dominant modes of engineering and economic thought that focus on efficiency and return time as being the key characteristics of resilience (Colbourne 2008) and cost-effectiveness as key characteristics of climate change mitigation (van den Bergh 2004), and that usually seek to remove any perceived system redundancies or inefficiencies (Colbourne 2008).

As already pointed out, a number of studies advocate the need to strongly integrate and couple the adaptation and mitigation policy and research domains (Klein et al. 2007; Bizikova et al. 2007; Corfee-Morlot et al. 2009; Warren 2011). An important barrier for integrating adaptation and mitigation policies to a larger extent is the existence of an institutional cleavage between the two. Whereas mitigation policies tend to unfold at a national scale, adaptation tends to operate on a local scale (Wilbanks and Sathaye 2007). Most mitigation policies are 'top down' in the sense that they are instituted at the national and supranational level (e.g. the adoption of new laws specifically addressing mitigation needs) and important measures are implemented at the national level (like taxes), but still resting on local implementation of measures to some extent (like land-use planning) (Jones et al. 2007). Adaptation policies are to some extent outlined more in general at the national scale (e.g. in the form of 'national strategies'), but the actual policy development and implementation is in many cases taking place at the regional or even local level of governance. Thus, adaptation has the characteristic of a 'bottom-up' policy area. Often major adaptation initiatives first appeared on the political agenda at the local level, and then as a result of the impacts of extreme weather events (Hall 2006), and then trickled up to the national level (Aall et al. 2012). Furthermore, whereas mitigation policies is mostly promoted by environmental policy institutions, such as the Ministry of environment or similar, adaptation policies are often promoted by civil protection institutions; and these two institutional systems tend to have opposite characteristics of a variety of institutional dimensions (Groven et al. 2012).

As the 'intensity' and 'extent' of adaptation and mitigation efforts hopefully will increase in the years to come, and eventually climate policies will change from an 'adjustment' to a 'transformative' nature, the chances of negative setback effects to occur within and between these two policy fields will most probably increase. This situation underlines the need to gain a better understanding of such setback effects, in which theories on rebound effects can prove to be of great value. Furthermore, this situation also calls for policy initiatives to achieve a higher level of integration between the two policy fields. If such increased integration fails to happen, chances are high that rebound effects will take place at an increasing rate in the fields of climate change mitigation and adaptation policy.

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Chapter 13
The Internet: Explaining ICT Service Demand in Light of Cloud Computing Technologies

Hans Jakob Walnum and Anders S.G. Andrae

Abstract Cloud Computing (CloudC) is one of the most prominent recent trends in the digital communications sector and represents a paradigm shift within the ICT industry. The supply of popular applications, such as cloud storage and cloud video streaming, has caused a surge in the demand for CloudC services, which offer the advantages of low economic cost, high data transfer speeds, and improved mobility, security, scalability, and multi-tenancy. In this chapter, we investigate the circumstances under which this new CloudC infrastructure is likely to reduce energy use of our new digital lifestyle, or when it simply catalyses a rebound effect that could hamper ICT-related energy savings. We classify CloudC rebound effects as either direct or indirect rebound effects, and we discuss the differences and overlap between rebound effects, enabling effects, and transformational effects. An understanding of these differences is important for understanding energy use associated with CloudC.

Keywords Cloud computing · Rebound effects · Enabling effects · Transformational effects

Direct and indirect global energy use by electronic as well as information and communications technology (ICT) devices is an emerging field of research. Thus far, energy use in the form of electricity associated with these devices has been considered a relatively small part of global electricity usage, but one that is growing in significance (Oscarsson 2014; Andrae and Edler 2015). Simultaneously, several emerging technologies have initiated broad and impacts across this sector. Cloud Computing (CloudC) promises efficiencies of scale in terms of both capital and

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H.J. Walnum (✉) · A.S.G. Andrae
Western Norway Research Institute, Sogndal, Norway
e-mail: hjw@vestforsk.no

A.S.G. Andrae
Huawei Technologies, Stockholm, Sweden

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operational costs; high-speed wireless networks promise near-ubiquitous access; and thin-client solutions, such as smart-phones and tablet devices, provide appropriate low-power user-interfaces for exploiting this emerging next-generation ICT infrastructure (Corcoran and Andrae 2013; Andrae and Edler 2015).

CloudC is one of the most prominent recent trends in the digital communications sector and represents a paradigm shift within the ICT industry. The supply of popular applications, such as cloud storage and cloud video streaming, has led to a surge in the demand for CloudC services, which offer the advantages of low economic cost, high data transfer speeds, and improved mobility, security, scalability, and multi-tenancy. Scalability is useful because it enables companies to scale their computing resources according to their immediate needs. Multi-tenancy means that several "tenants" (applications that need their own secure virtual computing environment) share common services of the cloud. Notably, energy efficiency and savings have, as such, not been the drivers of this surge. CloudC can simply be understood as '*a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction*' (Mell and Grance 2011, p. 2).

It can be argued that processing software computing power should also be included in the definition of CloudC. As such, CloudC is not a product, it is a service. Users can obtain nearly unlimited computing power on demand and, occasionally, on a rental basis; they do not have to make major capital investments to fulfil their needs and they can access their data from any place having an Internet connection. CloudC has the potential to reduce ICT expenditure and facilitate the development of new services, such as grid computing software,[1] CloudC interface,[2] and web application frameworks,[3] by efficiently routing large amounts of real-time data over the Internet (Subashini and Kavitha 2011).

Energy and water management systems, precision farming, smart grids, and dynamic workplaces are just some examples of innovative services that use CloudC for central management, integration, and visualisation (GeSI 2015). CloudC also enables users to overcome the limited memory capacity and processing power of mobile devices (Ranjan et al. 2015).

The overarching question posed by this paper is: How can we understand the potential of the CloudC infrastructure to reduce energy use of our new digital lifestyle? In other words, we want to find out what mechanisms lead to a saving potential and what mechanisms work in other directions. To understand this, we review recent literature that focuses on estimating the underlying global energy use

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[1] Grid computing software is a collection of computer resources from several locations that aim to attain a common goal.

[2] CloudC interface is a software that communicates with software applications and services.

[3] Web application frameworks facilitate the development of web applications, such as dynamic websites, by reusing code and templating frameworks from existing applications.

attributable to electronic consumer and ICT devices (Oscarsson 2014; Andrae and Edler 2015) as well as the net effect of CloudC services, including rebound effects (GeSI 2015; Sedlacko et al. 2014a). In particular, the report "SMARTer2030" presented by the Global e-Sustainability Initiative (GeSI)[4] has attracted considerable attention (GeSI 2015). This report indicates that there is much optimism regarding the enabling effects associated with ICT and CloudC, and foresees great potential for ICT to decouple environmental loads from economic growth. The report has also estimated direct rebound effects, and states that the enabling economy-wide effects, i.e. the potential energy and related GHG emission savings associated with the use of CloudC, are much stronger than the direct rebound effect. In this report, we critically discuss whether such optimism is valid. In the rebound discourse, it has been stated that general-purpose technologies (GPTs), such as steam engines, electric motors, computers, and the Internet, are prone to large rebound effects because they affect the entire economy (Sorell 2007).

In this chapter, we will first provide an overview of development trends in energy consumption and GHG emissions associated with cloud computing. Then, we present an overview of the detminates of energy use for cloud computing in a causal loop diagram (CLD), followed by an in-depth explanation of its relationships and variables. The diagram is based on the state of research on rebounds and cloud computing. The CLD will be used as a starting point for (i) a wider discussion on understanding the rebound effects associated with CloudC and (ii) a detailed discussion on the differences between rebound effects, enabling effects, and transformational effects.

13.1 CloudC Energy Consumption and GHG Emissions

Estimations of energy consumption and related GHG emissions associated with CloudC have proven to be challenging owing to a lack of data and ambiguity regarding the appropriate scope for calculating CloudC energy use and associated GHG emissions. Recently, the global GHG emission associated with CloudC has been estimated to be between 1 and 1.5 gigatonnes, i.e. around 2.5 % of the total global GHG emissions—equivalent to the global share of GHG emissions from Germany. CloudC is assumed to have the same scope as the ICT sector (Andrae and Edler 2015). This is a rather rough assumption because it is challenging to separate CloudC from the ICT sector. Some forecasts regarding CloudC energy use and GHG emissions have been carried out. There are two assumptions underlying these forecasts. The first is that the total data centre traffic will increase at a certain rate and the associated power usage and related GHG emissions will rise accordingly but with annual efficiency gains of 10–15 % (Andrae and Edler 2015). These annual gains may be underestimated and could reflect a worst-case scenario. The

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[4] GeSI is a source for information on existing and emerging issues in the area of ICT and sustainability. GeSI's members are mainly ICT companies.

other is based on the power usage effectiveness (PUE; a measure of how much of a data centre's power is used for processing compared to cooling), computing energy used, number of servers, amount of transferred data, and number of computing units (GeSI 2015). The forecasts predict a steep increase due to the growing demand for video applications, improved security, high data transfer rates, etc. Funk (2015) concluded that most types of ICT equipment, such as microprocessors, memory, cameras, lasers, and new displays, experience annual rates of improvement in energy efficiency that exceed 30 % per year. Andrae and Edler (2015) argued that 30 % improvement is not likely at the system level in the long term even though it may occur at the component level.

With regard to CloudC usage, a steep increase in data transfer, a steady increase in energy consumption, and a steady-to-slow increase in GHG emissions are expected in the future. The total data centre Internet Protocol (IP) traffic rose from around 1400 EB in 2010 to around 3900 EB in 2014, i.e. an annual growth of around 29 % (Andrae and Edler 2015). Similar growth rates are expected in the coming years. At the same time, the electricity usage of the ICT sector increased from around 2000–2300 TWh, i.e. by around 3 % annually (Andrae and Edler 2015). Using Cisco data, Velasco et al. (2014) predicted that around 78 % of the global workload will be processed by cloud data centres by 2018, illustrating the significance of CloudC for ICT sector growth. Oscarsson (2014) forecasted that CloudC could use 2000–4000 TWh of electricity by 2030 and as much as 5000–10,000 TWh of electricity by 2040—up several times from the present usage. This prediction is in line with that of Andrae and Edler (2015), who have estimated that the energy usage of data centres and the ICT sector in 2030 will range between 2700 and 8000 TWh. GeSI (2015, p. 54) has predicted around 2700 TWh of energy usage in 2030; however, it has also claimed that smart energy solutions could help reduce total global ICT electricity usage by 6300 TWh in 2030. Furthermore, GeSI has predicted that the electricity savings made possible by CloudC will increase annually until 2030. The scope of GeSI (2015) and the study of Andrae and Edler (2015) cover the entire ICT sector, which in this chapter is considered equivalent to CloudC.

CloudC was widely introduced in 2008. Figure 13.1 shows the estimated correlation between the data traffic and the energy use of data centres from 2015 to 2030 (Andrae and Edler 2015). Global data centre IP traffic is estimated by integrating Cisco's historical mobile data traffic, 2G/3G mobile voice traffic, fixed data traffic, and data traffic within and between data centres. The global data centre IP traffic is a measure of the total global traffic, and it is closely correlated with the growth of CloudC. Data for the years 2010–2014 are based on historical trends. Andrae and Edler (2015) extrapolated these trends to 2030. The best-case scenario of Andrae and Edler assumes a slower increase in traffic, faster improvement in electricity efficiency, and lower growth rate of data traffic than their expected-case scenario. The forecasting of the electricity usage was based on the estimated annual increase in data traffic and annual improvements in electricity efficiency. Figure 13.1 is adapted from the work of Andrae and Edler (2015), in which all details and assumptions can be found.

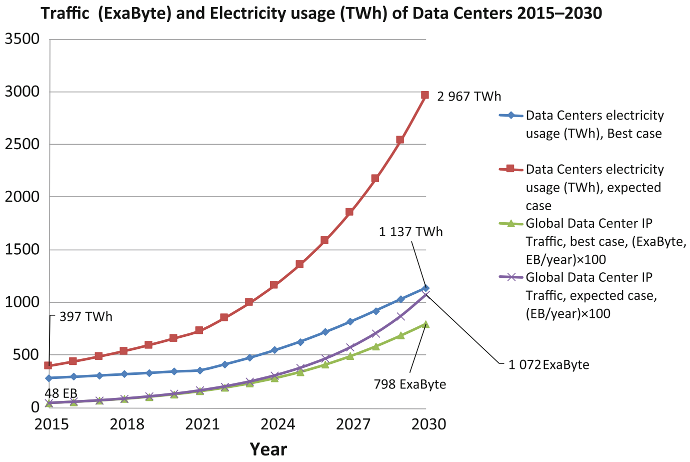

Fig. 13.1 Historical and future global data centre IP traffic and electricity usage

Cloud traffic is predicted to eventually account for the dominant share of global IP data centre traffic. In an environment witnessing an overall increase in global IP data centre traffic and cloud traffic, the proportion of data transferred *between* data centres is likely to increase, while the proportion of data transferred *within* data centres will likely decrease (see Fig. 13.2). The increase in data consumption is induced by increased delivery efficiency. Delivery efficiency is the delivery ratio of the data after optimisation of raw data. The delivery efficiency is improved, e.g. by optimising not only scheduling schemes for efficient delivery of data packets but also the type of cloud business model (Verma and Kumar 2012). Increasing computations between data centres are driven mainly by efficient movement of data between clouds (Velasco et al. 2014). This additional computation and traffic leads to increased energy usage in the ICT sector. The increasing electricity usage of data

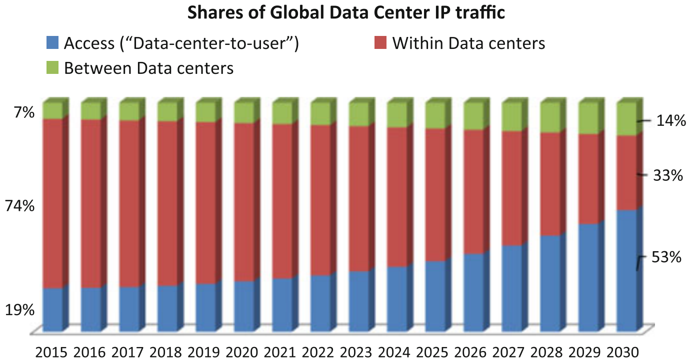

Fig. 13.2 Estimated share of global data centre IP traffic between 2015 and 2030

centres (Figs. 13.1 and 13.2) is propelled by a greater demand for CloudC services (Oscarsson 2014; Andrae and Edler 2015).

Many consumers use both personal server storage and CloudC-based storage, leading to additional energy usage. Furthermore, CloudC fosters additional data transfer in combination with applications based on CloudC, thereby increasing energy consumption by its inherently efficient properties and ease of use. The key variables to consider when determining the trends of global CloudC energy usage are the increase rate in the global data centre IP traffic and the overall energy efficiency improvements of data centres. As cooling represents a large proportion of data centre costs, energy efficiency has been improved by free cooling (Oró et al. 2015). Free cooling may involve air cooling or waterside cooling (Zhang et al. 2014). In the next section, we provide detailed explanations of the determinates of CloudC energy use.

13.2 Direct Drivers of Energy Use Related to CloudC

A causal loop diagram (CLD) for CloudC is shown in Fig. 13.3 [the diagram is inspired by the work of Sedlacko et al. (2014a, b)]. The diagram mainly considers the direct drivers of energy use related to CloudC, excluding external factors such as population growth and predicted economic development, which are also important drivers of CloudC use. The diagram shows causal relations between selected variables, focusing on whether they lead to increased or decreased energy use. They are either positive (increasing; denoted by a plus sign) or negative (decreasing; denoted by a minus sign).

As illustrated in Fig. 13.3, the *use of CloudC services* is predicted to increase rapidly owing to falling costs and increased use of applications such as video-on-demand (Velasco et al. 2014). There is a massive deployment of the CloudC market place, and Katsaros et al. have predicted that it will increase fourfold from 2016 to 2020 (Katsaros et al. 2016). Video-on-demand CloudC services are one of the most crucial variables to be considered, as they generate much more data traffic than other applications.

Box 1. The electricity cost per data centre is increasing with the scale of the data centres; thus, the electricity cost is becoming the fastest-growing component of data centres' operation costs (Zhang et al. 2015). There is an increasing trend towards large-scale data centres whose electricity cost may be around 30–50 % of their operation costs.

