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SCIENCE FOR A SUSTAINABLE DEVELOPMENT

# HOUSEHOLD ENERGY CONSUMPTION AND REBOUND EFFECT

# HECoRE

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**SCIENCE FOR A SUSTAINABLE DEVELOPMENT (SSD)**

*Energy*

FINAL REPORT

# HOUSEHOLD ENERGY CONSUMPTION AND REBOUND EFFECT

## HECoRE

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## SUMMARY

### CONTEXT

The European target of cutting greenhouse gas emissions by 20% by 2020 has generated a substantial body of energy efficiency policies, but real-world observations indicate that energy savings realized in practice fall short of energy savings estimates based on physical principles incorporated in engineering models. A partial explanation of this trend consists in what is called "rebound effect" or "take-back". As an increased consumption of energy services following an improvement in the technical efficiency of delivering those services, the rebound effect highlights a variety of tensions between the pursuit of wellbeing and the need to remain within ecological limits.

The rebound issue becomes particularly important in the context of a kind of 'double dividend' implicit in the idea of energy efficiency: the possibility that we might 'live better by consuming less fossil fuel'. If climate change imposes a drastic and urgent transition of the energy system, sustainability concepts that rest on the idea of resource- or energy-efficiency improvements thanks to technological progress tend to overestimate the potential saving effects, because they frequently ignore the behavioural responses entailed by technological improvements. So, the objective of keeping the greenhouse gas concentration below the 450 ppm $CO_2$–eq. threshold, necessary to keep temperature rise below 2°C with some acceptable probability, requires accompanying measures such as high 'fossil energy' taxes to keep prices of fossil fuels high, limit the rebound effects (by raising energy prices in line with energy efficiency improvements) and encourage the move to renewable energy sources.

For at least 40 years now, studies from different disciplines (psychology, sociology, economics ...) have shown that increased demand for energy from households depends on a wide range of mechanisms. In the 1970s, the oil and energy crises raised awareness for questions about the development and the determining factors of energy consumption and efficiency. The scientific field had predominantly adopted a technical stance based on engineering sciences and had focused on the technical side of optimizing efficiency. To include behavioural factors in this field, psychological and economic approaches were strongly developed in the 1970s and 1980s. In parallel to these disciplinary perspectives on the complexities of energy consumption, social sciences had investigated energy consumption from various angles. The efforts to conceptualize and explain the transformation of households' energy uses demand and require engagement with a significantly different set of concerns and considerations.

### OBJECTIVES

The main objective of the present study is to explore 'rebound effects' from different human sciences perspectives, so that we can broaden the understanding of the

phenomenon and provide an extended set of recommendations. The second chapter presents data and figures that frame the issue for Belgian households. The third chapter develops how *economics* has tackled the question of rebound and shows the limits of microeconomic neoclassical approach. The polemical debate on rebound phenomena is described. This controversy is partly due to the difficulty to gather relevant statistics. We then turn to the next chapter which expands on the idea, inspired by *behavioural economics*, that the 'indirect rebound effect' depends on the perception of the saving as a windfall of bonus. On the other hand, the explanation for the direct rebound effect rests on the notion of mental budget. While in chapter 3 (and partly 4) the rebound issue is considered at the micro-economic level, chapter 5 focuses on the economy-wide rebound problem in adopting a sociotechnical perspective. This chapter integrates the insights of *practice* and *transition* theories into a new framework of rebounds. In articulating micro (practices) and macro (infrastructures) levels, this approach discloses rebound effects as intrinsically linked to economic growth and the evolution of social norms as comfort and convenience. We conclude the report with a discussion of policy implications of our findings.

**CONCLUSIONS**

The data analysis of Belgian households expenses shows a slight decrease of the energy (heating fuel + electricity) share of the total household expenditure (see 5.1 in Annex), from 5,9 % in 1958 to 5 % in 2001. This is coherent with the assumption indicating that people are first concerned by their energy bill and not by their consumption. Energy consumption is not considered important because the bills following consumption only take up a small share of household budgets. Insofar as the energy bill represents a relatively small and decreasing share of the total household expenditures, there is no economic reason for citizens to try to mitigate their energy consumption. Mobility expenditures are a special case: whereas fuel expenditure share has remained at the level of 3% from 1973 to 2009, global mobility expenditure share have come from 8% to 14% in the average on the same period.

We observe three periods in which the energy consumption obeys to different dynamics. 1) 1960-1973 is characterised by low energy prices, the increase of household incomes and, as a result, the increase of energy consumption. 2) During the years 1973-1998, energy became more expensive, while household incomes were only slightly increased. Energy consumption decreases first (when energy prices were high) and then stabilises. 3) From 1998 until today, energy prices increase again, whereas incomes have been stable and energy consumption has begun to decrease progressively.

From a conceptual perspective, rebound effect is the idea that energy efficiency improvement is a partial cause of the increase in energy consumption with respect to what is expected. This causation is described with three mechanisms: direct and indirect effects (at the micro level) and macro effects. Direct rebound effects are so called because they refer to a change (increase) in demand for the energy service directly affected by the (energy) efficiency improvement. These effects are relatively well measured and amounts to 10-30% for space heating and personal automotive transport.

The indirect rebound effects at the micro-level refer to a change in demand for other goods or services which themselves require energy. For example, savings made through the more efficient heating of the home may be directed to extra overseas holidays. Through focus groups we have noticed that these effects exist. They are not however easily measured because they imply that people make choices while pondering about their energy consumption. Behavioural economics provides then some insights about how people achieve their mental accounting. For instance, behavioural economics shows that the money saved on a electricity bill will be valued and used differently according to the way it is framed (as a bonus or as a rebate), the way it is labelled (as a windfall or as an earning), the mental budget to which it will posted (provided it has been first booked), etc.