Box 2. CloudC services cost/unit is decreasing for end users because of competition and efficiency (Walterbush et al. 2013). Falling unit costs encourage companies to outsource more of their computer needs to data centres. Thus, there will be more efficient use of hardware as well as a reduced need for support teams. Different components of a company's server can be hosted by different clouds or Internet service providers depending on the cost. In the long term, it is not clear

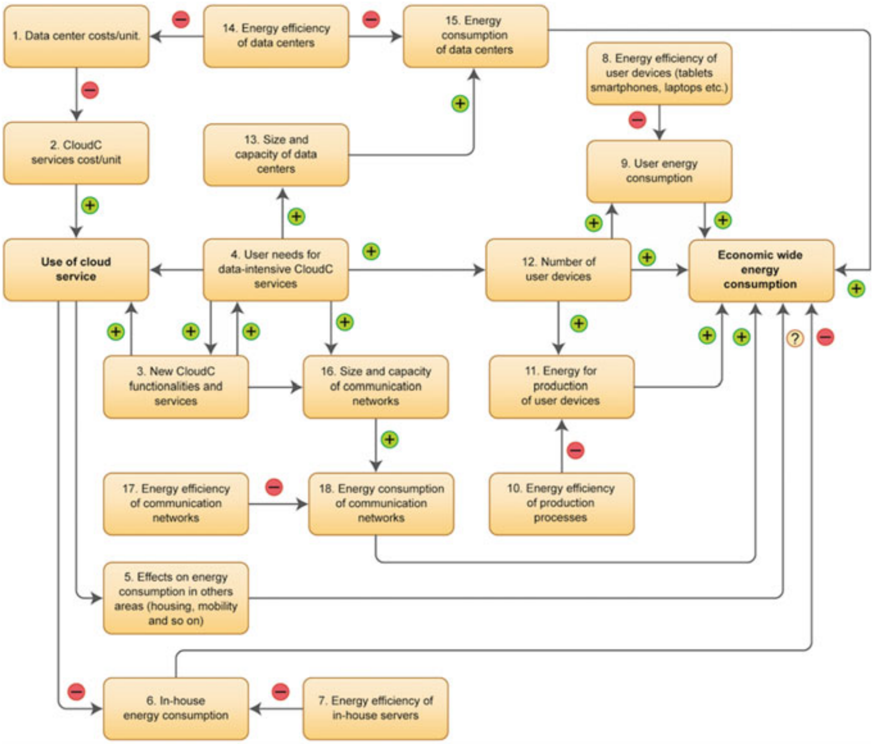

Fig. 13.3 Causal loop diagram for elucidating energy consumption associated with cloud computing (see text below for explanation of the 18 boxes)

whether the cost will decrease. User-specific cost situations should be investigated on a case-by-case basis.

Box 3. New CloudC functionalities and service functionalities are emerging rapidly, e.g. Dropbox, Netflix and YouTube have reported increased data downloads and related energy consumption. Mantas et al. (2015) presented a web service to provide satellite rainfall estimates, offering different data visualisation options including dynamic plots. Yue et al. (2013) showed how CloudC can bring geoprocessing services to geospatial users.

Box 4. User needs for data-intensive CloudC services are increasing. These include, e.g. enhanced search engines, page-rank computation, traffic shaping, layering, and streaming (Shamsi et al. 2013; Williams et al. 2014). New devices such as tablets and phablets, as well as lower data costs, are significant reasons for adoption of CloudC services. CloudC allows people to access a larger amount of data through a greater number of platforms (Shamsi et al. 2013). Video surveillance is a data-intensive CloudC service that is being increasingly employed in various fields.

Box 5. Energy consumption in other areas (housing, mobility, and so on) is predicted to decrease owing to, e.g. smart energy usage in buildings (GeSI 2015;

Malmodin and Bergmark 2015). This view has to be balanced against an increase in production and consumption owing to wider use of the technology at hand.

Box 6. In-house energy consumption of local data centres is predicted to decrease, as the general trend is that local data centres are being replaced by bigger shared facilities. However, local data centres are links in larger CloudC networks and will not disappear completely. Bigger data centres could be more energy-efficient than local data centres (Oscarsson 2014) because, e.g. a big data centre can be controlled by a single geographic CloudC controller, whereas every local data centre needs its own controller.

Box 7. The energy efficiency of in-house servers of local data centres is expected to increase (Andrae and Edler 2015). Even though the number of local data centre servers will decrease, their energy efficiency will follow the same trend as electronics (Funk 2015).

Box 8. The energy efficiency of user devices is increasing (Funk 2015).

Box 9. User energy consumption of personal end-user devices is expected to increase (Terry and Palmer 2015). Compared to 1990, in 2012, electricity used for computing in homes in the United Kingdom increased by around 60 %. This refers to the electricity usage of end-user devices and customer premises equipment such as gateways. However, conflicting messages exist in the literature as to whether this usage will increase or decrease. It is true that on one hand, the number of user devices is increasing, whereas on the other hand, the energy efficiency of each device is also increasing (Andrae and Edler 2015). Moreover, the emerging virtualisation technology is developing rapidly, e.g. gateway functions to the service providers' physical devices (data centres) (Whiteaker et al. 2012).

Box 10. The energy efficiency of production processes is increasing as less energy is required produce more units (Andrae and Edler 2015).

Box 11. The total global electricity required to produce personal end-user devices such as computers and gateways is expected to increase (Andrae and Edler 2015; GeSI 2015). The reason is that the number of produced devices is set to increase by 30 % between 2015 and 2020, which is lower than the rate of increase between 2010 and 2015.

Box 12. The number of user devices such as personal end-user devices, gateways, and Internet-of-things (IoT) devices will increase (Andrae and Edler 2015; GeSi 2015; Andrae 2015). IoT devices constitute a new class of devices that are not always personal end-user devices. IoT devices are expected to be sold in billions, e.g. video surveillance devices and sensor devices such as those used for personal health monitoring.

Box 13. The size and capacity of data centres will increase (Andrae and Edler 2015; GeSI 2015) owing to an increase in the number of computing units, amount of data transferred, and number of servers in use (GeSI 2015). Transport of data accounts for a large percentage of the relative power consumption of CloudC. The volume of data transported increases over time as the download cost per byte falls. For example, the virtualisation of gateways is spurring the transport of data (Whiteaker et al. 2012). Andrae and Edler (2015) argued that the global data centre IP traffic will increase by around 170 % from 2015 to 2020.

Box 14. The energy efficiency of data centres is increasing (Andrae and Edler 2015; GeSI 2015). GeSI expects the PUE to increase by 20 % between 2011 and 2030. Andrae and Edler expect the data transferred per unit of energy used (bits per Joule) to increase by 120 % between 2015 and 2020 (Andrae and Edler 2015).

Box 15. The electricity usage of data centres is increasing (Oscarsson 2014; Williams et al. 2014; Andrae and Edler 2015; GeSI 2015). GeSI argued that between 2011 and 2030, the computing energy will decrease by 30 % while the GHG emission will increase from 0.16 gigatonnes to 0.36 gigatonnes. Andrae and Edler argued that the global electricity usage of data centres will increase by around 60 % from 2015 to 2020.

Box 16. The size and capacity of communication networks will increase (Andrae and Edler 2015). It has become faster to obtain information and easier to access larger amounts of data, which requires higher computational power. In general, users' demand for higher speeds drives the size and capacity of communication networks.

Box 17. With regard to the energy efficiency of communication networks, the bits transferred per joule are increasing rapidly (Andrae and Edler 2015). From 2015 to 2020, for wireless communication networks and fixed networks, the energy efficiency is set to improve around tenfold and twofold, respectively (Andrae and Edler 2015). The fixed network energy efficiency improvements are likely underestimated by Andrae and Edler (2015).

Box 18. The energy consumption of communication networks is increasing (GeSI 2015; Andrae and Edler 2015). Significant measures have been taken to mitigate power usage; nevertheless, the global power usage is gradually increasing.

Economic savings could lead to wider use of CloudC services (a *direct rebound effect*) or to greater consumption elsewhere (a *indirect rebound effect* covered by the boxes 5, 15, 18 in Fig. 13.3). The possible rebound effects shown in Fig. 13.3 occur if consumers or producers save money by using CloudC, resulting in increased use of CloudC (as shown by the link between the boxes box 14, 1, 2). Reduced costs of data storage (CloudC reduces the energy locally used by servers in box 6) could also trigger a *direct rebound* effect. CloudC provides new services and opportunities for people to access a larger amount of data through a greater number of platforms (as shown by the relationship between box 4 and 12). New services associated with CloudC enable people to achieve fast data connections and save download time (shown by the connection between box 3 and 4 and use of CloudC services). Moreover, people can upload data more easily from several platforms (as shown by the relationship between box 4 and 12). The above-mentioned factors will be drivers of the increased demand for CloudC services and will therefore result in increased energy use associated with CloudC. However, in order to understand the *economy-wide* effects of CloudC usage, its effect on energy consumption in other areas (housing, mobility, etc.) needs to be understood. The energy consumption of non-CloudC sectors is predicted to decrease owing to, e.g. smart energy usage in buildings (GeSI 2015; Malmodin and Bergmark 2015). However, there is also a probability of increase in production and consumption, which would counteract the savings.

13.3 Rebound Effects and CloudC

The standard definition of the rebound effect in an energy-economic sense is an increase in energy service demand caused by improvements in energy efficiency. Rebound effects could be either direct or indirect. A direct rebound effect occurs when improvements in energy efficiency increase the demand for household products and services or the output of firms. Indirect rebound effects are associated with net cost savings that lead to a demand for other products and services or that cause firms to re-invest money in order to increase their production (Jenkins et al. 2011; Sorell 2007). The sum of *direct* and *indirect* rebound effects has been termed as *economy-wide* rebound effects (Sorrell 2007).

The direct energy efficiency potential and energy savings at the *micro level* are undisputable; however, thus far, the amount of data transferred has offset the *macro-level* energy savings, possibly via *rebound* effects. It is likely that cloud data centres will grow to such an extent that their overall energy use will increase in spite of improved energy efficiency. Williams et al. (2014) qualitatively identified several potential *direct* and *indirect rebound* effects of CloudC without attempting to include them in their *economy-wide* estimation of the GHG saving effects of CloudC. They argued that any rebound effects would be offset by the *economy-wide* savings. GeSI partly attempted to include *direct rebound* of CloudC-related services and, at the same time, estimated the *economy-wide* savings without considering the *economy-wide* rebound effects or the enabling and transformational effects (GeSI 2015). GeSI estimated that by 2030, CloudC ("ICT") will emit 1.25 gigatonnes CO_2e and be able to off-set 12.08 gigatonnes, i.e. 9.7 times its own GHG emissions (GeSI 2015, p. 10). Starting with off-setting 1.5 times its own emissions in 2015, GeSI assumed that the off-setting will increase annually owing to gradually increasing adoption rates of smart solutions. GeSI presented 12 use cases in which, despite their direct energy usage, ICT solutions have enabled and will enable economy-wide reductions: smart energy, agriculture, logistics, building, manufacturing, connected private transport, traffic control, e-commerce, e-health, e-learning, e-work and e-banking. GeSI estimated savings for these use cases in nine different nations (USA, UK, China, India, Canada, Germany, Brazil, Australia, and Kenya), obtaining specific results for each country. Then, the results were extrapolated to obtain figures on the global impact from the use cases.

CloudC was mentioned to be necessary for all these use cases, the estimated *direct rebound effects* of which are summarised in Table 13.1. *Direct rebound* was assumed to thrive under lower prices induced by increased efficiency.

GeSI (2015) claimed that *economy-wide* energy and GHG emission savings will be possible. However, the authors did not take into account and indirect or economy-wide rebound effects. On the other hand, Galvin (2015) identified rebound effects of 115–160 %. He surveyed the rebound effect literature, based on studies that explored 'transformational' change caused by increasing energy efficiency. Further, he identified structural changes in business, education, the military, and households owing to the increasing energy efficiency of ICT/electronics, which

Table 13.1 Assumed direct rebound effects of ICT and services partly based on CloudC (GeSI 2015)

Use case service	Assumed direct rebound effect (%)	CloudC necessary?
Smart energy, agriculture, logistics, building and manufacturing, traffic control	10	Yes
Connected private transport, e-health, e-learning and e-banking	7	Yes
E-work	27.4	Yes
E-commerce	27.6	Yes

he found to lead to the proliferation of ICT/electronic devices, and consequently, increased energy consumption.

From the state of the art, we can conclude that there is a disagreement with regard to the savings potential of CloudC for energy use, because there is a profound difference in the assumptions on how micro-level savings will affect energy use at the macro level. To what extent does energy efficiency increase the demand for and use of CloudC? How has this induced the adoption of new approaches by consumers and producers? How does CloudC affect social and economic structures? In the following section, we present a detailed discussion on what is meant by rebound effects, enabling effects, and transformational effects in the context of CloudC as well as how these perspectives differ and overlap.

Galvin (2015) found that the classical typology of rebound effects works well for cars, washing machines, and home heating systems, i.e. traditional consumer product. However, this type of scheme is not easy to apply to ICT-related products such as cloud computing because the satiation of consumer needs does not hold for ICT in the same way as it does for other products, and ICT tends to lead to increased production of goods.

The CLD diagram in Fig. 13.3, which indicates an increased use of CloudC owing to reduced costs because of energy efficiency improvements, and thus, money savings, may also imply, e.g. that the lower cost of music and film streaming via CloudC services as compared to physical compact discs and DVDs spurs the demand for CloudC. This could be covered by the classical energy-economic understanding of rebound effects. However, the same is not applicable to the case of new consumption (and production) options that were not available earlier, e.g. increased availability and thus download of music and movies, which is possible at any time and from anywhere. This calls for the need to go beyond the traditional understanding of rebound effects to grasp the potential energy use associated with CloudC services. In most cases, energy-economic rebound effects assume that the consumer preferences and the social and economic structures have remained the same, and under these conditions, the demands of people and companies increase. However, the introduction of CloudC, where energy efficiency is an important driver, increases the number of options for consumers and companies.

13.4 Transformational Effects in the Context of CloudC

Greening et al. (2000) refers to situations where changes in technology “have the potential to change consumers preferences, alter social institutions, and rearrange the organisation of production” (p. 391). For example, ICT has changed social practices and social structures, and has also influenced social exclusion (Galvin 2015). This emphasises the importance of looking beyond economic reasons and focusing on social and psychological aspects for understanding the increased demand for ICT and CloudC services. The rebound debate states that the rebound effects for general-purpose technologies (GPTs), such as steam engines, computers, and the Internet, are large because the opportunities offered by these technologies have long-term and significant effects on innovation, productivity, and economic growth (Sorell 2007).

When it comes to understanding the rebound effects associated with GPTs, the cause-effect relationship becomes blurred, because it is difficult to distinguish the effect of the innovation in itself from the relative importance of energy efficiency to the innovation. Therefore, we will argue in favour of discussing such effects as transformational effects. Even though innovation and energy efficiency are closely related, as discussed in Chap. 9 of this volume, improvements in efficiency and technology are highlighted as necessary conditions for an exceptional degree of social acceleration by modern societies. Energy efficiency improvements enable technological acceleration, which in turn enables social and economic acceleration; all three increase the demand for energy services, which is also relevant for CloudC services.

Lipsey et al. (2005) defined four characteristics of GPTs:

1. Generic products, processes, or organisational forms.
2. Scope for improvement and elaboration.
3. Applicable across a broad range of use, and have potential for use in a wide variety of products and processes.
4. Have strong complements with existing or potential new technologies.

Lipsey et al. (2005) distinguished between different GPTs, mainly addressing what could be called ‘transforming GPTs’. Transforming GPTs leads to massive changes in many, and sometimes most, characteristics of economic, social, and political structures—changes that may radically alter our ways of life. Some important new GPTs, such as lasers, fit into the existing facilitating structure and require few structural changes. Lasers do not qualify as a transforming GPT because when introduced, they fitted into existing social, economic, and institutional structures and caused no major (infrastructural) transformations. Growth is sustained when one GPT enables another and then another, such as when electricity enabled the computer, which then enabled the Internet, which again enabled smart services through CloudC. It is difficult to determine whether CloudC can be classified as a GPT, because it is too early to fully understand its impact on today’s society. The economy-wide transformation associated with technology over long timeframes—in some cases, 50–100 years—must be visible before the effects of efficiency improvements associated with GPTs can be understood (Walnum et al. 2014). We doubt that CloudC can be classified as a transforming GPT because it fits well into existing structures of ICT. However, even though CloudC is not a transformational GPT, as the computer or the Internet, it certainly contributes to a shift in the 'basket' of consumption and production, as CloudC services allow people to, e.g. access their work e-mails from their mobile phones (which has the impact of blurring the differences between personal and professional life) or easily access movies and music. CloudC has increased the number of options that the Internet has given us but has not changed the overall preferences and social structures in the same way as the Internet has; this also matter for energy consumption associated with CloudC.

Even though there is an agreement that CloudC has at least led to incremental economy-wide transformational effects, there is a difference in opinion on its impact on energy use and related GHG emissions. The two positions, arguing for enabling effects on one hand, and for transformational effects on the other, agree that the introduction of CloudC could lead to a wider application in other sectors of the economy and throughout society, than was initially foreseen. However, they disagree as to whether CloudC and other ICT solutions could lead to reduced energy use in economic sectors. The enabling position (GeSI 2015; Malmodin and Bergmark 2015) focuses on how ICT and CloudC could help avoid GHG emissions. These studies assume a linear and direct relationship between improvements in energy efficiency or energy productivity and reductions in aggregate energy consumption. The GeSI included a calculation of *direct rebound* effects for GHG emissions. However, they concluded that *direct* rebound effects were negligible as compared to the *economy-wide* savings from CloudC and therefore are of minor importance. Taking an example from the transport sector, there is great potential for video conferences, tele-meetings, and 3D printers, which will eliminate the need for physical transport of passengers and cargo (GeSI 2015). If such enabling effects could be achieved, CloudC and ICT could decouple economic growth from resource consumption, energy use, and GHG emissions.