The causality between energy efficiency improvement and energy consumption increase is even more difficult to establish at the macro level. Causality in complex system is complicated to unravel. We point however to infrastructure development as a cause for both energy efficiency improvement and energy consumption increase. The expansion of the road network and of energy delivery systems can indeed explain the correlation between both. The improvement of energy efficiency of individual elements can then be accompanied with the increase of energy consumption by the whole system.

### CONTRIBUTION OF THE PROJECT IN A CONTEXT OF SCIENTIFIC SUPPORT TO A SUSTAINABLE DEVELOPMENT POLICY

In analysing rebound effects our aim is to better understand the energy efficiency policy instruments and how we could prevent their adverse effects. The report concludes with the discussion of different policy measures. Energy taxation is a straightforward recommendation, but if no complementary measure is taken, the fuel poverty issue would get bigger. Household preferences and practices should evolve, but this is a hard task for policy makers.

Furthermore, rebound effects occur as involuntary redistribution of gains and losses between energy and money. Counteracting rebounds would mean to get a grip on this redistribution process. We discuss a tentative proposition of energy currency that would help households to design more consciously their energy consumption.

A very concrete recommendation is to follow the UK standard that sets a 15% of comfort taking when a new heating system is implemented. This figure is incorporated in the models that forecast energy conservation following the implementation of energy efficiency measures.

### CONTRIBUTIONS TO THE PRESENT REPORT AND ACKNOWLEDGMENTS

Although all the members of the HECoRE team have been involved in the development of the different parts of the report, each institution has developed more specific parts. Introduction, chapters 2 (empirical observations) and 6 (policy implications) have been written by the whole team. Universiteit Antwerpen is the author of the chapter 3. IDD has written the chapter 4. ULB and ICEDD are responsible for the chapter 5. Given the technical and controversial nature of the rebound effect issue, each author is responsible for his own chapter and does not necessarily endorse everything that is claimed in the other chapters. These chapters adopt different approaches in order to circumscribe the rebound phenomena. The different parts are therefore complementary.

Original data and figures used in this report have been collected by the ICEDD. Much effort has been devoted to gather useful data, but it proves impossible to get continuous and homogeneous statistics over several decades. Different attempts have been made to develop indicators of energy efficiency and to analyse the energy consumption evolution through household profiles. All these figures and attempts are shown in a separated annex, in which all the sources are indicated.

We are very grateful to the members of the follow-up committee who have yielded interesting discussion and relevant comments on the different drafts our research. We express our gratitude to the experts who participates to the final workshop that aimed to discuss our policy recommendation. We thank warmly the people who accepted to take part to the focus groups and interviews.

## 1. A FIRST DEFINITION

The topic of this research is household energy consumption and its *rebound effects*. At this point, 'rebound effect' is not a well-defined term. We will see through the next chapters how this phenomenon can be defined and described in different disciplines as regards as energy (or resource) consumption. It is however interesting to notice how other fields have apprehended sorts of rebound effects. Economics, technology studies, medicine, psychiatry, psychology, all these disciplines have developed an idea of 'rebound effect'.

In a nutshell, the phenomenon is always considered as an adverse effect of an improvement. In economics and technology, rebound effects designate the unexpected consumption of resource that follows a resource efficiency improvement (cf. chapter 3). Rebound effect does not occur only within energy consumption, but with any technology that makes a significantly use of a natural resource. It can be water, metal or any precious material. In medicine, mental and physical damages can occur when a treatment is discontinued. The healing of sickness or health deficiency may be followed by the return of the same or other symptoms. In psychology, the attempt to eliminate disturbing thoughts may result in either a preoccupation with unwanted thought or an anxiety. In this case the rebound appears as the diminished controllability over other thoughts.

From these different definitions, we can summarise the rebound effect as being a counterproductive consequence of what was conceived as an improvement. The concept challenges a certain technological determinism and its belief that improving the efficiency of resource use will necessarily lead to lower consumption. We should note however that rebound effects can be seen as something positive as well. It has, for instance, been often observed that after the increased insulation of their homes, households consume more energy for heating just because it was impossible to heat it acceptably before. In this case the rebound effect is directly linked to the improvement of comfort. Therefore the incriminated effect is adverse only from the point of view of the environment.

# 2. EMPIRICAL OBSERVATIONS ON HOUSEHOLD ENERGY CONSUMPTION, ENERGY PRICES AND BUDGET SHARES

## 2.1. INCOME AND ENERGY CONSUMPTION

In many relevant simulations of (energy) policy changes, the availability of microdata on both expenditures and (taxable) income is highly recommended. This is certainly the case if one wants to assess the distributional consequences of these changes [Decoster et al, 2004]. But statistically matching fiscal data on gross incomes and household survey data on consumption is a difficult task, given the incomparability of both datasets. Figure 2.1 therefore simply shows the evolution of average income and expenditures for Belgian households over the period 1958 - 2008. In this period, the mean annual income of the Belgian household increased by a factor of 1.7, whereas the mean total annual expenditures rose by a factor of 1.5.