On the other hand, analyses of transformational effects within ICT emphasise the opportunities offered by these technologies. They discuss long-term and significant effects on innovation, productivity, and economic growth that increase *economy-wide* energy use (Sorell 2007). Here, the focus is on new consumption and production options made possible by CloudC. The Internet has increased the possibility to, e.g. shop from anywhere at any time. In particular, ICT-related innovation and energy savings have not achieved a major reduction in global energy use and GHG emissions since their introduction (Galvin 2015). This would also suggest that the decoupling possibilities of ICT and CloudC are limited because increased efficiency does not necessarily lead to a reduction of *economy-wide* energy use.

13.5 Conclusion

The chapter presents an overview of energy use and GHG emission associated with CloudC. To understand this, we tried to identify the determinates of energy use associated with CloudC, and we also showed that it is important to distinguish between rebound effects, enabling effects, and transformational effects to understand economy-wide energy use associated with CloudC. Here, rebound effects represent an increase in energy service demand caused by improvements in energy efficiency associated with CloudC. Further, enabling effects represent the energy savings potential, e.g. from transport, precision farming, and smart production processes. However, new consumption (and production) options that were not available earlier lie beyond the scope of such enabling effects. Finally, transformational effects represent new consumer preferences and thus changes in the social and economic structures associated with CloudC; we stress the importance of having an interdisciplinary perspective (e.g. psychological and sociological) to understand transformational effects. Future studies should attempt to further develop a framework for understanding rebound effects and transformational effects related to ICT and CloudC.

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Chapter 14
Transportation: Challenges to Curbing Greenhouse Gas Emissions from Road Freight Traffic

Hans Jakob Walnum and Carlo Aall

Abstract We discuss the implications of rebound effects for various policies intended at curbing greenhouse gas (GHG) emissions in road freight transport. The aim is to provide an understanding of how climate policies must be designed to achieve major reductions in GHG emissions. A number of studies have been conducted on the rebound effect related to energy efficiency improvements of passenger cars; however, the findings cannot easily be translated into results for the heavy-duty vehicles used in the freight sector. From an energy economic perspective, applying econometric and general equilibrium modelling, research on rebound effects on road freight transportation has found that efficiency improvements can reduce fuel costs, increasing the cost-effective transport range of freight and the capacity for generating surplus that might be transformed into other energy consuming activities that can partly offset initial savings. This chapter discusses whether a broadening of rebound effects to also include measures of substitution (i.e. change to less polluting means of transport) and reduction (i.e. policies that aim to decrease the volume of freight transport) will lead to an increased understanding of how to achieve a major reduction in GHG emissions from freight transport.

Keywords Freight transport · Rebound effects · DPSIR framework

The long-term goal in the EU and Norway is an absolute reduction in GHG emissions from the transport sector. The goal of the EU is to reduce transport GHG emissions by 60 % until 2050 (with 1990 as reference year). The goal for the transport sector is lower than what is stipulated for other sectors (80–95 % reduction) due to political, economic and technologic barriers involved in the transport sector and the belief that a sufficient access to transportation services is crucial for securing economic growth, particularly relating to freight transportation (European Commission 2011). However, since 1990, there has been a steep increase in the demand for freight transportation, thus leading to an associated

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H.J. Walnum (✉) · C. Aall
Western Norway Research Institute, Sogndal, Norway
e-mail: hjw@vestforsk.no

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increase in energy use and GHG emissions from freight transportation, especially from road freight transportation. In Norway, GHG emissions from lorries in 2010 amounted to about 2.8 million tonnes (5 % of national GHG emissions).

Road transport has for the case of Norway (as for most other European countries) the largest share of domestic freight transportation measured in tonne-kilometres, and this transport work has more than doubled for Norway since 1990, due both to a greater volume of freight and a strong increase in the average length of haul. Freight is transported over longer distances due to increased specialisation and changes in logistic solutions with centralised production and storage facilities as well as a general decrease in the use of storage. Thus, there is a large need for research to support the ambition to radically reduce GHG emissions from freight transportation. During recent years several projects, both at the national level and the EU level have been started to gain a better understanding of the freight transportation system and how to achieve major reductions in energy use and GHG emissions (Akyelken et al. 2012; Helmreich and Keller 2011; Liimatainen et al. 2012; Piecyk 2010). This research has identified key variables that determine energy use and GHG emissions, has analysed the interaction among these variables, and has presented scenarios for freight transportation development according to different policy options. Although most of this research has focused on road freight transportation, some of it has also addressed barriers and suggestions on how to achieve a switch from road to sea and rail transportation.

Despite these improvements, current research to understand the road freight transport system has ignored a detailed discussion of rebound effects. This chapter intends to fill this gap. It aims at identifying possible rebound effects connected to technology changes and climate change mitigation policies directly or indirectly addressing road freight transportation. It is worth noting that in the tradition of energy economic research, rebound effects are not treated separately from deliberate policies, but that they could emerge as a result of "autonomous" changes (Madlener and Alcott 2009); in this connection measures for energy saving or mitigating GHG emissions carried out by the transport industry independent of any existing policy goals and measures. Examples of such changes are technology changes (e.g. better fuel efficiency due to motor technology), logistical changes (e.g. better utilisation of vehicles) or structural changes (e.g. larger supply chains because of globalisation in production processes where increased efficiency is both a driver and a response)—all of which can have rebound effects to a larger or lesser extent. In this chapter we treat rebound effects more broadly than merely those effects that may be associated with autonomous changes. We will also include "planned" changes; that is, changes due to the implementation of policy measures that aim to reduce energy consumption or GHG emissions in freight transport (Høyer 2011). Furthermore, we have applied and adapted the Driving force-Pressure-State-Impact-Response framework (DPSIR) developed by the European Environment Agency (EEA 1999). The framework consists of five dimensions which are linked together by a cause-relationship. In the centre of the cause–effect chain is the "state"; that is, in our context the manifestation of freight transportation—described by means of transport work (tonne-km) and choice of transport mode (lorry, railroad, boat or

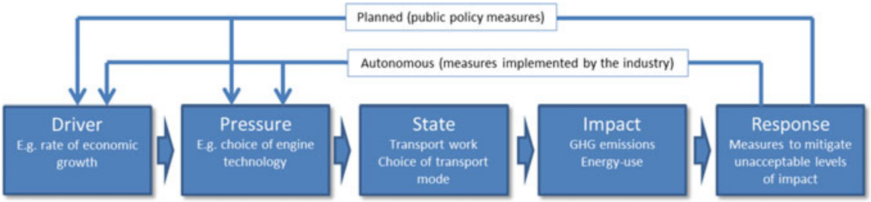

Fig. 14.1 The adopted driving force-pressure-state-impact-response framework

air). The "impact" of this is described by means of GHG emissions and energy use. The category "response" consists of those measures (autonomous or policy measures) implemented in order to mitigate unacceptable levels of impact. These responses could in this context aim at influencing either the "drivers"—which are the societal driving forces behind the manifestation of freight transportation (e.g. level of economic growth)—or the "pressure" which directly influence the manifestation of freight transportation (e.g. the choice of engine technology in lorries) (Fig. 14.1).

The rebound effect occurs when the actual impacts of a given response (be it autonomous or planned) differ from their expected impacts. In this paper, we understand this *as an increase* in tonne-km of lorries following behavioural or other systemic responses after the implementation of new technologies or policy measures that have aimed to curb GHG emissions from road freight transport. In order to differentiate rebound effects from other effect categories (like "side effects" or "trade-off effects"), the rebound effects must be a behavioural or other systemic response that takes place *because of* (and thus after) the implementation of the specific measure in question (cf. Fig. 14.2). Furthermore, our approach is not limited to measures that address efficiency improvements (e.g. improving engine technology in order to reduce energy use per tonne-km); we also include two other generic categories of measures—"substitution" (e.g. shift from transportation by road to railroad) and "reduction" (e.g. to reduce the volume of transportation work in absolute terms).

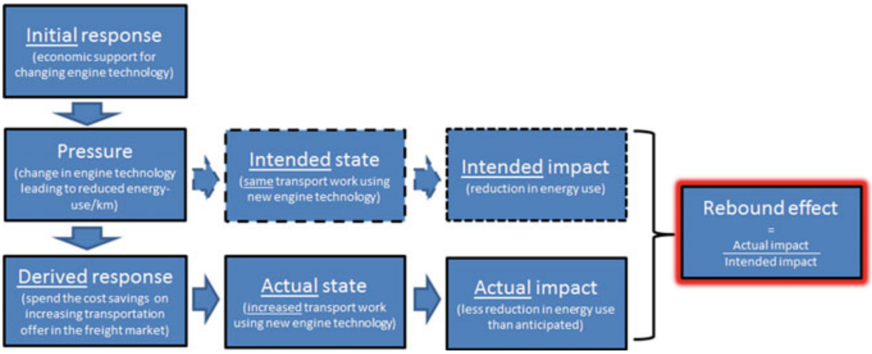

Fig. 14.2 Conceptualisation of the rebound effect applied in this chapter

This chapter addresses the challenges in radically curbing GHG emissions in the road freight transport sector by also addressing rebound effects in freight transportation. We use Norway as a critical case example. We start by introducing the concept of sustainable mobility, followed by presenting a critical literature review of previous research on rebound effects. We then go on by presenting new empirical data from Norwegian freight transportation regarding the historic development of transportation work and its accompanied energy use and GHG emissions, as well as an assessment of policy measures implemented in order to curb GHG emissions and energy use. We conclude by discussing ways to understand possible rebound mechanisms involved when implementing measures to curb GHG emissions and energy use in freight transportation and how to mitigate such rebound effects.

14.1 Sustainable Mobility

In this section we develop a theoretical framework for discussing the policies that are likely to decrease GHG emissions from freight transport. How to achieve major reductions in energy use and GHG emissions associated with transportation has been widely debated in political and scientific sustainable mobility discourses. In a 1992 green paper, the Commission of the European Union launched the concept *sustainable mobility*. The concept evoked considerable interest, both in politics and science. In his thesis, “Sustainable Mobility—the Concept and its Implications”, Høyer (1999) identified three strategies for achieving sustainable mobility: The *efficiency* strategy is about developing new and more efficient technologies to replace the old, inefficient and polluting materials or technologies. The *substitution* strategy proposes replacing today’s dominant transportation systems with more environmentally benign transport systems (for freight, this implies switching from road to rail or sea transport). The *reduction* strategy proposes decreasing freight volumes. According to Høyer (1999), a policy aimed at achieving sustainable mobility as well as any research aiming at analysing sustainable mobility has to include all of the three strategies.

Givoni (2013) explained three different pathways to low-carbon mobility in which he also clarified the relationship between economic growth and transport. He reported that the most applied strategy is the “technological fix” pathway. In many respects, this strategy does not substantially change “business as usual” because the current way of living does not need to change. Transport speed continues to be central and therefore travel time, and not distance, is important. This pathway, which can be associated with the tradition of “ecological modernization”, assumes that environmental and economic objectives do not necessarily contradict each other. It primarily looks at the reduction per unit of transport (in the case of freight transport, emissions per tonne-km) and not the underlying societal causes for transport growth.

Givoni’s second pathway achieves low-carbon mobility by maintaining or increasing rates of economic growth without increasing (or even decreasing) mobility. According to Givoni (2013), decoupling between freight transport and economic growth could be achieved by a change from globalisation towards ‘glocalisation’ which implies production in self-contained local or regional markets. The production, distribution, and consumption of goods and services are then performed across much shorter distances. ‘Glocalisation’ entails reducing the demand, and need, for the long-distance physical movement of people and goods. Globalisation can still occur under ‘glocalisation’; however, ‘glocalisation’ implies a moving away from the principle of ‘just in time’ (which is the principle of delivery a component before the assembly line needs it), as well as a change from long supply chains (transcontinental) and towards the replacing of long-distance transport by transferring of knowledge and know-how to the local level so that local production can take place (ibid.). Furthermore, another main component of this pathway is to make the full environmental cost of transport visible. The pricing of carbon and other pollutants should be at a much higher level than today because transport cost is included in the prices of all products. This strategy emphasises reducing distance rather than increasing speed.

Givoni’s third pathway goes under the slogan “less can be better” and “re-thinking growth”. This strategy challenges gross domestic product (GDP) as an indicator of prosperity and instead focuses on well-being as a main policy objective. This implies a shift in societal values towards alternative forms of production and consumption (avoiding travel is one result of this strategy) and perhaps even towards different forms of ownership. Thus, a change towards a different economic and societal system is central to this pathway.

Looking more closely at the three sets of sustainable mobility strategies, the first strategy in both sets (“efficiency” and “technological fix”) has a main focus on technological solutions. However, technological fixes only addresses the negative environmental *effects* and not their underlying causes. As a result, the fixes could lead to transferring environmental problems from one sector to another or lead to the creation of new environmental problems. The second strategy in both sets (“substitution” and “glocalisation”) could be termed as an intermediate position that seeks to change the transport system and the mode of transport. The third strategy highlights the need to have an environmental policy that looks at the underlying causes as well as the need to achieve sustainable development through societal transformation.

14.2 Rebound Effects Further Defined and Previous Research on Rebound Effects in Freight Transport

Looking at the meaning of the word “rebound”, it is something that sends you back to a state in relation to what you have been trying to achieve (Levett 2009). In this chapter, we understand the rebound effect as an increase in energy service demand or GHG emissions that has been caused by behavioural or systemic responses to the autonomous implementation of new technologies or to policy measures, which aim to reduce energy use or GHG emissions in freight transport (Høyer 2011).

A key question is how resources that are freed up through better efficiency are used. Banister (2011) points out that the dominant paradigm within transport analysis has been to focus on travel time and travel time savings, which has led to a desire to speed up traffic. However, increased speed generates higher energy use and might in addition lead to longer travel distances. A reason for this situation to occur could be that travel has been seen as a derived demand, i.e. where travel is a means to an end, and therefore that distances and travel time should be as short as possible. However, this hypothesis should be challenged because travel distances have increased over time.

For freight transport, it is also acknowledged that measures to increase supply chain efficiency can reduce supply chain costs, which can potentially result in an increased demand (since costs are lower). In the long term, this process can lead to a rebound effect that increases emissions. Throughout the supply chain improvements can be made to increase speed, such as the introduction of new vehicles and reduction of time used for loadfill. However, fast transport implies high energy consumption and increased emissions across the supply chain. So the balance between efficiency, energy use and related GHG emissions is a key issue for freight transport and the logistics industry (Liu 2013).

During recent years there has been a growing interest in possible rebound effects from freight transportation within the energy economic understanding of rebound effects. The way of estimating these kinds of rebounds has been by applying econometric methods, which use price elasticities to estimate rebound effects. For instance, calculations are based on the elasticity of demand for useful work with respect to its energy cost or to the price of energy, or the elasticity of demand for energy with respect to its price (Winebrake et al. 2012). An alternative method is that of general equilibrium modelling (Anson and Turner 2009). Both methods define rebound effects as behavioural changes associated with a lower cost of transport caused by improvements in energy efficiency. Thus, when calculating the size of the rebound effect, it is crucial to be able to make an estimate of the fuel efficiency (or fuel intensity). Without this variable, it is not possible to estimate the rebound effect according to an energy economic understanding. The variable of fuel intensity needs to been seen in connection to vehicle-kilometres or tonne-km; for example, improvements in fuel use per tonne-km.

A calculation of possible rebound effects needs to control for other variables as well. However, it is difficult to isolate and quantify all variables that should ideally be controlled for from an energy economic perspective.

Research on rebound effects relating to road freight transport has pointed out that many efficiency improvements have in fact reduced fuel costs, thus also increasing the cost-effectiveness, which has—as an effect—also increased the transport distance and hence, caused direct rebound effects. At the same time, increased cost-effectiveness has led to an increased capacity for generating surplus that might be transformed into other energy consuming activities and, hence, cause indirect rebound effects (Anson and Turner 2009; Winebrake et al. 2012).

Matos and Silva (2011) analysed road freight transportation data in Portugal from 1987 to 2006. They considered the elasticity of freight transportation with respect to its energy cost. According to the authors, the demand for lorry freight transport was governed by the energy cost of transportation, the economic output (GDP) at constant prices, and the price of oil.[1] They found a rebound effect of 24.1 %. De Borger and Mulalic (2012) used time regression analyses to estimate the short- and long-term rebound effects of fuel efficiency gains for the trucking industry in Denmark from 1980 to 2007. They found a long-term rebound effect of 16.8 %, which was higher than the short-term effect (9.8 %) because firms rearranged their operations to capitalise on their efficiency gain, for example, by investing in more energy-efficient lorries.

Anson and Turner (2009) studied the rebound effect of energy efficiency improvements that could be associated with logistics improvements and vehicle technical improvements within the Scottish commercial transport industry. The key focus of their study was to find the economy-wide oil rebound effect from energy efficiency improvements in the Scottish commercial transport industry. They found an economy-wide rebound effect of 36.5 % in the short term and 38.3 % in the long term. The minor difference between the short- and long-term effects is because the latter effect also includes disinvestment effects. Long-term adjustments are constrained by disinvestment effects, reducing the productivity capacity in the energy sectors. Such disinvestment effects may occur in domestic energy supply sectors if direct and derived demands for energy are not sufficiently elastic to prevent falling energy prices from leading to a decline in revenue, profitability and return on capital in these sectors.