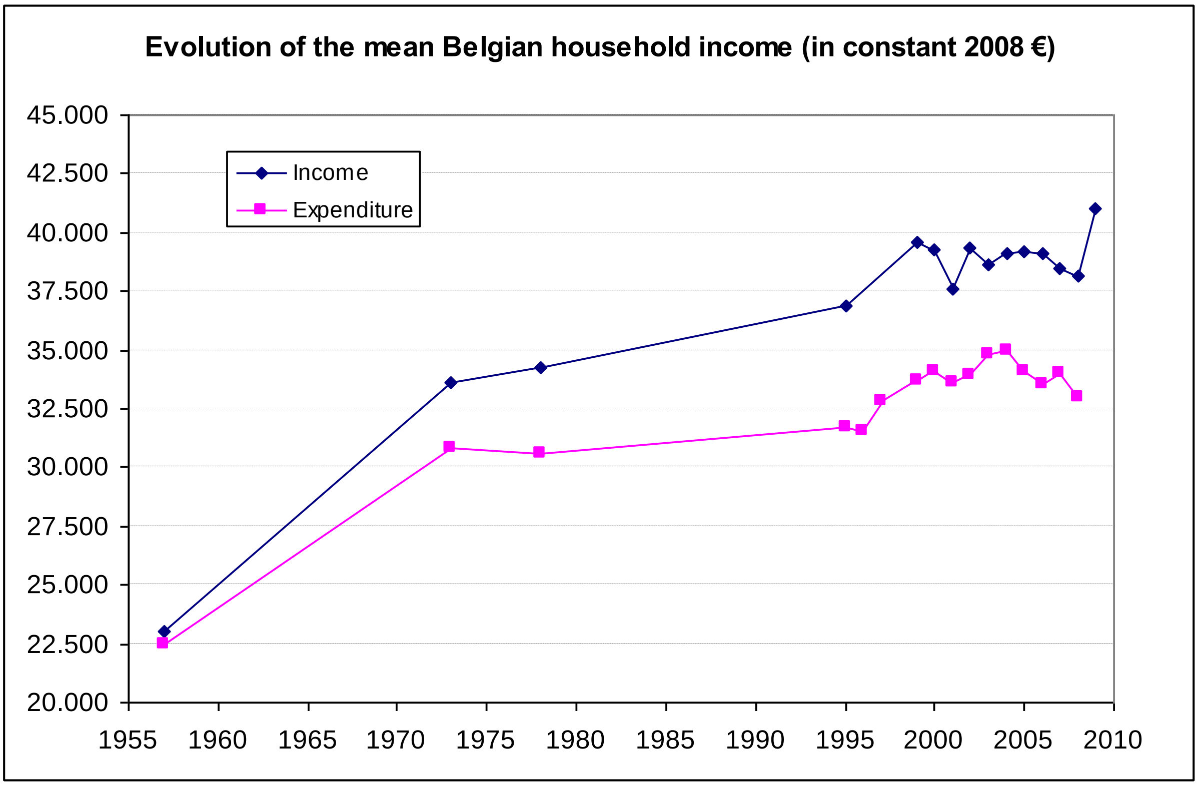



Figure 2.1 Evolution of the mean Belgian household income (in constant 2008 €)

The Belgian household expenditure surveys collect information on consumption expenditures for almost 1000 different (categories of) goods and services. In order to focus on the energy practices that will be analysed in chapter 5 of this report, we constructed a number of broad categories, as described in figure 2.2 In figure 2.2 we can observe that between 1958 and 2001, the shares of mobility and housing expenditures respectively increased by 11 % and 8 %, mainly to the detriment of food and health (- 16 %) and of clothing (- 6 %). The detailed categories are presented in the Annex A.

A closer look into the housing expenses shows a slight decrease of the energy (heating fuel + electricity) share of the total household expenditure (see Figure 5.1 in Annex), from 5,9 % in 1958 to 5 % in 2001.

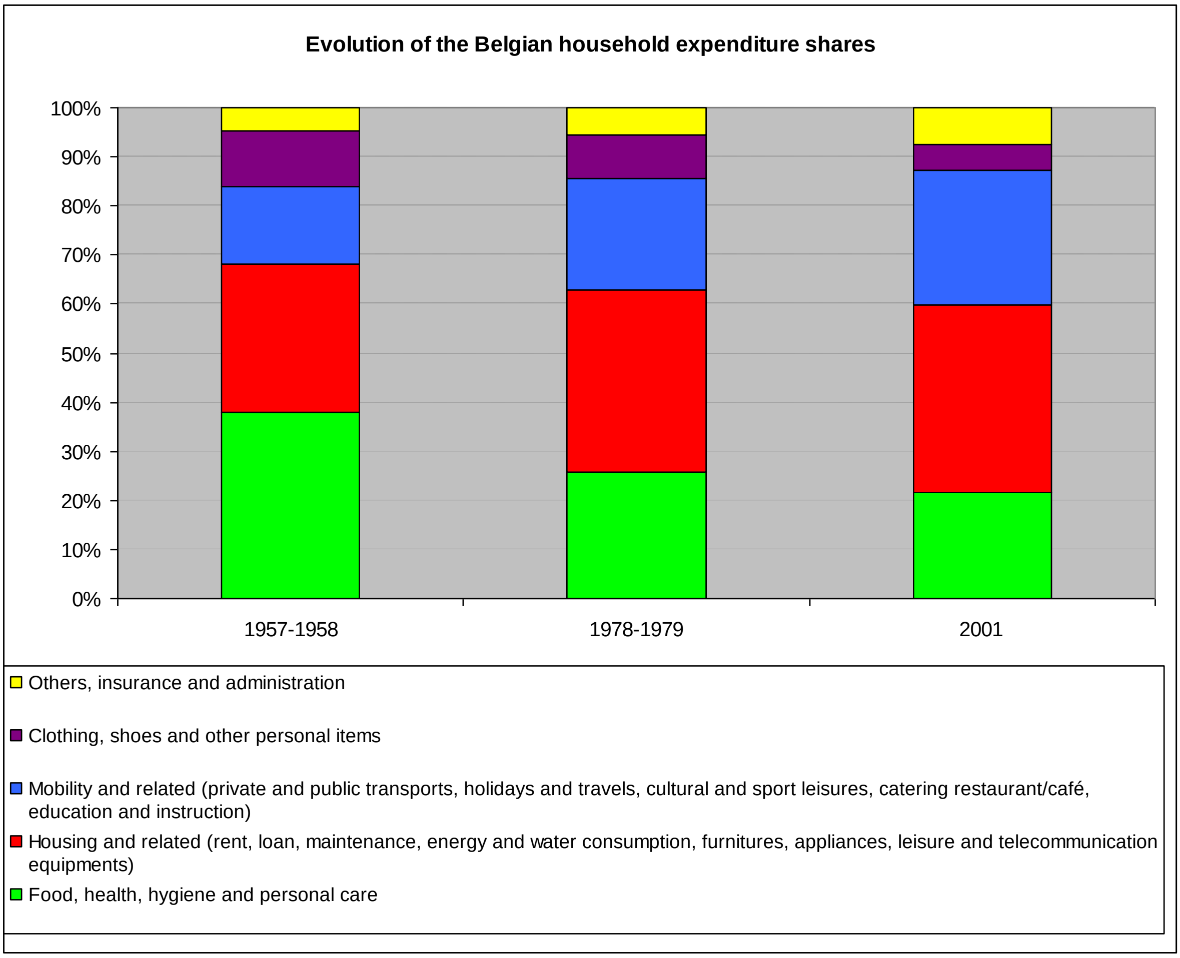



Figure 1.2 Evolution of the mean Belgian household expenditure shares

The analysis of the energy share by household type (see Figures 6 and 7 in Annex) indicates that people are first concerned by their energy bill and not by their consumption. Energy consumption is not considered important because the bills following consumption only take up a small share of household budgets (this share stayed at around 5 % in the last 50 years). Insofar as the energy bill represents a relatively small and decreasing share of the total household expenditures, there is no economic reason for citizens to try to mitigate their energy consumption.

It is interesting to point out that the evolution of heating fuel consumption (adjusted with degree-day variations) per household can at least partially be explained by the changes in energy prices, as those two evolutions seem to be correlated. In figure 2.3 the prices of coal (from 1950 to 1967) and heating fuel oil (from 1968 onward) are taken as a proxy for the average fuel prices. After a 50 % increase of fuel consumption per household during The Glorious Thirty (until beginning of 70's), household consumption has almost been halved following the two oil shocks of 1973 and 1979. Fuel consumption decreased from 3 toe/year before 1975 to 1.7 toe/year in 1983, and from that moment onward stayed relatively constant until recently, years), The real heating fuel oil price increased by 24 % between 1973 and 1974, and doubled between 1978 and 1982. After the oil counter shock of 1986 real oil prices fell down to a very low level during the nineties. The prices decreased by 35 % between 1986 and 1998, and slowly but gradually kept decreasing until the end of the 90's. The first decade of the new century seems to open a new era of high energy prices. Indeed, oil prices tripled from 1998 to 2008 reaching the same level as in the early eighties (in 2008 they even exceeded the previous maximum of 1981). This seems to induce a new drop in energy consumption per household.