Winebrake et al. (2012) conducted a literature review on the direct rebound effects from road freight transport. Their review highlighted the challenges associated with estimating the amount of the rebound effect and what influenced the result. They found that current models do not fully account for the complexity of the freight transport sector when estimating the direct rebound effect. The transport sector consists of a large number of different economic actors, such as shippers, carriers, logistics providers, and goods handlers. Furthermore, freight parameters are dynamic; for example, payload and other operating practices change in correlation with lower fuel cost. It is also difficult to model decision-making by lorry owner-operators and freight customers, and how variables, such as fuel and vehicle capital cost, factor into decision-making related to fuel consumption and demand for lorry services. Furthermore, these types of detailed rebound calculations for freight transportation are dependent on detailed data on commodity type, distance shipped, and the availability of modal alternatives (Winebrake et al. 2012).

From the state of the art within energy economic studies on rebound effects in the freight transport sector we conclude that rebound effects are of some importance, but that a large share of the savings potential from energy efficiency improvements is actually realised. At the same time, the findings suggest that

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[1] A weakness in their model is that there is a close connection between fuel costs and price of oil. These two variables could not been seen as independent of each other.

reaching the European Union targets to reduce GHG emissions from freight transportation appear to be a challenging endeavour.

In recent years, rebound research has shifted from solely being within an energy economic tradition into becoming an interdisciplinary research field which includes a number of different theoretical positions, research disciplines and methodologies (Giampietro and Mayumi 2008; Peters et al. 2012; Santarius 2012; Walnum et al. 2014; Weidema 2008). One example of this process of widening out the rebound research agenda is that of applying thermodynamic theories; for example by Ruzzenenti and Basosi (2008) who have stated that an efficiency improvement may actually be used for power enhancement in a time-frame analysis. They have shown that technological improvements that were initially made to reduce consumption, such as enhanced engines and improved aerodynamics, actually led to increasing the power of the lorries during the period 1970–1995. They argued that energy conservation policies should manipulate energy costs or impose time-rate limits—e.g. by increasing the weight of lorries and decrease their speed. Increasing weight affects the efficiency process, whereas decreasing the speed reduces the power output of the process (ibid.).

The main emphasis of previous studies, most of them conducted within an energy economic understanding of rebound effects, has been on determining the size of the rebound effect. In this chapter, we discuss what influences growth in freight transport from a system perspective and look at indirect, direct and response drivers, using a simplified version of the DPSIR framework. Indirect drivers are societal factors (economic growth and industrial development); whereas, direct drivers are physical entities connected to freight transportation that directly govern the amount of GHG emissions and transport costs (e.g. transport distance, type, volume, and weight of goods transported; technical characteristics of lorries; and type of fuel). Response drivers are policies that may interfere with either direct or indirect drivers. The main emphasis of this discussion is not to find the size of the rebound effect in a Norwegian context but to find out how to achieve a major reduction in GHG emissions from freight transport. An important part is to address the possible rebound effects associated with response drivers.

14.3 Methods Applied

We have analysed and combined a number of statistical sources from statistics Norway connected to freight transport, concentrating on those that have relevance for road freight transport (for a detailed outline of which statistical sources that are applied see Walnum et al. 2015). In order to get a clearer picture of the actual trends in freight transportation developments we wanted to look as far back in time as availability in accessible and reliable transport statistics allowed us. We ended up looking at the period 1990–2013.

We have reviewed the literature on models that are developed in order to explain drivers for freight transport as well as the literature on rebound effect relating to the freight transport sector. We also assessed Norwegian governmental policy documents and research reports to identify possible policy measures (response drivers) that were primarily or subordinate motivated by a goal of reducing GHG emissions.

Furthermore we do a theoretical discussion of the possibilities for rebound effects associated with the suggested and implemented policy measures. The scope of our analysis is road freight transport, but we also included to some extent perspectives relating to other means of transport. We look first and foremost at domestic transport, but we are also to some extent looking at freight transport to and from Norway.

14.4 Development in Freight Transport Performance and GHG Emissions

14.4.1 Economic Development and Transport Work

Economic growth is closely related to freight transportation, and the possibility of decoupling economic growth and energy use and related GHG emissions has been the subject of considerable research (see e.g. Smith et al. 2010 for an overview)—and research has also taken place specifically aiming at the freight transportation sector (Åhman 2004; McKinnon 2007; Sorrell et al. 2012a; Tapio 2005). It is common to distinguish between absolute decoupling—e.g. when the transport volumes decrease and GDP increases—and relative decoupling; when they grow at different rates (Sorrell et al. 2012b). Tapio (2005) refines the categorization of different forms of decoupling: According to him, for the case of transportation, negative decoupling occurs when transport volume increases faster than GDP; weak decoupling occurs when transport volumes increase more slowly than GDP; strong decoupling occurs when transport volume decreases when GDP is increasing; and recessive decoupling describes a situation in which both GDP and transport volume decrease, but transport volume decreases faster than GDP. Some authors have found signs of absolute decoupling in freight transportation, in some countries for specific time periods (Rommerskirchen 2005; Tapio 2005), while others have found only relative decoupling, when taking into account the shortcomings of current statistics (Åhman 2004; Sorrell et al. 2012b). An important point is that there are large differences among countries and during the different times under study. Studies made by Tapio (2005) and Rommerskirchen (2005) find large differences among countries—even within Europe in the same time period—in the relationship between tonne-km and GDP. This relationship often differed across periods in time. Looking at Sweden, both Trafikverket (2013) and Andersson and Elger (2007) find that tonne-km/GDP develops differently during different stages of economic cycles. Overall, there seems to be some agreement that the tonnage transported has recently increased less than GDP in Europe, and that vehicle-kilometres and emissions per tonne-km have declined somewhat due to increased capacity utilisation and use of larger lorries.

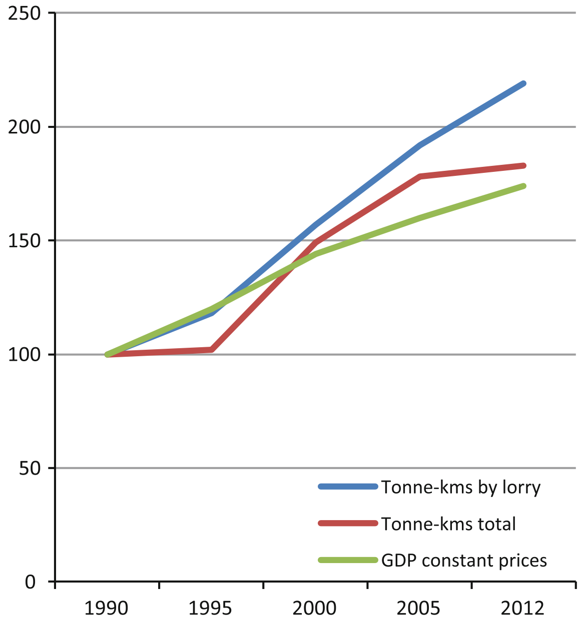

Fig. 14.3 Development of domestic transport performance and GDP at constant prices in Norway. Index figures, 1990 = 100 (Walnum et al. 2015)

Figure 14.3 illustrates that for the case of *Norway* there is however *no* sign of decoupling taking place within the road freight sector for the period 1990–2012 (Hille 2014). Throughout the years 1990–2012, total domestic transport performance has increased only slightly faster than GDP (82 %, compared to 74 %), and if we include cross-border hauls, total transport performance has grown by just over 83 %.

Obviously, there is a connection between economic growth and transport performance, but having a higher resolution of explanations of variables will let us determine which variables have accentuated and which have mitigated this effect. As exemplified by the international literature, the relationship between growth in GDP and road tonne-kms can be decomposed in several ways. The three words "road", "tonnes" and "kilometres" already point to three separate drivers. *Road* freight transport could have evolved differently from the total of freight transport, due to modal shifts.

14.4.2 Volume of Tonnes Transported and Length of Haul

Figure 14.4 shows that the tonnage of goods transported between points within Norway has grown strongly since 1990, but the average length of haul has grown even more. This could partly be a spurious effect in the sense that goods need not be

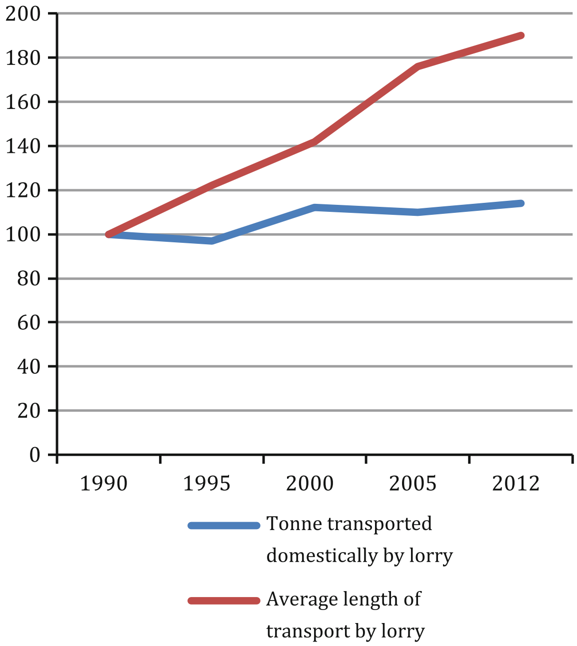

Fig. 14.4 Development in tonne transported and average length of transport domestically by lorry. Index figures, 1990 = 100 (Walnum et al. 2015)

moving that much further on average, but moving in fewer stages. The same goods could be moving further, which in common sense terms means an increase in *kilometres*, although it will not necessarily show up that way in freight transport statistics. If a given type of goods were moved 100 km on average in year A and 200 km in year B, but moved only once in both years, then this will appear as an increase in the average length of haul (km). However, if the 200 km in year B consisted of two trips, such that the goods were unloaded at warehouses midway and then loaded onto new lorries to travel further, then this will appear as a doubling of the number of tonnes transported, and no change in the length of haul. The tonnage of goods is counted anew each time they are loaded onto a new vehicle. The number of such events is called the handling factor. However, we could not follow the true distances of goods moved since the Norwegian statistics does not take into account the handling factor. For some consumer goods, this is certainly a plausible trend—that instead of being moved from a national distribution centre to regional distribution centres and then on to retail outlets in the region, goods are being moved from one distribution centre directly to outlets all over the country. However, the trend towards longer hauls is so strong that it is likely to have more causes than this.

Possible explanations for the growth in average length of haul include both *concentration* and *specialisation* among domestic producers of goods transported.

The phenomenon of concentration, noted by McKinnon (2007) with reference to the UK, implies a trend towards fewer but larger production facilities for the same goods. If each producer supplies a regional market, the size of these markets—and the average distance over which goods have to be transported to reach consumers or intermediaries—will grow as the production facilities become fewer, larger and farther between. If we are talking of industrial producers whose raw materials are sourced from widely distributed primary producers—typically processors of agricultural products—then the average distance over which the raw materials have to be transported to reach the processing plants will also tend to increase as the latter become fewer and farther between. Such a tendency to concentration has long been evident in parts of the food processing sector in Norway.

Tendencies to concentration, albeit less dramatic, can also be seen in brewing and soft drink production (several major breweries which previously served regional markets have closed or discontinued soft drink production since 1993), sawmilling (the number of sawmills employing at least five persons declined from 194 to 138 just in the period from 1999 to 2012), and probably also in sectors such as grain milling and packaging of vegetables.

However, in the domestic sector which generates the most freight measured in tonnes—quarries, gravel and sand pits—no such tendency to concentration is evident; on the contrary, the number of enterprises has increased somewhat since the late 1990s.

Specialisation means that each enterprise, although still belonging to the same generic sector, tends to produce a narrower range of goods. For instance, of the 34 dairy plants still operated by TINE (Norways largest producers of agricultural products) in 2013, only 15 delivered liquid milk products; some others produced, for instance, only a few varieties of cheese or readymade desserts, of which they might be the only producers in the whole country, so that the products in question were distributed from one point to the whole of Norway.

Few of the sawmills deliver the whole range of sawn and planed products that local builders may desire. In the case of products from quarries, etc. specialisation may explain most of the two-thirds increase in average length of haul since 1993, as construction firms demand not just any crushed stone from the nearest quarry, but particular qualities which they may have to obtain from further away. Growing exports of crushed stone to other European countries may also be a partial explanation, as stone destined for export appears to travel a longer average distance to port than that destined for domestic consumption.

However, there is one other "industry" in which both concentration and specialisation since 1990 are likely to have had a significant effect on lengths of haul, and perhaps more than a negligible effect on transport performance by lorry. This is *waste treatment*. Unfortunately we cannot follow the trend in waste transport further back before *2008*, since waste does not appear as a separate category in transport statistics before then (cf. discussion of trends in lorry transport by type of goods). However, we know from waste statistics that as late as 1995 over half of all household and industrial waste (52 %) either went to landfill or was disposed of in "unknown" ways, which is likely to mean that it was either dumped or incinerated locally, perhaps privately if not illegally. Moreover, most of what was landfilled in the early 1990s was disposed of locally. In 1992 there were 330 recognised landfill sites in Norway—most municipalities had their own. Today, as a result of progressively tougher regulations, only some 60 remain, so that whatever goes to landfill must on average travel much further. But by 2012 only one-sixth of waste either went to landfill or was disposed of in “unknown” ways. The remainder often travelled still further—some of it to be burnt at a district heating or CHP plant, the food waste sometimes to a regional biogas plant and other fractions to be recycled, sometimes at far distant paper mills or other factories or construction sites and sometimes even abroad (which can still involve *domestic* lorry transport, to a regional depot and/or onward to a harbour).

Concerning finished products from manufacturing industry, the situation is simply that few of them are produced in Norway on a major scale for the domestic market, or have been at any time since 1993. Overwhelmingly, most capital as well as durable consumer goods is imported, so that lengths of haul by lorry within Norway depend mainly on the point and manner of border crossing and the structure of wholesaling or distribution centres within the country.

Finally, a reason may be that the average length of haul by road could have increased as a result of lorries having taken over some of the long-haul transport that was formerly done by ship or train. It is difficult to deduce from statistics whether this has actually taken place. If it has, one might, but need not necessarily, assume that lorries would mainly have taken over some of the shorter hauls that were formerly carried out by ship or train, and that the average length of haul by these other modes would also have increased. One might perhaps also expect the tonnage of goods moved by ship or rail to have either declined or grown less than that of goods moved by road. In fact, the average length of haul both by ship and by rail has grown over the 1990–2012 period, albeit moderately (by 15–20 % in both cases). The issue of whether lorries have actually displaced ships and trains on some long hauls (i.e. longer than average for lorries, though possibly shorter than average for ship or rail transport) therefore remains moot and demands closer examination.

14.4.3 Development in GHG Emissions and Total Transport Performance

Figure 14.5 shows that GHG emissions from road freight transport have grown somewhat less than transport performance. Emissions measured per tonne-km have declined by some 20 % from 1990 to 2012.

There could be several reasons for this:

- Average capacity utilisation in lorries could have improved, due to higher loading factors.
- The share of heavy lorries in transport performance could be increasing. There is a well-known tendency for heavy vehicles to use less fuel per tonne-km than lighter vehicles. If vehicle-kilometres have increased less than tonne-km there is therefore reason to expect a decline in fuel consumption per tonne-km.

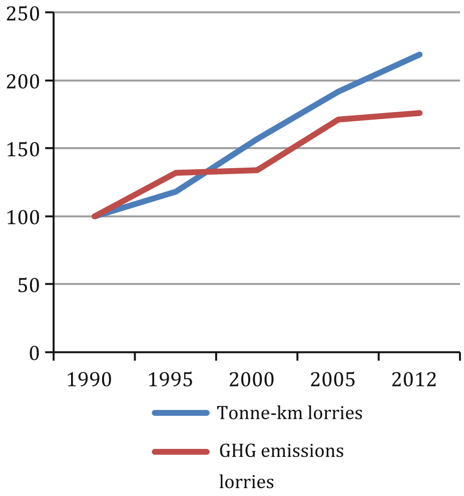

Fig. 14.5 Development in tonne performance tonne-km and GHG emissions from 1990 to 2012. Index figures, 1990 = 100. *Blue line* tonne-km, *red line* GHG emissions (Walnum et al. 2015)

- The average fuel efficiency of lorries could also have improved for other reasons, such as better engines, reductions in aerodynamic or rolling friction or better driving techniques.
- GHG emissions could have grown less than fuel consumption due to substitution of fossil fuels with other sources of energy, e.g. biofuels.

Apparently, most of these factors have been at work. From 1990 to 2012, the share of loading factor in domestic goods transport has declined from 29 to 26.4 %, which could explain a reduction of over 3 % in fuel consumption per tonne-km. The average tonnage carried by lorries on loaded trips has increased from 11.3 to 12.3 tonnes. This is probably a combined effect of heavier lorries and better capacity utilisation and could explain a further drop of some 6–8 % in fuel consumption per tonne-km. Since 2009, almost all diesel oil sold in Norway has contained a fraction of biodiesel, now commonly 5–7 %, which could explain the corresponding drop in GHG emissions per tonne-km. The few percentage points of a likely drop in specific emissions that cannot be explained by the three factors may be the result of more efficient engines and drive trains, less friction, and better driving techniques.

14.5 Measures to Curb GHG Emissions

As presented above, we have chosen to group relevant measures under the three headings—efficiency, substitution and reduction (cf. Table 14.1). We will use this typology to structure the review of proposed and implemented measures aimed at curbing GHG emissions or reducing energy use.

Table 14.1 Strategies for achieving sustainable mobility and radical less carbon emission in freight transport

	Strategies		
Term used by Høyer (1999) and Givoni (2013) respectively	Efficiency/technological fix	Substitution/glocalisation	Reduction/rethinking growth
Approach to policy	Effect oriented	Intermediate	Cause oriented strategy
Commonalities among the Høyer and Givoni	Main emphasis on reduction through more efficiency such as less energy use or GHG emission per tkm, either by logistical improvements or engine improvements	Changing the transport system, a shift to more environmental benign transport forms, as well as a shift in production to shorten transport distances	Highlighted the volume problem with transport and the need to reduce goods transport by a reorientation of societal values
Differences between Høyer and Givoni	Givoni states that this strategy does not influence our way of living and the goal of continues economic growth	Høyer (1999) only highlight the need for shift in transport modes, Givoni (2013) main emphasis is on changing the production system so it demands less transport	Differs in the way that Givoni (2013) connects the strategy to the need for changing our thinking about economic growth

14.5.1 Efficiency

It is within the category "efficiency" that we find the most examples of measures actually carried out with the overall or subordinate goal of reducing GHG emissions or energy use in freight transportation. Bio-blending is a legislative measure with the combined aim of increasing the renewable share of the total energy use of society and reducing GHG emissions from road transportation. The EU has set a target for increasing the share of renewables in transport fuels (European Union 2009). One measure to achieve this target is the blending of biodiesel with fossil diesel. The B7 diesel-variety (7 % biodiesel) is commonly used in large parts of the EU as in Norway. B7 was implemented in Norway in midyear 2009. Indirect energy use associated GHG emissions could outstrip some of the stipulated gains of bio-blending—which in case is an indirect rebound effect, since the aim with the regulation is to curb GHG emissions.

Regulation concerning the energy efficiency or size of lorries is a measure that can reduce both GHG emissions and energy use. Norway allows modular lorries of up to 25.25 m long and a weight of 60 tonnes in specific stretches from 15th of September 2014 (in the period 2008–2013, these lorries were allowed on a trial basis). Norway allows lorries up to 19.5 m and a weight of 50 tonnes in general. Larger lorries allow for better logistical efficiency since more goods can be transported per driver and at lower costs and an accompanying reduction in the need for drivers, fuel, as well as payments connected to using toll roads. The energy use per transported tonne has decreased. A study by the Norwegian Institute of Transport Economics (TØI) for the period 2008–2013 documents that module lorries can provide more efficient and environmentally benign freight transport on a few stretches of road with good standard (Wangsness et al. 2014). However, reduced costs could lead to increased demand as well as a modal shift from rail to road, thus representing a potentially large rebound effect. In order to avoid such negative rebound effects, restrictions have been implemented specifying that modular lorries are not allowed on stretches where they compete with railways.

Eco-driving is a measure that is applied for both freight and passenger transport. It is about shifting behaviour of the driver. It promotes itself as a measure that is both environmentally and economically benign. Several studies document that modifying driving behaviour can reduce fuel consumption, though to a varying degree (Walnum and Simonsen 2015). A difference was found for bus drivers in the short and long run. In a situation where eco-driving was reported to have saved 10–15 % of fuel consumption during training, this figure had decreased to about 4–5 % 3 months after training; and long-term savings were found to be around 2 % (af Wåhlberg 2007). Eco-driving is not a mandatory part of driving license education in Norway. However, an increased awareness about eco-driving has been documented in recent years (Walnum and Simonsen 2015). Several EU countries have incorporated both a theoretical and a practical introduction to eco-driving into driver's education, and many of the largest transport companies operating in Norway offers courses in eco-driving to their drivers. Furthermore, the sale of onboard systems to monitor fuel consumption as well as eco-driving practices in the transport sector has increased rapidly during recent years (ReportLinker 2014).

Technical measures, such as adjustments to the type of trailer, tires, lubricants, and curb weight, as well as the aerodynamics of trailers, could easily save fuel consumption by 5–10 % (Demir et al. 2014; Nylund and Erkkilä 2005). These measures fit with the efficiency strategy and are first and foremost connected to competition between lorry producers; to some extent it could also be influenced by transport companies and lorry drivers.

Better logistical efficiency and improved capacity utilisation may reduce the cost per tonne-km connected to work, hence also reducing energy use and GHG emissions. However, this can also lead to an increased demand for lorry transport and thus create a rebound effect. Eco-driving, logistical efficiency, technical improvements, allowing for larger lorries as well as bio-blending are all examples of measures with the potential of reducing energy use and GHG emission. From our statistical analysis we have documented that GHG emissions per tonne-km for the case of Norway have declined by some 20 % from 1990 to 2012. However, using available statistics, it is difficult to explain why this situation has occurred. Furthermore, we do not know how the development in lorry size has been during the period investigated due to limitations in public statistics.

Within the energy economic tradition, the size of the rebound effect is measured through improvements in fuel efficiency (for example, per tonne-km) and the contributions that the related reduction in operating costs makes to the increased demand for lorry transport. Central to the estimations of the rebound effect is the ratio of fuel costs to other lorry costs, such as capital and wages. In Norway, this ratio is approximately 24 %—if fuel consumption per tkm decreased by approximately 15 % over that period (we estimated that GHG/tkm dropped by 20 % and we subtracted a bio-blending share of between 5 and 7 %), then the cost of truck transport may have decreased by slightly less than 4 % per tkm for the period 1990–2012, relative to what it would have been with no improvement in fuel efficiency. In could be that in some cases then, lorry transport has gained an advantage over rail transport or that the slightly lower cost of transport may have strengthened the incentive to centralise production and logistics facilities.

However, the rebound effect cannot be calculated more precisely because of a lack in detail in official transport statistics. It is also evident that larger lorries allow for better logistical efficiency because more goods can be transported per trip, resulting in lower wage, fuel and road toll costs. This efficiency must be accounted for when economic gains are made because of shifts to larger lorries. However, we could not follow up on this factor because of data limitations. What is still evident is that, during the period of our investigation, the increase in fuel efficiency was not able to counteract the increase in GHG emissions because of an increased volume of road freight transportation.

14.5.2 Substitution

Norway, as well as the EU, has an overall goal of shifting freight transport from road to rail and sea. However, in many cases, the reduction of GHG emissions is not used as a main argument when arguing for increased public investments in “better” rail and sea transport (Klimakur 2020 2010). The main argument seems to be to reduce transportation costs and to avoid congestions in road transportation. Achieving this goal, for the government, has been about providing investments in the form of subsidies and grants for railway infrastructure (for freight transport, investments could be in infrastructure for crossing railway tracks and building new terminals) as well as grants for harbours, even if they are much smaller compared to railway. We have analysed the investment in railways since 1993 using the actual expenditures for each year, not the amounts planned for in the national budget, and we deflated the numbers to get constant monetary units (Walnum et al. 2015). There has been a steep increase in investment in railways from 2009 onward. It is still too early expect very visible effects when it comes to any reduction in GHG emissions from freight transportation. Stretches of new track on which work was started during the last few years of our investigation period may not have opened by the end of our period of investigation. Even if improved track maintenance makes freight trains run more punctually, it may take some time before businesses count on this as a lasting situation, and reconsider their choices between lorry and rail transport. Furthermore, passenger transportation has priority over freight transportation for most railroad tracks.

Theoretically, measures that would increase the competition from railway (for example, through rationalisation such as fewer terminals and container transport) could possibly lead to the use of lorries for the transport of smaller amounts or shorter distances. Another possibility is that a shift from road towards sea or rail may decrease road congestion, since fewer lorries would be on the roads. In the long run, this space could be counteracted by an increase in newly generated freight and person transportation by road. For Norway, there has actually been no net shift from road to sea and rail, rather the tendency is in the opposite direction. However, we do not know what the situation would have been with fewer measures in action aimed at promoting a shift from road to rail and sea. Thus, it is difficult to specify the level of rebound effects that might have come into play without additional, more detailed studies than our research allowed for.

14.5.3 Reduction

We have not been able to come across any examples of Norwegian policy measures that are specifically aimed at reducing the volume of transportation. However, the current legislative framework in Norway for transport and land-use planning has as one of its prime objectives to reduce the transport need for person transportation—and has thus probably contributed in actually reducing demands on person transportation, and thus probably also slowed down to some extent the increase in energy use and GHG emissions from person transportation during the last decades (Næss 2003). The potential effects of this on freight transport is however unknown, most of all because this is an under-research area, and thus very little is known about how land-use planning may influence on freight transportation. Still, it does not seem likely that current land-use practices in Norway as well as other rich countries have had any major effect on mitigating energy use and GHG emissions from freight transport as a whole—most of all because this concern has not been part of any goals involved in land-use planning. Still, partial effects of specific land-use strategies may occur. Intra-urban freight transport by vans, for example, will in principle be more extensive in low-density sprawling cities than in dense cities because of the longer average distances between origins and destinations in the latter.

Still, it is reasonable to assume that land-use planning has the potential to influence freight transport. It might promote modal shifts (e.g. if business areas are located near railways or harbours) as well as shorter lengths of haul (e.g. if different parts in the business value-chain are located close to each other). Research-based knowledge on how land-use planning influences freight transportation is, however, scarce; and few policy strategies exist on how to apply land-use planning to influence freight transportation. Research in this area needs to be strengthened. Anyone wishing to establish a factory, warehouse, or distribution centre needs planning permission. In principle, this could be used to ensure that businesses locate as close as possible to their likely main markets or suppliers. It could also be used to ensure that they locate close to harbours or rail terminals, to encourage use of ship or rail transport (if these are relevant options for the business concerned). However, land-use planning in Norway, as well as in many other western countries, is in the hands of local, not central, government, and the local authorities have little scope for "steering" localisation choices at the macro level. Also, the majority of Norwegian municipalities do not have railway terminals or general cargo harbours within their borders. In our empirical study, we did not examine the extent to which local authorities, that might have had some leverage, had exploited it to make businesses locate in areas that would minimise lorry transport, but we assume that the effect of any such policies on the overall volume of road freight transport at the national level has been small.

14.6 Discussion

The EU has set a goal of decoupling road freight transportation (measured in tonne-km) from economic growth (measured in GDP index), but this has been interpreted by most policy actors and commentators as a relative, and not an absolute, decoupling goal—to reduce the tonne-km *per unit* of GDP index. According to EU policy documents, the total energy use and GHG emissions from freight transportation can, in principle, continue to increase while, at the same time, meeting the EU objective (Sorrell et al. 2012a). The lack of any EU policy that is in accordance with a strategy of achieving an absolute reduction in GHG emissions and energy use from freight transportation (cf. Høyer 1999; Givoni 2013) could be related to the complexity of the freight transportation sector, but could also be related to the important role that freight transportation is set to play in supporting the goal of continued economic growth (Walnum et al. 2014). The sector includes many actors: haulers, shippers, and governments, as well as producers and consumers that rely on freight transportation. It is not entirely clear who should bear the responsibility for making freight transportation more sustainable, and there is little coordination between actors. Furthermore, there is a close connection between economic growth and freight transport, where enhancing economic growth, and therefore transport volume, takes priority rather than curbing freight transport. Thus, there is an obvious element of goal conflicts involved in the discussion of implementing sustainable mobility policies that may lead to a reduction in the volume of freight transport.

An alternative mitigation strategy to that of reducing the total volume of freight transportation, which is very much discussed in the European Union as well as in Norway, is to move goods from road towards sea and railway. However, development during the period of our investigation has gone in the opposite direction. Barriers connected to price, speed (faster competing transport modes, such as faster boats, will make competing transport forms less environmental benign) and to urge to make deliverables "just in time" make such a change difficult.

A rather positive sign from an environmental policy point of view is that there seems to be a decrease in relative GHG emissions associated with road freight transport throughout the period, and that logistical efficiency has, at least for part of the period, been increasing. However, this has not been sufficient to curb the increased volume of transport or the volume of GHG emissions. Looking at theories associated with rebound effects, efficiency gains would likely be used to increase activities and at least partly counteract savings from the efficiency gains. It seems likely that as long as the demand for freight transport increases in basically an unregulated and competitive market economy, efficiency gains will be used, first and foremost, for increasing the offer for transport services and more freight transportation will occur on roads. If the demand for freight transport is allowed to continue to grow as it has over the past 20 years, it seems unlikely that efficiency measures would be sufficient to substantially reduce the total GHG emissions.

The potential for major modal shifts and options for major fuel switches in freight transportation also seems rather limited within the current policy regime. Large-scale technological GHG emission mitigation possibilities for road freight transport appear to be more limited than for passenger transport since the same possibility for the utilisation of electrical batteries do not exist, with the exception of small-size lorries in a city environment. The use of biofuels has been discussed—however, several problems, such as an increased energy use and associated negative effects on land-use and biodiversity from producing biofuels may impede this strategy. The use of fuel cells (i.e. to deliver power to onboard devices) has also been discussed; however, such measures will not counteract the need of a drastic reduction of energy use and GHG emissions from the road freight transport sector.

In the short term, we see *no realistic technological measures* available for making the Norwegian freight transportation system radically less carbon intensive in order to achieve a cut in GHG emissions by up to 80 %. If freight transportation is to be protected from major GHG mitigation measures and allowed to continue having large GHG emissions, then other economic sectors will have to reduce their GHG emissions correspondingly more.

Our approach has been novel by making a theoretical consideration of rebound effects associated with both self-regulative and policy measures that have had the reduction of GHG emissions as a primary or subordinate goal, which we have discussed as ways for achieving radically less GHG emissions in road freight transport. We see that it is challenging to expand the *cause of rebound effect(s)* from technical efficiency changes, i.e. an improved input/output efficiency and, in the case of transport fuel efficiency, per kilometre and tonne-km, towards including policy measures aimed at curbing GHG emissions. It becomes very difficult to know the exact expected impact from, for example, a shift from transport by road to transport by sea and rail. Also, when widening the concept to policy, it is even harder to isolate cause–effect relationships. Many of the proposed solutions connected to reducing GHG emissions in freight transport contain several goals that might counteract each other, such as to be environmentally benign as well as to contribute to increased amount of traffic. Even Norway's effort for increased railway investment is only partly motivated by a reduction of GHG emissions, and is rather motivated by other issues such as increased accommodation or labour market. On the other hand, many of the policies work in the same direction as energy efficiency-generated rebound effects. The changes make transport faster and cheaper and thus are probably prone to rebound effects.

We found that that the available transport statistics in Norway did not allow for calculating detailed estimates of the rebound effects by using the methods within the energy economic tradition (i.e. to calculate how increases in fuel efficiency may reduce transport costs and thereby increase transport demands). However, such a calculation needs to take into account that freight parameters are dynamic; for example, payload and other operating practices can change in correlation with lower fuel cost. We will argue that determining the aggregated fuel intensity savings per tonne-km, approximately 4 % for the period under investigation, should not be the main research focus. Instead, our main interest has been "the big picture". By applying the so-called DPSIR model, we looked at the drivers for growth in road transport and found that the growth in the economy and the increased amount of tonnes transported are the main drivers.

Given the comprehensive and complex insights of our data and discussion, we find it unlikely that measures connected to efficiency improvements will lead to drastic reductions in the GHG emissions from road freight transport. The measures we looked at will most likely have rebound effects attached to them. The increased investment in railway will be an interesting case to follow to see if it has had any effect on modal shift; however, increased road investments may partly counteract a modal shift from road to rail.

14.7 Conclusion

In our investigation of the road freight transport sector in Norway we have looked for examples of measures that fit with three different pathways and strategies to *substantially reduce* energy use and GHG emissions: efficiency, substitution and reduction. Beside these three categories lies a possibility for business as usual or "no change", which implies that no additional measures are implemented in order to substantially reduce GHG emissions from freight road transportation. Looking at the statistics and literature we can conclude that systematic policies aimed at achieving reductions in energy use or GHG emissions from road freight transportation have only to a very limited degree been implemented in Norway—with the exception of bio-blending and—possibly—increased railway investment. Nor have we been able to detect any important autonomous technological changes that might substantially contribute in the same way—although capacity utilisation has slightly improved.

The volume of road freight transportation and the accompanying energy use and GHG emissions has gone in the wrong direction. Several valuable policy and technological changes have been identified. However, this has not been enough to yield an absolute reduction of GHG emissions from road freight transportation in Norway for the last 30 years. Many of the proposed measures do not aim to do anything about the underlying causes of increased energy use and GHG emissions from road freight transportation. When the underlying causes are not addressed, we believe there will be room for large rebound effects to come into play, which again may cause that freight transport volumes will continue to increase, with the likely result that no major reduction in GHG emissions will be achieved.

Acknowledgments This chapter builds on the report "Driver and response model for Norwegian road freight transport in the period 1993–2013" which the authors wrote together with John Hille (1954–2015). John passed away in September 2015 at the age of 61. He was especially competent in processing large amounts of statistical material and combining different statistical sources in novel ways—which he did to a great extent in the report and his work has been essential for writing this chapter.