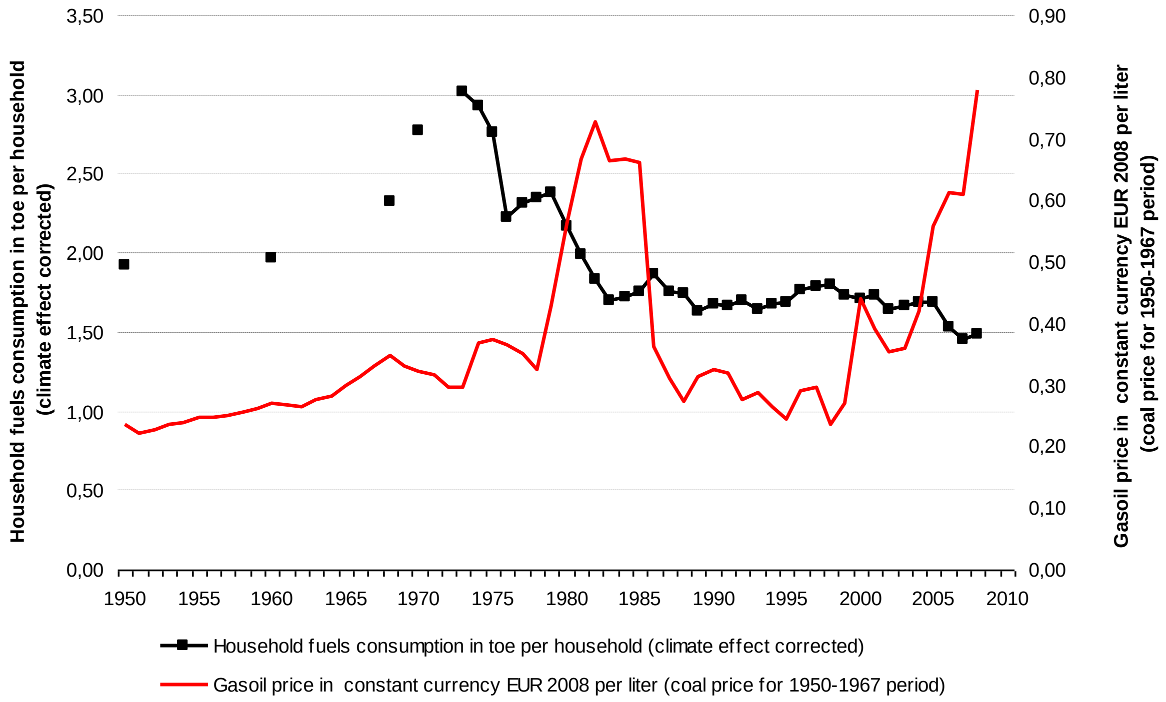



Figure 2.3. Fuel price and household fuel consumption

Energy bills that surpass the acceptable or affordable level as they did beginning 1980s trigger a reduction in end-users energy demand. The above seems to illustrate that there exists no relationship between the height of the energy prices and the share of the energy bills in the household expenditures. Instead of a generally alleged positive relationship between heights of prices and bills, we find a rather negative relationship. "…The 'law of acceptable energy bills or of affordable budget shares teaches us that end-users adapt energy use to prices for attaining the bills they can afford. High prices stimulate high efficiency but have no significant impact on the height of the bills" [Verbruggen, 2003, p. 1431]

The above analysis is limited to the aspect of intensity or efficiency of energy use, namely efficiency improvements in space heating per household. It does not answer questions about the absolute extent of energy consumption for space heating in Belgium related to population growth (increasing number of households), rising income levels (e.g. increased use of central heating), lifestyle changes (e.g. increasing size of dwellings), etc.

The absolute energy consumption of the residential sector only fell from around 11 Mtoe in 1973 to a minimum of 7 Mtoe in 1983 (see figure 9 in Annex). Indeed, since that year, the global trend is an increase until 2005. The explanation is that the total Belgian population grew while the household average size fell (from 2,98 persons/household beginning 70's to 2,33 persons/household in 2005. The increase in the energy efficiency of heating dwellings did not sufficiently compensate the growth of the number of households to avoid a global increase of energy demand. Since 2005, we observe a new fall of the global household energy consumption. Even if we still lack historical perspective, this fall could perhaps be explained by soaring energy prices coupled with active regional policies and measures encouraging households to insulate their dwellings, to replace their boilers or more generally to enhance the energy performance of their dwellings. Given the above observations, overall and persistent energy efficiency can only be realised by adopting high final prices for commercial end-use energy. When the prevailing prices are low, energy intensity is high and overall energy efficiency is low [Verbruggen, 2003, p. 1435].

Transport is another household practice which is highly energy consuming. The share of transportation or motor fuel purchases stayed relatively constant at around 3 % of the global household expenditures (figure 2.4) since the mid-seventies, while oil prices fluctuated greatly. Once more this suggests that citizens adapt their long term consumption behaviour to the economic conditions.

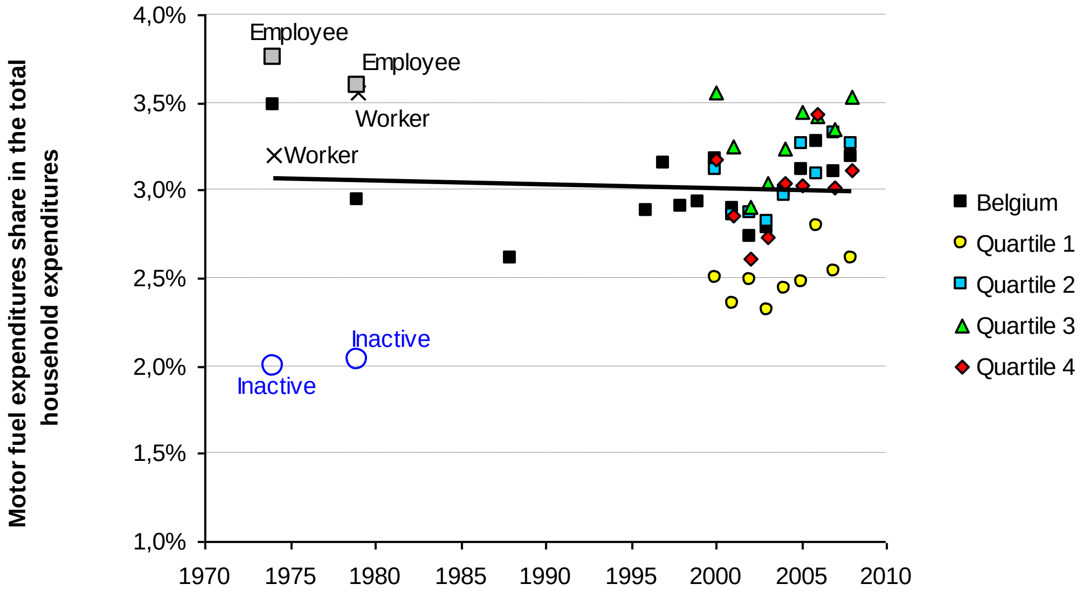



Figure 2.4. Motor fuel expenditure share

On the other hand, the share of global mobility expenditures (private and public, professional and leisure, see 2.5) in the global household budget increased continuously during the last 50 years (from 5,7 % in 1958 to 13,2 % in 2001). Those expenditures include car purchases, car maintenance and additional costs such as renting a garage, and expenses for public transport.