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Chapter 15
Between Green Growth and Degrowth: Decoupling, Rebound Effects and the Politics for Long-Term Sustainability

Jørgen Nørgård and Jin Xue

Abstract Taking the simple equation: I(impact) = P(population) · A(affluence) · T(technology) as the point of departure, this chapter discusses the delusion of decoupling economic activities from environmental impacts by resorting to reduce eco-intensities through technological advancement alone. It is argued that the rebound effect is both a natural consequence of the growth dedicated society and a driver of further economic growth. Through rebound effects, labour productivity and eco-efficiency technologies in the growth society tend to contradict the goal of achieving environmental sustainability. To address the environmental problems, attention should therefore be redirected to the growth ideology and policy in current society. Drawing on the emerging degrowth debates in the affluent countries, the chapter proposes pathways towards a degrowth transformation by, respectively, discussing the role of population, affluence and technology in the attempts at reducing environmental impacts. Overall, it is suggested that from an analysis not confined to monetary terms, but with real cost and real benefits represented by environmental damage and human satisfaction, respectively, a degrowth in affluent countries can be achieved at no net cost.

Keywords Degrowth · Delusion of decoupling · Rebound effect · $I = PAT$

The equation $I = P \cdot A \cdot T$, which combines population P, affluence level A and technological eco-intensity factor T into the consideration of total environmental impacts I, has been well-known for a long time. Since the equation's development by Ehrlich and Holdren in 1971, the focus on how to lower environmental impacts has

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J. Nørgård (✉)
Department of Civil Engineering, Technical University of Denmark,
Building 118, 2800 Lyngby, Denmark
e-mail: jsn@byg.dtu.dk

J. Xue
Department of Landscape Architecture and Spatial Planning,
Norwegian University of Life Sciences, Ås, Norway

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shifted within the three right-side factors. Although Ehrlich and Holdren at the initial stage emphasized the impacts of population (P) on the environment (Ehrlich and Holdren 1971), today, the factor T is almost totally dominating the debates about solutions to resolve the environmental deterioration (e.g. von Weizsäcker et al. 1998; WCED 1987; OECD 2011). Population (P) is often tabooed and rarely included as a variable in the analyses and debates, although it obviously is still a key factor. In more recent debates, particularly in affluent regions, the factor A is highlighted as key to solve the ecological crisis (Martinez-Alier et al. 2010). For instance, a call for reducing affluence level is well-captured in current discussions on 'degrowth'.

The quest for reducing the affluence level (A) in rich nations, measured as per capita level of consumption of goods and services, is partly based on the impossibility of reducing resource consumption and pollution (I) to a level necessary for environmental sustainability by resorting to technological advancement (T) alone. This failure is to some extent attributed to the ignorance of the rebound effects from increasing resource use efficiency, which pushes upwards (P) and (A). In other words, the right-side factors in the equation are not constants, but mutually interdependent and dynamic (Alcott 2008, 2010). This chapter goes beyond this explanation, and points towards the infinite political quest for economic growth, i.e. growth in $P \cdot A$, as the fundamental problem. Consequently it is difficult to eliminate rebound effects and sufficiently reduce environmental impacts without addressing directly the developments of the A and P factors, in addition to lowering the eco-intensities. Invoking the term 'degrowth', we also propose an alternative society beyond the ideology of growth and suggest pathways towards approaching this desirable future.

In this chapter, the environmental impact (I) is mostly exemplified by energy consumption and carbon emissions, but it does as well refer to all other degradation of nature, such as biodiversity loss, resource depletion, pollution of air, water and soil. By definition, a degrowth society "*challenges the hegemony of growth and calls for a democratically led redistributive downscaling of production and consumption in industrialised countries as a means to achieve environmental sustainability, social justice and well-being*" (Demaria et al. 2013: 209). Degrowth therefore calls for strategies to decline the aggregate impact from $P \cdot A$ in addition to lowering technologically the eco-intensities (T). A degrowth society cannot be interpreted merely as a downscaled economy in the quantitative sense. It also implies a qualitatively different society with different socio-economic structures and institutional settings from the current growth society (Asara et al. 2015). In addition, degrowth has the ethical premise of distributive justice and intergenerational equity. Although today, the P factor is not given sufficient attention in the degrowth debates, and the propositions on population development among degrowth proponents are inconsistent (Kerschner 2010; Latouche 2009; Martinez-Alier 2009), we believe that reducing the size of the global population is essential for bringing human economic scale down to a sustainable level and thus should be advocated as a strong part of the solutions.

The chapter will proceed as follows. In Sect. 15.1, the 'growth and decoupling' approach for environmental sustainability is criticised as a delusion. Section 15.2

analyses how rebound effects are associated with the growth economy, and proceeds by arguing that attempts at enhancing labour and resource efficiencies in a growth society tend to contradict the goal of environmental sustainability. We therefore call for shifting the focus of critique from rebound effects to the growth ideology and policy itself in order to resolve environmental problems. This is followed by proposing a degrowth society. Drawing on the equation $I = P \cdot A \cdot T$ as an analytical framework, the chapter in Sects. 15.3, 15.4, and 15.5 discusses options for degrowth of all three right-side factors, as well as some of their dynamics. Finally, the concluding section provides some reflections on the need for a concerted degrowth strategy taking into account capping the left-side factor I and emphasizes the importance of addressing the deep socio-economic structures as part of the degrowth transformation apart from the factors in the $I = P \cdot A \cdot T$ equation.

15.1 The Delusion of Decoupling Economic Activities from Environmental Impacts

During the 1960s and 1970s ecological crises attributed to an exponential economic growth triggered a critical discussion on environmental and social consequences of growth. The criticism culminated with the publication of a report from the Club of Rome, *The Limits to Growth* (Meadows et al. 1972), together with a number of other reports and books presenting similar growth critique (e.g. Daly 1973; Goldsmith and Allen 1972; Schumacher 1973). During the 1980s, the growth critique was played down as the economy regained its momentum, and was gradually replaced by the view of 'decoupling' economic growth from environmental deterioration. This 'decoupling' view was emphasized, for instance, by the World Commission on Environment and Development as a key strategy of sustainable development in their report *Our Common Future* (WCED 1987) as well as in a number of publications that developed the concept 'Ecological Modernization' (Huber 1985; Spaargaren and Mol 1992; Hajer 1995). More recently, however, the possibility of maintaining environmentally sustainable economic growth through decoupling has been questioned by critics. Together with the multiple socio-economic political crises, this has revitalized the criticisms of economic growth, manifested in the increasingly heated debates on degrowth (Asara et al. 2015; Jackson 2009; Martinez-Alier et al. 2010).

According to the decoupling view, economic growth and environmental sustainability are *not* incompatible, but can be combined. To illustrate the decoupling notion with the $I = P \cdot A \cdot T$ equation, it means that ecological impact (I) grows at a different, usually a lower, rate than the growth in economic affluence level of whole population, i.e. $P \cdot A$. In order to materialize decoupling, the T factor becomes the key solution. The belief in decoupling has been formed along with an efficiency progress in the wake of the 1970s' oil crises. Many analyses then showed remarkable potentials for increasing the efficiencies of energy use (e.g. Goldemberg et al. 1985; Lovins 1977; Nørgård 1979a, b). In the 1990s, the concepts of Factor 4 (von Weizsäcker et al. 1998) and Factor 10 (Schmidt-Bleek 2001) emerged and became popularized specifications of the options and goals of de-materialization in national environmental policies. Factor 4 means that the same amount of commodity can be produced with only a quarter of the previous resource consumption (thus, factor 10 means using one tenth of the previous resource consumption). At an aggregate level, Factor 4 implies 'doubling wealth while halving resource use'.

These large potentials in reducing eco-intensities were mainly low-hanging fruits from the neglect of resource efficiency options during the post-war period with almost free oil. This, however, results in a strong faith in the possibility of decoupling endless economic growth from environmental damage by resorting to eco-efficiency technologies. 'Reviving growth' was pointed out as an essential objective, and the suggestion was just that the quality of growth should be changed (WCED 1987). The Western euphoric faith in technology as the solution to reduce environmental impacts has now for half a century shaped environmental policies.

This decoupling notion can be challenged in several different ways and is subject to serious criticisms. The conventional use of the term distinguishes 'relative decoupling' from 'absolute decoupling'. If the ecological impact (I) grows at a lower rate than economic growth measured as GDP or $P \cdot A$, relative decoupling occurs. Absolute decoupling requires that growth in GDP—or $P \cdot A$—does not result in an increase in the overall ecological impact, i.e. (I) is kept stable or even declines. What matters for the ecological sustainability is whether the absolute environmental impacts increase or decrease. From this perspective, absolute decoupling is of fundamental concern in most cases. However, a broad range of empirical evidence substantiates a low achievement of absolute decoupling. At the aggregate economy level, the total emissions of CO_2 in OECD countries showed relative decoupling from economic growth during the 1990s (OECD 2002). Similar modest relative decoupling has been observed at sector level in traffic volume versus CO_2 emissions (Tapio 2005), as well as in housing sector's growth versus growth in residential energy consumption and land use (Xue 2014). The general picture is that the drop in environmental impacts per unit of product is cancelled out by rising scale of the economy. Only if the speed of T going down equals the growth rate of $P \cdot A$, can environmental impacts I be stabilized. But, this will not suffice.

Among environmentally concerned scholars it is generally agreed that present global environmental impact is not sustainable. Taking Ecological Footprint as the indicator, we are presently overloading the Earth by a factor around 1.5 (WWF 2014), implying a need to reduce the ecological footprint by at least 35 percent. Another study shows that four out of nine planetary boundaries have already been crossed by human activities, including climate change, biosphere integrity, biogeochemical flows and land system change, which might push the Earth system into a new state (Steffen et al. 2015). This means that for some specific environmental damages, a more drastic reduction is required in order to reverse the unsustainable trend. For the emissions of CO_2 and other greenhouse gases, the reduction has to be "net 100 %" by 2100 if we are going to achieve the goal of keeping global warming below 2° (IPCC 2014).

By ascribing all humanity equal right to use the environment, it is argued that people in affluent countries, such as USA, EU, and Japan, would need to reduce their impacts (*I*) down to only around one tenth the present to reach world-wide sustainability (Schmidt-Bleek 2001). To achieve such reduction target in the course of 50 years with an annual economic growth of 3 % would require the overall eco-intensity (*T*) to be reduced to only around 2 % of present levels, i.e. reduced by a factor 40 (Nørgård 2009; Jackson 2009). In comparison, the much praised environmental efforts in Denmark's energy system have over the past 25 years managed only to reduce *T* by around 28 %, i.e. by a factor of 1.4! (Danish Energy Agency 2015) And this has been achieved by 'picking the very low-hanging fruits'. It therefore seems even theoretically implausible to reduce the environmental impacts to reach a sustainable level by relying on the *T* factor alone.

Linguistically, decoupling implies that the two parameters—economic activity and environmental impact—are separated (Webster 1986) or with no coupling at all. OECD (2002) in their energy analyses defines 'decoupling' as breaking the links between 'environmental bads' and 'economic goods'. Physically, there will always be some amount of 'coupling', since every economic activity is—directly or indirectly—reliant on a minimum of resource supply from nature and emission of wastes back into nature. Vice versa, all eco-impacts have their roots in economic activity. The fact that economic activity and the eco-impacts grow at different rates does not imply that the two parameters are not coupled.

The misleading term 'decoupling' should therefore not be used in analyses and debates about economic growth and the environment. Instead, the term 'relative decoupling' can be referred to as a reduction in eco-intensity (*T*), while the term 'absolute decoupling' can be referred to as a decline in eco-impact (*I*). These are not just some linguistic trifles. The real problem is that the very use of the term 'decoupling' might—probably sometimes intentionally—leave the readers with the false perception that we can let economic activities grow forever, without having to worry about ecological constraints. The use of this term can therefore be seen as a false 'peacemaker' between environmentalists and growth-dedicated politicians, and thereby contributes to the maintenance of growth far beyond the economy's optimal size (Nørgård 2009).

15.2 Rebound Effects in a Growth Society

Normally the concept 'rebound effect' depicts the phenomenon that eco-efficiency improvements through technological advancement do not reduce the adverse environmental impacts as much as expected due to induced increase in production and consumption. It was already observed by British economist Jevons in the nineteenth century that increasing efficiency in the use of coal was not accompanied by corresponding reduction in the use of that resource at the aggregate level, rather the opposite (Alcott 2005).

Here, we extend the efficiency improvement to embrace other production factors, which we merge into just labour input by considering capital as stored labour. Throughout industrialisation, technology has increased labour efficiency (productivity) in the sense of less work being needed per unit of output. A substantial part of the labour efficiency gains were in early days of Western industrialization utilized to reduce the more than 80 h labour input per week. However, later on, more of the labour efficiency gains were turned into growth in overall production and consumption $A \cdot P$. In recent decades this rebound effect has approached 100 %, as illustrated by the average work time in the USA, which has since the 1930s roughly been frozen around 40 h per week despite substantial gains in labour productivity (Schor 2005). Almost all labour productivity gains are presently used to increase GDP and consumption in general, rather than to relieve the environmental impacts by lowering consumption. Also, instead of reducing the input of labour, during the past 50 years, global *workforce* has enlarged substantially, partly by general population growth, and partly by absorbing ever more men and (in particular for the case of affluent countries) women into the economic (monetary) production sectors.

The direct and micro-level causes of rebound effects from eco-efficiency technologies can be ascribed to the ignorance of the socio-cultural elements and the neglect of individual’s subjectivity in consumption behaviour (see Chaps. 5, 6, and 7). In addition, increasing productivity through technological advancements involves a general trend of social acceleration, where the speed of production, consumption, and mobility increases, leading to more consumption of resources (see Chap. 8). Nevertheless, there is nothing deterministic about the growth impact of improving resource and labour efficiency through technologies. As shown above, labour productivity gains can be employed to shorten work time instead of increasing production levels. It is, therefore, an open choice of which way we utilize the benefits of efficiency improvements.

Arguably, the conversion of efficiency gains predominantly into higher levels of production and consumption is attributed to the ideology of economic growth and the structural growth imperative of a market-dominated socio-economic system. In the growth society, ‘quality of life’ and ‘well-being’ are interpreted as possession of material wealth and consumerism is a dominant value entrenched in the society. Continuously enhancing material living standards becomes a widely accepted social norm without being questioned. When basic needs are satisfied, as in affluent societies, positional goods and conspicuous consumption are promoted as new engines of growth through advertisements and consumption-stimulating policies (Hirsch 1976). This growth path was after pressure from big business, ‘deliberately’ picked in 1933 by US president F.D. Roosevelt as a way out of economic depression (Hunnicutt 1988; Cross 1993). For consumers under the hegemony of the growth discourse, it is very likely that the reduced cost due to lower *resource intensity* per unit of product is harnessed to secure higher material standards, just as the case with rebound from higher *labour efficiency*. In other words, the growing purchasing power derived from either of the two efficiency gains has to be channelled to somewhere, leading to higher levels of consumption (Schneider 2008).

Furthermore, the fact that most of the efficiency improvements are turned into drivers of growth is highly associated with the market economy characterised by a structural necessity of growth. Several authors have pointed out that the growth imperative is intrinsic to the market-dominated socio-economic system (Gordon and Rosenthal 2003; Griethuysen 2010; Harvey 2010). Fierce competition in the market economy sets the 'grow or die' dynamic in motion and forms the profit-driven economy. Individual corporations through enhancing resource use efficiency and labour efficiency are able to reduce the costs of products so as to gain excess profits compared to their competitors and increase their market shares (see Chap. 3). Therefore, the rebound effect on the production side is an intentional pursuit of producers who consider imperative to seek higher profitability. Eco-efficiency and labour-saving technologies are employed as a business strategy to increase profits rather than a way to benefit the environment and the well-being of people. Not only business sectors, governments also seek high rebound effects. The Danish government earlier has directly *required* that "*Energy savings should contribute to growth and commercial development*" (Danish Energy Agency 2004).

Based on the discussion above, it can be argued that the rebound effect is both a natural consequence of a growth society and an important contributor to spurring further economic growth. It is received with welcome in current growth society and cannot be considered as a problem from a perspective of economic growth. Only when being examined from an environmental perspective is rebound effect regarded as problematic, as it increases the level of production and consumption which offsets intended environmental gains from efficiency strategies. But does not a growth society aim at a perpetual growth in output? This suggests that the rebound effect is not the fundamental problem—and thus it is neither "good" nor "bad". What remains as the fundamental problem is the strong commitment to economic growth and its contradiction with environmental sustainability. Both labour- and eco-efficiency strategies tend to be 'co-opted' by the growth ideology and serve the purpose of maintaining growth. The more we reduce the eco-intensity (T), the more difficult it will be to decrease the aggregate impact of $A \cdot P$, as technologies for efficiency and productivity are a key driver of economic growth. Attempts at enhancing labour and resource efficiencies *in a growth society* tend to contradict the requirements for environmental sustainability. It is thus impossible to reduce environmental impacts as much as needed by resorting to eco-efficiency strategies in a growth society. It becomes necessary to address the growth issue if the intention is to get rid of rebound effects and achieve long-term environmental sustainability (Nørgård 2009).

Focusing on the growth issue means the adoption of a degrowth strategy that seeks to stabilize or even lower the affluence level (A), and the population size (P). Besides pursuing lower eco-intensities, the technology factor T will be redirected towards prolonging the durability of products. What would such a degrowth society look like? Which policies are necessary to implement in order to avoid problems like unemployment, poverty and inequality, during the process of shrinkage? The following sections aim to sketch some suggestions for achieving a prosperous degrowth society by exploring the role of each of the right side factors in the $I = P \cdot A \cdot T$ equation.

15.3 Population Development in a Degrowth Society

Global population has over recent decades moved from exponential growth into what appears more like linear growth. But this growth is still annually adding a staggering 80 million people to the limited planet. With a continuous growth in population, a sufficiently low level of environmental impact can hardly ever be reached and maintained. Despite the significance of the population size in affecting the environment, today there is a taboo about including human population development as a variable when analysing future options for sustainability (Nicholson-Lord 2008). Analyses on future scenarios typically start out by just referring to the latest UN medium estimate of future population development (see Fig. 15.1), and accept this one population scenario as a fact. This lack of scientific and political courage by experts to include a reduction in population size as one solution option, constitutes one of the most serious flaws in present environmental debates.

When politicians in Europe in rare cases do touch the issue of population, it is usually from a growth promoting viewpoint, as for instance about how to encourage higher birth rates to secure sufficient labourers and consumers for continuing GDP growth. Such growth strategy will, as historically hinted by philosophers in the 1700s (Lütken 1760; Malthus 1798), sooner or later through rebound effects from productivity increase, result in ecological and human misery and starvation for part of the world population.

Demographers and politicians contend that, when peoples' standard of living in developing countries approaches a Western level, birth rates would by itself drop and thus prevent a global overpopulation. One problem was that in many poor regions of the world, economic growth could hardly keep pace with population growth, which has resulted in stagnating or even declining standards of living, blocking the way for the 'automatic' decline in birth rates. Furthermore, it is often forgotten that the

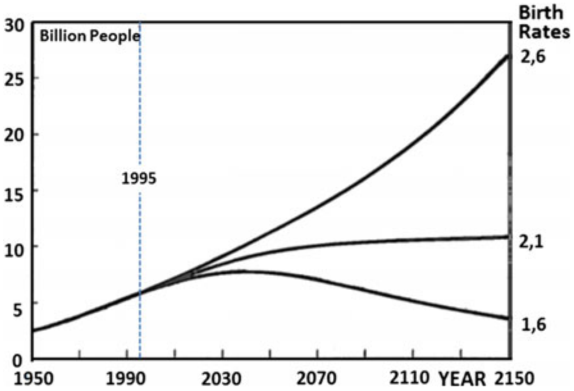

Fig. 15.1 UN scenarios for future world population development as a consequence of three average fertility rates (*Source* The Population Division of the UNs Secretariat 1998)

European population 'explosion' in the 1800s and 1900s was partly 'resolved' by millions of Europeans migrating and taking control of 3–4 'empty' continents, North America, South and Middle America, Australia and parts of Asia and Africa. Only recently has such population 'explosion' crowded other world regions, e.g. Africa, but there are no more 'empty' continents for people to migrate to.

What is then the *optimal* number of people living simultaneously on the earth that could balance the number of people with the resource intensity of their lives? It seems evident that there is a trade-off between the two aspects, since with more people (P) follows lower options for a good life (A).

A number of estimates of optimal population have been carried out. One such analysis was in the 1990s based on energy needed for high quality of life versus the environmental problems from using fossil fuels. Given the average energy consumption of 7.5 and 1 kW per capita in, respectively, industrialized and developing nations at that time, researchers suggested 3 kW to suffice, and found an optimal population of 1.5–2 billion people (Daily et al. 1994). More recent analysis, based on the lifestyle's ecological footprint versus the earth's bio-capacity and ecological space for biodiversity, found that future optimal population levels range from 2.7 to 5.1 billion people (Desveaux 2008). This depends on average footprints, maintenance of bio-capacity and allowances for biodiversity. The lowest, 2.7 billion allows for 20 % margin for biodiversity. Despite the variations in these estimates, they all indicate an optimal world population size significantly below the present 7.3 billion. This underlines the urgency of starting a gentle reduction of the number of people on the planet.

The taboo on population is practiced by decision makers in an attempt to appear neutral on this sensitive issue of people's choice of family sizes. It should be stressed, however, that no policy can be neutral on population development. All political decisions have indirect effects on fertility rates through tax system, education, health care, social security, etc. Some decision makers defend their silence on the urgency of active population limitation policies by the fact that population policies mainly have long-term effect. This is an odd way to justify the postponing of action.

Suppose we decide to aim for half as many people as today, as the lowest UN scenario for world population development suggests (Fig. 15.1). If we act now, we could reach this goal around 2150 by convincing all women to have on average 1.6 children, rather than the present average of 2.6. Reaching a worldwide birth rate of just 1.6 should not be ruled out politically, considering that it is in fact the present average in two politically quite different regions of the world, namely Europe and China. In Europe the low birth rate and the resulting contraction of population has been reached voluntarily as a consequence of the general economic and welfare policy. In China, the low fertility has been promoted by a more direct and active family planning policy.

Although China's family planning policy is effective in slowing population growth, it has been criticised for its authoritarian and coercive approaches (Dietz and O'Neill 2013). Later optimistic experiences from a number of developing countries, mainly in Asia, have shown, how similar effects as those in China has be achieved based on non-coercive means, e.g. through education and empowerment of women (Kingholz and Töpfer 2012).

It is hard to see any disadvantages of living in a future world with say half as many people as today. On the contrary, all the basic problems mankind is facing today will be easier to solve. Even in monetary terms, reducing population is the most cost-effective strategy for mitigating climate change. This also applies to biodiversity loss and other resource and pollution problems, and even international conflicts that are often derived from shortage of land, food, resources, etc. Lowering fertility rate to be below the replacement rate 2.1 and stabilizing a nation's population at lower level will improve material standards of living in general and provide a prospective continuous environmental benefit in the form of the saved ecological footprint from the unborn children and all their descendants.

Usually, politicians associate monetary cost with the transition adjustments of GDP, where the ageing population will need more care to be provided by a shrinking productive workforce. Considering the gentle pace in the transition these problems are manageable, especially when remembering that a shrinking population will require less childcare and educational services, and a lot of infrastructures like highways, buildings, power systems, libraries, schools, etc., will be inherited in plenty from the earlier, larger generations. This heritage will cost maintenance and replacement, but a lot of investment for expansion can be spared, reducing also environmental impacts.

15.4 Affluence and Work in a Degrowth Society

In the Western economies average consumption per capita (A) has reached a level which qualifies as a dominant and very obvious factor in the environmental impact $I = P \cdot A \cdot T$. According to the Living Planet Report 2014 (WWF 2014), the ecological footprint per capita of high-income countries is about five times more than that of low-income countries, and furthermore these high income countries often rely on the bio-capacity of other nations or the global commons to meet their consumption demands. Growth in this affluence does not primarily serve to satisfy human basic needs or even deep wants, but rather to satisfy the basic needs of a debt-based financial economy designed for unlimited GDP expansion. This explains why, not only private businesses through massive commercial advertisement, but also governments and most politicians encourage people to consume still more.

When aiming at a degrowth economy, the quests will be contrary to those voiced for a growth economy. Fortunately, a call for curbing people's excessive consumption offers some rewards in return, mainly in the form of more free time, less stress, better health, more options for meaningful life, in addition to a better rather than worse environment.

The affluence level (A) is not only coupled to environmental impact, but also affects our own health. Obviously economic growth in wealthy countries might still bring about some health improvement through better technology, medicine, etc., but at this stage, overconsumption has also caused negative health impacts in the form of lifestyle diseases. These diseases are caused by overconsumption of food and motorized transport, heavy smoking, alcohol abuse, excessive sugar and animal fat intake and various narcotic drugs. Overconsumption alone in USA was in 2004 found to result in more than one million premature deaths every year, and in that connection U.S. Secretary of Health made the point by ‘a slip of the tongue’, that these and other “social problems and complaints stem from our affluence not our poverty” (Samuelson 2004), admitting severe and rising human cost of the growth policy.

If we assume that consumption can be expressed by people’s annual income, study shows that a growing income gives a diminishing return in the form of wellbeing or happiness, particularly when annual income exceeds $10,000 per person (Jackson 2009). When observing the historical relationship between economic growth and happiness in USA, it is found that the percentage of people who report being very happy has stabilized at around 30 percent during the years 1945–2005, although income has more than tripled (Dietz and O’ Neill 2013). This indicates that there are other aspects of life, which are more important for people’s wellbeing than their level of consumption or income. Some of them are equity in income, education, job guarantee, etc. (Wilkinson and Pickett 2010). This discussion demonstrates that further economic growth in the developed countries is not a necessary condition for human progress.

Apart from arguing for continuously increasing the affluence level in terms of its social benefits, the most common political argument for increasing consumption is to avoid involuntary unemployment as a result of productivity increase. In general, there are three ways to accommodate the gains from labour productivity increase: increasing public and private investments, increasing consumption, and reducing work time to fit the production wanted. So the simple long term, obvious solution to secure a full employment is to share the work to be done annually by lowering the work time instead of creating more jobs by increasing consumption.

Annual work time in various nations is quite different, with people in USA, Russia, Korea and Japan working about 20 % more than the Europeans. This suggests that Europeans, as in the population issue, are on the right track towards degrowth. In addition, in a future degrowth society, productivity increase can be slowed down to below zero, as a means for adapting production to a declining consumption and simultaneously making working condition better and more meaningful in various ways.

Lowering affluence can appear like an impossible task, given the dominance of the growth ideology in the current societies. After lifelong exposure to intensive commercial advertisement, political urge to buy more and neighbours buying new cars and bigger houses, it is understandable that people may be reluctant to shrink their consumption. But several surveys on work time preferences have actually indicated an increasing wish among people for less work time (Gorz 1983;

Hayden 2000; Sanne 2000; Schor 1991). A series of surveys conducted regularly in Denmark over some decades showed that the fraction preferring less work over more income increased from 44 percent in 1964 to 73 percent by 2007 (Nørgård 2009).

People's preferences for more leisure over more income, as illustrated above, might well be based on concern for their own near future, but not explicitly based on the environmental benefits of their choice (Hayden 2000). With this argument added, the preference would probably be higher. However, increase in leisure activities cannot be supposed to necessarily lead to fewer environmental problems, due to the possibility of time-use rebound in terms of resource use (see Chap. 9). Spare-time activities are not equally environmentally friendly (Aall 2011). However, stabilization or even decline of income due to reduction in working hours constitutes one of the mechanisms counteracting the tendency to increase the total consumption level. In addition, tax policies can be adopted to encourage people to engage in leisure activities that are relatively less resource intensive and environmentally harmful.

The fact that most people in affluent Western nation express a wish to use productivity gains to get more free time rather than more income, if given the choice, should be seen as a welcome opportunity for politicians to gently change economic path away from the money dominated growth economy to a degrowth economy. In a degrowth society, the environmental impact from the affluence level will decline in combination with an improvement in quality of life in the form of better health, more freedom and non-material sources of happiness.

15.5 Technology in a Degrowth Society

The existence of rebound effects of eco-efficiency technologies should not lead us to reject technological advancement as one part of the strategy for environmental sustainability in the degrowth society. Nowadays, the problem with the technical solutions is that they often overshadow many more effective 'soft' solutions, including political regulations and social innovations. Arguably, technological advancement in a degrowth society with a cap on the affluence level (A) and a control on population size (P) will not lead to rebound effects and thus will effectively contribute to reducing environmental impacts. Besides seeking for higher efficiency in *direct use* of resources, this section will also address how technologies on the consumer side can be utilised in interplay with lifestyle and behavioural issues to contribute substantially to reducing also the *indirect resource use and pollution*. In this regard, the technological potential includes enhancing consumer efficiency by sharing and prolonging the useful life expectancy of durable consumer goods. Such policies have been neglected or counteracted in economies dedicated to growth in GDP.

People's material affluence (A) can be expressed by the consumption of three types of goods and services: (1) flows of non-durable goods, defined as consumption of goods, the value of which lies in actually being consumed, such as food, water, electricity, heat, etc., (2) stocks of durable goods, defined as physical goods, e.g. houses, clothes, appliances and cars, the value of which lies in having a stock of them at one's disposal, and (3) services, such as trade, entertainment, education, administration, health care, etc., which are provided to people by durable and non-durable goods outside their personal daily sphere (Nørgård 2006).

Most awareness on energy saving options has been devoted to the non-durable flow of direct energy used for providing services like transport, light, comfort, meals, etc., that is caused by operating energy consuming durables like cars, lamps, houses, refrigerators, TVs, etc. In these fields substantial room for energy efficiency improvements has been pointed out and to some extent also implemented. These efficiency gains have led to many examples of rebound effects, as for instance when a saving on the energy bill has been spent on energy intensive travels.

However, investigating indirect energy consumption, defined as the energy used to produce and provide the durable goods, opens up more room for reduction in environmental impacts, in particular when technological improvements are integrated with behaviour and lifestyle adaptions. The potentials for these savings lie in: improving energy efficiency in the whole chain of the system providing the durables; reducing the number of durable goods people possess, e.g. by more sharing of goods; and finally, extending their useful lifetime before being scrapped. In the following the focus is on the latter.

The useful lifetime of durable goods is determined by three factors (Nørgård 1979a, b): *technological obsolescence,* meaning the physical wear and tear and inability to fulfil the basic purposes of the products; *functional obsolescence,* in the sense that new products can fulfil the purpose in a better way, for instance by being more energy efficient or providing better service options; and *psychological obsolescence,* or becoming out of fashion compared to novel designs on the market. The most striking example of fashion driven purchase is clothes, but today the sale of most items, is to a large extent driven by changing fashion design. Obviously, when considering these three, the first occurring obsolescence of a product will determine the factual useful lifetime of the product.

In the growth economy, a *planned obsolescence* that deliberately makes products obsolete faster in any or all of the three ways is a business strategy towards accelerating capital accumulation and at the macro-economy level boosting growth in GDP (Slade 2006). There is therefore a basic conflict between increase in the consumption of durable goods and preservation of the environment. In a growth dedicated economy, public campaigns aimed at saving energy or the environment have been half-hearted in emphasizing the indirect use of energy, because this would imply a general curb on economic activities. This argument can obviously not hold if sustainability is given higher priority. In contrast to the call for speeding up the flow of durable goods in the growth society, a degrowth society aims at slowing down this flow and reducing the total amount of durable goods people possess.

Extending the useful lifetime of durable goods might be the most fruitful effort in lowering environmental impacts, through combining behavioural and technical changes. This could apply to electronic products, clothes, buildings, plastic and much else. Manufacturers could use their technical expertise to design more durable products with longer intervals between functional and fashion changes. Sharing various durable goods also constitutes a significant potential for reducing energy use and other environmental impacts, since this will substantially reduce the size of the stock of durable goods. Besides examples like cars, tools, and clothes, the concept can also include architectural design to facilitate flexibility and co-housing (Lietaert 2010).

The main obstacle for beginning the path towards such indirect energy saving is not technology, which is readily available. We do not need new invention before starting the transition. As an example electronic devices like mobile phones now often scrapped after a year or two can easily last for 10 or 20 years. Similarly, with clothes. In certain areas, e.g. urban sustainable development, it is also a matter of reinvigorating well known environmentally friendly options, such as bikes, buses and apartment buildings or cohousing to reduce the predominance of private cars and individual houses (Næss and Vogel 2012). What seems to be more challenging is the change in economic and financial targets, in work pattern as discussed in Sect. 15.5, and in culture and lifestyle. Fashion and advertisement can, as demonstrated in recent decades, be quite effective in changing people's consumer behaviour towards faster obsolescence replacement. We could then use the advertising experts to explain to consumers, little by little, the benefits of focusing more on the physical services or use values provided by the car, the clothes, and the other durable goods, and less on fashions and novelty.

To summarize, attempts at enhancing eco-efficiencies through technological advancement should not be abandoned in a degrowth society. However, technological innovation should to a higher degree be reoriented in the direction of use values and longevity of durable products. This should accompany an emphasis on cultural and lifestyle change.

15.6 Concluding Remarks

In this chapter, we have argued that although the phenomenon of rebound effect constitutes a barrier to achieve environmental sustainability, we should instead direct our critical attention to the growth economy which is both a fundamental causal mechanism of the rebound effect and partly a consequence of it. Throughout this chapter, we have employed the $I = P \cdot A \cdot T$ equation to illustrate and develop our argument. We first criticised the belief in decoupling economic growth from environmental impacts and the misleading use of the term 'decoupling' that seems to suggest the material independence of economic activities. We then argued that the options for utilizing efficiency improvements in resource and labour hold much larger potentials than just being rebounded into increased levels of production and consumption. It is the growth ideology and the structural necessity of growth in a market economy that constantly converts efficiency gains into drivers of further economic growth. Therefore, rebound effects are more than welcomed in a growth society and efficiency improvements in a growth economy are likely to contradict the goal of environmental sustainability, leading only to increased consumption elsewhere. In the light of this argument, we further proposed a degrowth society which addresses simultaneously decreasing population size, reducing affluence levels by work sharing and redirecting technology towards longevity of goods in addition to increasing resource use efficiency as pathways towards reducing environmental impacts to a sustainable level. Such a degrowth society not only reduces environmental and resource problems, but may also contribute to a happier and more meaningful life.