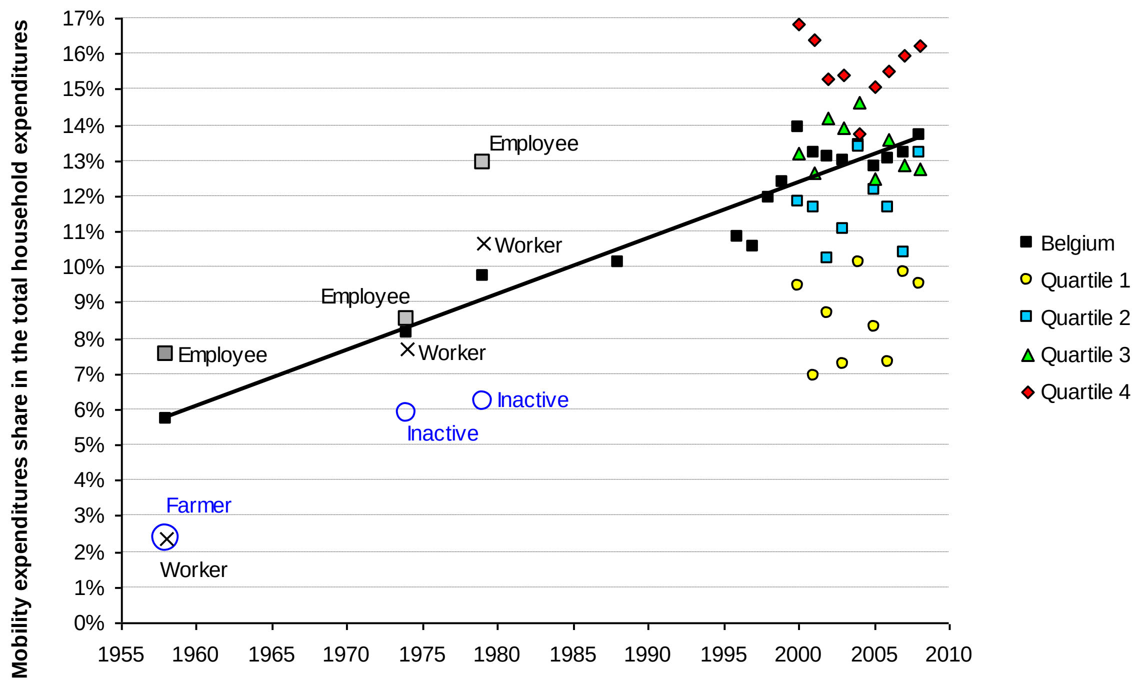



Figure 2.5. Total mobility expenditure share

In absolute terms, the motor fuel consumption grew by 71 % between 1961 and 1981. This can be linked to the increased number of households owning a private car 63 % of the Belgian households in 1981 compared to 21 % in 1961), and to the exponential growth of traffic (+ 160 % between 1961 and 1981, especially on highways where car traffic grew by a factor of 13). Between 1981 and 2001, the motor fuel consumption dropped by 16 %. This drop, in spite of a 20 % increase in the average annual mileage by private car, is most probably related to the improved energy efficiency of cars. This appears to confirm that income as well as fuel prices are key drivers for transport demand. Also, the impact of fuel prices on transportation demand works increasingly through fuel economy improvements rather than through reductions in the amount of driving [Small & Van Dender, 2007, p. 3-4]. This rebound effect in private mobility seems possible because the budget share of motor fuel is approximately constant.

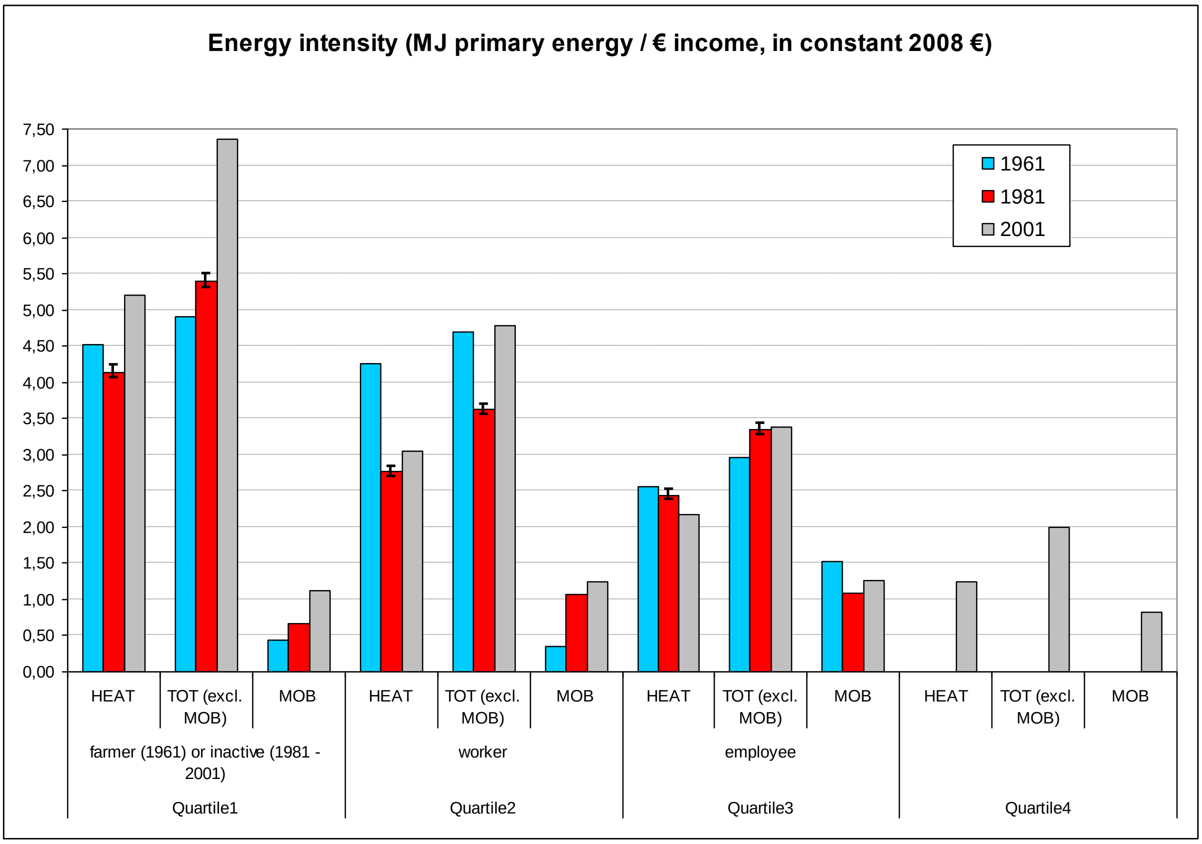



Figure 2.6. Energy intensity (primary energy / € income, in constant 2008 €)

Figure 2.6 presents the energy intensity of a mean household for each category defined in the Households Budget Surveys and for 3 energy uses: fuels and electricity consumption for home heating (HEAT), total at home fuel and electricity consumption (TOT excl. MOB), fuel consumption for mobility (MOB).

De-coupling the consumption of commercial energy from the generation of economic wealth and from living a comfortable life has been the crux of energy policy discussions since the mid-1970s. Highlighting the importance of the height of the end-use prices for underpinning energy efficiency should not result in an attitude of neglecting other policy instruments that can advance energy efficiency breakthroughs. On the contrary, when the price level pushes end-users to look after their own interests, households should be guided by reliable information on what can be done to realise the most efficient solutions [Verbruggen, 2002, p. 1435].

# 3. ECONOMIC VIEW ON ENERGY REBOUND EFFECTS FOR HOUSEHOLDS

## 3.1. INTRODUCTION TO ENERGY REBOUND EFFECTS IN ECONOMIC LITERATURE

### 3.1.1. RELEVANCE OF THE ENERGY REBOUND EFFECT FOR ENERGY AND CLIMATE CHANGE POLICIES

As early as the 1970s, energy analysts like Lovins [1976] promoted a "soft energy path", not only based on a diversity of energy production methods (matched in scale and energy quality to end-use needs) and "soft technologies" (renewable energy, biofuels, cogeneration), but also on a prompt and firm commitment to efficient use of energy. Contemporary policymaking relies on a linear, direct, and one to one relationship between energy efficiency improvements and carbon emission reductions [Jenkins et al., 2011:52]. These concepts rest on the notion that an increase in energy efficiency by 1% will also lead to a decrease in aggregate energy use by approximately 1%. However, (cost-effective) technological efficiency improvements induce or evoke behavioural responses by the economic agents (households, firms) that may partially or completely offset the expected energy savings and subsequent environmental gains [Berkhout, 2000:425]. An increase in efficiency by 1% may thus cause a reduction in energy use that is far below 1% [Binswanger, 2001:120]. This phenomenon is variably known to energy economists as the 'snap-back', 'take-back' or 'rebound' effect. Sometimes, an increase in energy efficiency may even cause a net increase in energy use at the macro level, which is also known as the 'backfire' effect. The latter was first put forward by Stanley Jevons, in his classic work 'The Coal Question', published in 1865. Jevons observed that the introduction of the new efficient steam engine initially decreased coal consumption which led to a drop in the price of coal. This meant not only that more people could afford coal, but also that coal was now economically viable for new uses, which ultimately greatly increased coal consumption [Gottron, 2001, p. 1-2]. For this reason, the backfire effect is sometimes labelled "Jevons' paradox" [e.g. Polimeni & Polimeni, 2006]. The truthfulness of the rebound phenomenon "*...directly undermines the effectiveness of energy efficiency measures that are used as policy instruments for meeting $CO_2$ emissions targets*" [Dimitripoulos, 2007:6360].

In broad terms (figure 3.1), we can distinguish two dimensions to the economy-wide rebound effect: a structural shift in activities (a.k.a. 'composition effect') and an economic growth effect. As stated by Dimitripoulos and Sorrell [2006]: "*A fall in the real price of energy services may reduce the price of intermediate and final goods throughout the economy, leading to a series of price and quantity adjustments, with energy-intensive goods and sectors gaining at the expense of less energy intensive ones. Energy efficiency improvements may also reduce energy prices and increase economic* *growth, which could further increase energy consumption"* [Dimitropoulos & Sorrell, 2006:3].