Apart from addressing the right-side factors in the equation, the pathway towards the degrowth society requires combining this with policies of directly capping the resource use and environmental impacts (I) on the left side of the equation. As Alcott (2010) suggested, the cap strategy can take the form of (1) production caps where limits are imposed on the input of raw materials to production, (2) consumption caps restricting the end-use of energy and other resources, and (3) pollution/emission impact caps. A multi-scalar cap system can be developed where individual and municipal caps are deduced from the national and global maximum. The capping strategy should be adopted in a concerted and coordinated way with the right-side factors. This will avoid potential rebound effects, which are generated by focusing separately on the factors regardless of the dynamics between them.

To build the degrowth society also requires a profound socio-economic transformation apart from adopting the strategies targeting the four factors in the equation. As discussed earlier, the growth commitment and the consumer culture emanates from the ‘grow or die’ dynamic in the market economy. Without confronting the hegemony of this economic structure, it is hard to eradicate the growth imperative; any policy aiming at, e.g. slowing down productivity, curbing the demand for consumption, redirecting the technology towards use value and durability, will meet resistance from business and financial sectors. Today's world wide neoliberal agenda is at odds with the policy suggestions for a degrowth society. However, the weaknesses of this system have been increasingly manifested through its failures in tackling the social, ecological, political and economic crises it has generated. There is an urgency to transform the economy and society not only for a better environment but also for long-term human prosperity.

The degrowth transformation should be first pursued in the developed countries where the current economic volume has qualified the so-called ‘uneconomic growth’ (Daly 1999). For less developed countries where economic growth still plays an important role in enhancing people’s wellbeing, increases in consumption levels is acceptable, but only temporarily. After a period of growth leading to a point safely within the planet’s ecological capabilities, these countries should also prepare for a long-term development with no-growth.

The cost for a degrowth transition can be very low or negative if analysed in *real economy terms,* i.e. not confined to what happens to be measured in money. In the real economy, *real benefits* are measured in people’s satisfaction and *real cost* in the destruction of the natural environment. In that case, most of the actions needed in the affluent nations towards humane and environmentally sustainable societies as proposed in this chapter are available at no *real net cost*. If people prefer to have no more than two children, it makes no sense to ascribe a real human *cost* to this essential ecological *benefit*. Similarly, if people at a certain affluence level prefer more relaxed work condition over more material consumption, a degrowth economy can give them more of what they really want, again at no real *cost* and with *benefit to* the environment and quality of life. And if technological development is directed towards longevity and eco-efficiency in general, it is possible to provide decent and comfortable lives to all humans and preserve or even enhance natural ecosystems.

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Part IV
Conclusion

Chapter 16
Conclusions: Respecting Rebounds for Sustainability Reasons

Tilman Santarius, Hans Jakob Walnum and Carlo Aall

The United Nations World Commission on Environment and Development outlined two major environmental policy approaches in its report "Our Common Future" from 1987: The effect- and the cause-oriented approach. The former represents an attitude to environmental policy, acts and institutions with the main emphasis on mitigating environmental effects; whereas the latter focuses on the roots causing these effects. The UN Commission emphasized that it is the former which has prevailed until then, whereas it is the latter which must be included in any policy approach aimed at promoting a sustainable development (WCED 1987). 30 years after this point was made by the UN Commission it seems rather uncontroversial to state that environmental policy still seems to be stuck within the effect-oriented approach.

16.1 Rethinking Climate and Energy Politics

Still in line with the WCED, we believe that to truly tackle anthropogenic climate change, the cause-oriented approach will be much more reliable and effective in ensuring significant reductions in greenhouse gas (GHG) emissions. Carbon capture and storage (CCS), protection of rainforests, afforestation and reforestation, and the

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T. Santarius (✉)
Institute for Ecological Economy Research, Technical University of Berlin,
Berlin, Germany
e-mail: santarius@tu-berlin.de

H.J. Walnum · C. Aall
Western Norway Research Institute, Sogndal, Norway
e-mail: hjw@vestforsk.no

C. Aall
e-mail: caa@vestforsk.no

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somewhat ‘science fiction’-like proposals named geo-engineering or climate intervention, to mention some examples, are measures that all fit with the effect-oriented approach. In contrast, understanding possible rebound effects and outlining ways to mitigate such effects is an important element in a cause-oriented approach to environmental policy. Strengthening the knowledge base that understands cause-effect relationships is an important part of reinforcing that approach.

As already pointed out in the introduction to this volume, there is an urgency in getting into place climate policies that can deliver substantial cuts in GHG emissions—if we are to achieve a reduction of GHG that would limit global warming below 2 °C or even at 1.5 °C. In order to have a likely chance to achieve the least ambitious of these two goals—i.e. the 2 °C goal—the Intergovernmental Panel on Climate Change (IPCC) has stated that global GHG emissions have to be reduced in the order of 40–70 % by 2050 compared to 2010 levels, and be near zero by 2100 (IPCC 2014, p. 10). Furthermore, although being a more contested proposition, we argue that it is not realistic to believe that getting rid of literally all energy-related global GHG emissions can be achieved while at the same time keeping the current level of global energy consumption, let alone accepting a continuous increase in energy consumption. Again, this proposition still seems in line with the WCED report from 30 years ago. For a very common interpretation of this report is that it recommended rich developed countries to reduce their levels of energy consumption by at least 50 % within 40–50 years, with 1980 as the base year (Høyer 1997). Irrespectively of how fast global society is able to get rid of its GHG emissions and reduce its total energy-use, society has to adapt to major and in many cases still unknown consequences of climate change. To set appropriate adaptation measures into place will likely require an additional share of energy consumption. Thus, a post-carbon and climate change-resilient society must most probably also be a low-energy society.

This book clearly outlines that reducing energy and resource consumption by absolute levels, and on a significant scope, will be difficult unless rebound effects are taken into account. Still, and the world over, most decision makers pay only little attention to the possibility of rebound effects taking place and thus offer few if any options for mitigating such effects. The more society waits implementing policies, the tougher these have to be, and the more important it will be to identify—and accordingly to mitigate—any rebound effects that can delay the anticipated effects of reducing GHG emissions, reducing energy-use, and adapting to climate change.

This remains true even if one envisages a global cap on GHG emissions as, for example, has been included in IPCC scenarios (IPCC 2014). There is no doubt that emission caps can be a valuable instrument in the toolbox of climate policy makers. Yet, despite the fact that real-world politics is far away from installing a truly global cap—which would cover all energy as well as land-use-related emissions, and which would span the entire community of states from Afghanistan to Zambia—we believe it is fallacious to assume that once such a global emissions cap be installed, rebound effects would not matter anymore. For one, because environmental (and social) sustainability encompasses much more than the climate challenge. If rebound effects continue unchecked, the potential trade-off between solving the climate challenge on the one hand and biodiversity and other resource-related challenges on the other is likely to be aggravated. Yet more particular, and even when focusing on climate alone, will rebound effects pose a constant threat to the implementation and maintenance of a global emissions cap if their causes are not addressed. After all, capping emissions remains in the logic of the effect-oriented, and not the cause-oriented approach. If the systemic relationship between efficiency and expansion continues to increase demand and economic output, this will exacerbate the struggle to implement global emission reductions.

Metaphorically phrased, placing a cap on emissions in a world where technological efficiency continuous to improve is like putting a lid on a boiling pot: If one increases the boiling temperature, i.e. using pressure cookers that cook vegetables at ever increasing degrees in an ever shorter amount of time, it will gradually become more difficult to design lids (caps) that keep the pot from overheating or exploding. Or, to put it in the logic of the IPAT equation (see Chap. 15): The more *T* (technology) improves, the harder it will be to decrease *A* (affluence). Understanding the various mechanisms behind the rebound phenomenon inevitably suggests that in those countries where the aggregate size of energy and resource consumption and GHG emissions is already significantly above a sustainable level, obtaining meaningful reductions through technological efficiency improvements alone does not only 'not suffice'; it may counteract these policy endeavours if the causes of rebound effects are not addressed at the same time. Therefore, climate and energy policies must be designed 'rebound-proof'.

16.2 Rethinking Sustainability and Degrowth Politics

The idea for this volume arose during a seminar in which several of the authors of this book participated. The name of the seminar was "The rebound effect: Energy, efficiency and growth" and it was organized as part of the "Fourth International Conference on Degrowth for Ecological Sustainability and Social Equity", which took place in Leipzig, Germany, in September 2014. One idea behind the series of Degrowth conferences is a claim that it is not sufficient in the long run to compensate for growth in production and consumption by constantly reducing the environmental load per unit produced. Rather, an absolute reduction in the global volume of the economy is necessary in order to obtain sustainable development. However, the concept of degrowth is not merely a quantitative claim for a shrinking economy. More fundamentally, it is about a paradigmatic re-ordering of values and, in particular, the affirmation of social and ecological values and a re-politicization of the economy and society (Latouche 2009; Demaria et al. 2013; D'Alisa et al. 2014).

One of the key questions in the degrowth debate is: What are actual drivers of growth, and how can they be 'domesticated' in order to reach a post-growth society? And while there surely are numerous (other) drivers of economic growth, in particular Chaps. 2 and 4 of this volume as well as Chaps. 9, 13, and 15 have presented fresh analysis to what extent rebound effects contribute to demand and economic output growth. Understanding the various mechanisms and conditions that generate rebounds is an indispensable prerequisite for developing policies as well as planning and business strategies that can be ‘growth neutral’.

Another key question in the degrowth debate, or more accurately, in the debate about a ‘great transition’ or ‘socio-ecological transformation’ of industrial societies, is: How can economic actions be re-embedded into a normative context that puts environmental and social sustainability—as ends—over economic growth—as merely a means? This question links back, among others, to the debate about Karl Polanyi’s analysis on The Great Transformation (1944) and how it can be revitalized today (e.g., Raskin et al. 2002; New Economics Foundation 2009; German Advisory Council on Global Change 2011). This volume provides some contributions to this challenging question. In particular, Chaps. 6, 7, 8 and also Chap. 4 provide reflections about *why* consumers actually generate rebound effects. Understanding the various reasons and conditions that motivate individuals to use new and efficient technologies more frequently or intensively, or else to increase their demand in the aftermath of an efficiency improvement, is crucial to advance debates about sufficiency in consumption, sustainable prosuming and peer production, and other suitable ways to propagate post-growth life- and working styles.

Again a key question in the degrowth debate is: What kind of strategies are suitable to tackle not only environmental, but also social, developmental and other concerns of sustainability in a coherent manner? This question stems, among others, from literature that pictures many of today’s crises—including the climate, resource and biodiversity crises but also the world financial or the EURO crisis, soaring unemployment, deterioration of terms of trades and others—not as separate snags, but rather as one ‘multiple crisis’ (e.g. Schneider et al. 2010; O’Brien 2012; Brand and Brunnengräber 2013; Næss and Price 2016). The idea is not only to make sure that, e.g. the climate crisis will not be tackled in a way that increases unemployment or aggravates developmental issues. Beyond that, policy coherence is considered key because many of the seemingly different problems may go back to similar root causes. Understanding the basic causes of the rebound phenomenon can help identify and grasp these root causes and hence, contribute to design more coherent and viable sustainability strategies.

Last but not least, a key concern in the degrowth context is whether a sufficient decoupling of economic growth (in terms of income, GDP) from energy and resource consumption is possible or not. This is a highly complex and controversial debate, which until today witnesses antagonistic assessments (e.g. Edenhofer et al. 2009; Jackson 2009; International Resource Panel 2011, 2014; Antal and van den Bergh 2014). Much, though not all of rebound research can be read as a strong argument that a sufficiently deep and quick absolute decoupling is not possible if rebound effects from efficiency improvements remain unchecked (Sorrell 2010; Santarius 2015). After all, there is a delicate policy trade-off between increasing economic wealth and reducing energy consumption (see also Chaps. 2 and 15 in this volume). However, this volume has pointed out that the rebound paradox is not limited to technological progress. For instance, Chap. 3 has found that promoting sufficiency in consumption can lead to rebound effects, too (see also Alcott 2008); Chap. 10 presents data that a reduction in working hours, which represents a long-sought policy measure in the degrowth debate, can generate an increase in consumption; or Chap. 11 elucidates that forms of compensatory behaviour may arise in relation to both more or less environmentally sound residential locations. The common lesson learned from these broad-reaching considerations is: All kinds of sustainability strategies must be highly integrated policy approaches that aim at understanding potential countervailing rebound and other effects from policy measures and try to contain them. Hence, even degrowth policies must be designed 'rebound-proof'.

16.3 Rethinking Rebound Research

Designing 'rebound-proof' climate, energy and sustainability strategies requires a profound understanding of how the rebound phenomenon, i.e. various forms of rebound effects, play out in reality. Along with many other recent publications on the issue, this volume contributes to this understanding. At the same time, it points out where future rebound research should focus on. In the introduction to this volume, we have differentiated four phases of past rebound research, which highlight how the complexity of the discourse evolved over the years. The early 1980s were marked by controversies about the 'theoretical exploration' (*phase 1*) of the phenomenon. During the 1990s, the discourse witnesses a large number of econometric studies, which provide a growing 'empirical foundation' (*phase 2*). Since the 2000s, the debate about rebounds was increasingly exposed to 'political evaluation' (*phase 3*). And only recently, it experienced a 'multidisciplinary extension' (*phase 4*) with analysis moving from economics into other disciplines as well. The works in this volume build on this evolution. In part I, they deliver some fresh aspects for the rebound debate in energy economics (Chaps. 2–5); in part II, they develop new psychological and sociological rebound analyses (Chaps. 8–9). The works thus significantly advance the multidisciplinary approach to the issue. In part III, however, this volume applies the rebound concept to cases of policy-making in the real world (Chaps. 10–15), which had scarcely been done in rebound research before. We argue that policy case-specific discussions carry the potential to open up a new and *fifth* phase in rebound research.

What can be learned from applying the rebound concept to sectoral and policy cases is that the detailed discussions about price and substitution elasticities in energy economics, which used to set the stage and still dominate much of today's rebound literature, only to a limited extent explain the emergence and appearance of rebound effects in the real world. Yet the same seems true for other disciplinary approaches. For instance, identifying changes of behavioural mechanisms that have been caused by technological energy efficiency improvements through the lens of environmental psychology (see Chaps. 6–8) greatly improves the understanding of how rebound effects emerge, but again only provide one perspective on a complex interrelationship of causes and clouts, feedback loops and second- or third-order effects. This complexity becomes highly visible, for example, in the context of urban planning (Chap. 11): When comparing daily and leisure travel from residents in urban areas with suburban/more rural areas, various behavioural effects can be identified. But the border between what is a rebound effect, i.e. a demand reaction to the efficiency of a given living environment, and what are other types of compensatory and reinforcing effects, gets blurred. Another example can be derived from the analysis of efficiency improvements of ICT services und user behaviour in the Internet (Chap. 13): It is highly plausible that the cost-effectiveness of Cloud Computing increases overall demand of Web-based services. But at the same time, the efficiency of Cloud Computing induces other enabling effects and transformational effects, which go beyond what would strictly be considered a rebound effect. The lesson that can be learned from applying the rebound concept to concrete policy cases is: When rebounds are contextualized in real-world situations, the mechanisms behind the phenomenon intermingle, amplify, but sometimes also run counter to numerous other forces and effects.

Note that we do not intend to promulgate the notion that price elasticities (rebound economics), changes in motivation (rebound psychology), structural changes (rebound sociology), and other disciplinary approaches would not matter. Of course they do, which the chapters in part I and part II of this volume elaborate. But as the examples of urban planning and ICT services show, and as can be derived from all other case studies discussed in part III of this volume, pure ‘laboratory-like’ effects of efficiency elasticities, attitudinal changes and the like can hardly be isolated when considering the praxis. This should not give way to hasty conclusions that the rebound effect is but a statistical or theoretical phenomenon. Rather, our real-world contextualizations show that effective policy-making cannot consider rebound effects in isolation, but has to picture them within the interplay of various effects that might feedback on the implementation of a certain policy and measure.

In order to better grasp these interrelationships, rebound researchers should once more increase the complexity of analysis. An overarching conclusion of this volume is that rebound research needs to enter a new phase. This phase (5) might be labelled ‘*transdisciplinary application*’. Inter- and transdisciplinary rebound research should indeed build on the insights from energy economics as well as psychology, sociology, and other disciplinary rebound approaches to be further developed in the future, but should also try to focus its efforts on problems that cross the boundaries of two or more disciplines, and create a holistic and application-oriented approach. And furthermore, it should invest time and effort on involving people from ‘the real world’ in academic discussions on what rebound effects are, and how to avoid them; a scientific practice which has also been termed ‘post-normal science’ (Funtowicz and Ravetz 1991).

As readers can observe in part III of this book, one of the key challenges in transdisciplinary and real-world-oriented rebound research is to clearly and most precisely define what a rebound effect is, and how it can analytically and empirically be distinguished from other effects, with which it will likely interact. Hence, making rebound research more applied and real-world oriented comes along with the challenge to be even more precise and clear in defining causes, drivers and effects. But at the same, it will reap the benefit to better empower decision makers to design ‘rebound-proof’ climate, energy and sustainability policies. And we believe, the quest for sustainability desperately requires this.

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