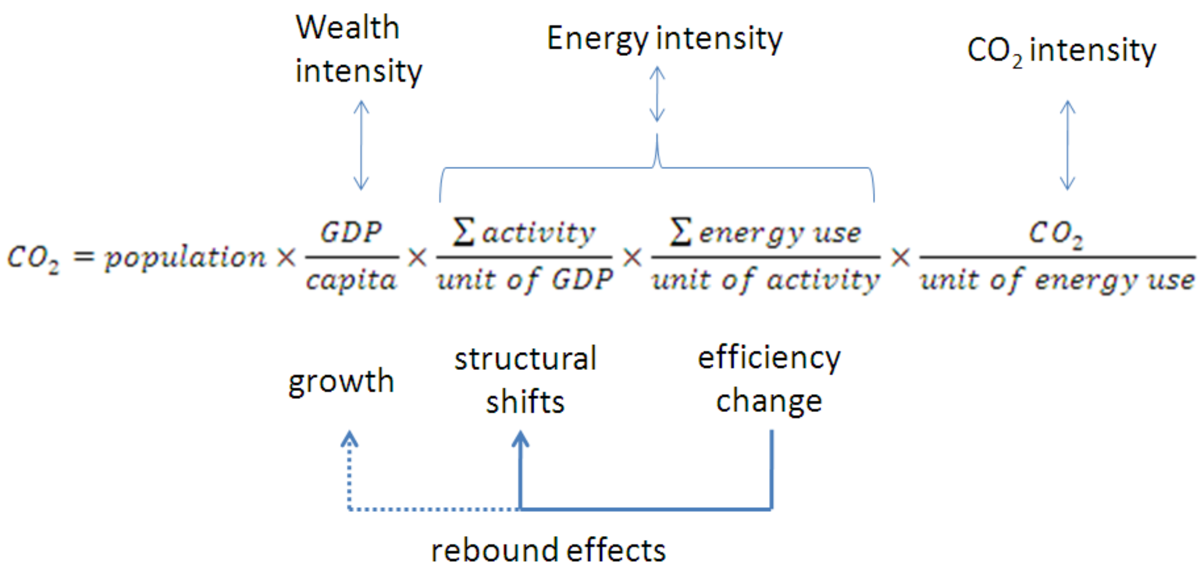



Figure 3.1: Relevance of the economy-wide rebound effect .

We base figure 3.1 on Verbruggen [2009], who decomposes energy intensity as the sum of many products of two factors: the technical energy efficiency[1] in performing a societal activity, and the weight of that activity in the GDP of the country. The latter factors depend on the sector structure of the economy (relative importance of the different sectors), and of the detailed composition of the various sectors, technologies, goods and services, etc. [Verbruggen, 2009:2932]. It thus becomes clear how an increase in 'energy efficiency' (i.e. a decrease in total energy use per unit of a particular activity), through a structural shift (increase in energy intensive activities at the expense of less energy intensive ones), may actually reduce, cancel out or even negate the potential impact of these technical improvements on the 'energy intensity' (total energy use per unit of GDP) of an economy [Verbruggen, 2009:2932; Pears, 2004:3; Birol & Kepler, 2000:458].

For a number of reasons the *economy-wide rebound effect* remains *"a controversial subject that has generated great debates among energy economists"* [Dimitripoulos, 2007, p. 6360][2].

Firstly, it is very difficult to estimate economy-wide rebound effect, because this effect *"represents the net effect of a number of different mechanisms that are individually*

[1] Strictly speaking, since 'energy efficiency' in engineering terms refers to the ratio of useful output over total energy inputs (more or less analogous to 'energy productivity' in economics), and intensity is considered as the reciprocal of efficiency (or productivity), 'technical energy intensity' as opposed to '(economic) energy intensity' would have been a more consistent term.

[2] To illustrate how controversial the subject (still) is, one of the news items in the 17 February 2011 Nature issue reads "Experts tangle over energy-efficiency 'rebound' effect".

*complex, mutually interdependent and likely to vary in importance from one type of energy efficiency improvement to another"* [Sorrell, 2007:3]. It is particularly hard to trace or prove the exact causality underlying certain mechanisms [van den Bergh, 2011:52]. As stated by Sorrell [2010], the key question is "*whether economic growth is the cause of increased energy consumption and/or improved energy efficiency, or whether increased energy consumption and/or improved energy efficiency is a cause of the growth in economic output*" [ibid.:1887].

Secondly, in evaluating the empirical evidence of the rebound effect, it is important to realize that "*Rebound effects need to be defined in relation to particular measures of energy efficiency (e.g., thermodynamic, physical, economic), to relevant system boundaries for both the measure of energy efficiency and the change in energy consumption (e.g., device, firm, sector, economy) and to a particular time frame*" [Sorrell, 2010:1786].

A third observation is that while accelerating the adoption of energy efficiency improvements may not make for particularly efficacious climate policy, it does probably make for very good economic policy, as it "*is likely to result in greater economic productivity and growth*" [Jenkins et al., 2011:53], increasing real income and generally improving welfare [Sorrell, 2010:1786]. Furthermore, given the actual activity levels, energy consumption would most probably be significantly higher than it would have been without the energy efficiency improvements [IEA, 2004]. The existence of rebound effects is not an argument for abandoning energy efficiency [Linares & Labendeira, 2009:10].

Finally, a lot of the controversy seems to arise from the fact that economic growth and structural shifts in activities, as invoked by energy efficiency improvements, are neither anticipated nor intended in most energy or climate change policies. The view that improvement in energy efficiency (or energy productivity) certainly takes back some of the expected energy savings is now widely accepted in literature [e.g. Laitner, 2000; Dimitripoulos, 2007, p. 6360; van den Berg, 2011, p. 51; Maxwell et al., 2011, p. 32, EMF, 2011, p. 8]. Point of contention remains the exact magnitude of the economy-wide rebound effect. But even so, "*Rebound effects tend to be almost universally ignored in official analyses of the potential energy savings from energy efficiency improvements*" [Sorrell, 2009:2001], a sentiment echoed by Jenkins et al. [2011] stating that "*…it is remarkable that rebound mechanisms remain almost entirely ignored in projections of energy efficiency's ability to drive lasting reductions in energy use or greenhouse gas emissions*" [id., ibid.:50]. Huge uncertainties regarding the magnitude notwithstanding, policy makers and energy analysts should take probable economy-wide rebound effects into consideration when designing energy or climate change policies [IEA, 2005, p. 36].

### 3.1.2. Formal definition of energy rebound effects

Most formal definitions try to describe the rebound effect as somehow measuring the discrepancy between the expected (engineering) energy savings (assuming that production or consumption levels do not change as a result of efficiency changes) and the "actual" energy savings (where production or consumption levels do change as a result of efficiency changes).


Figure 3.2 Graphical definition of the rebound effect (based on Gavankar & Geyer, 2010:17).

The name 'engineering savings' refers to "*a theoretical quantity of energy that could be saved after an increase in energy efficiency, if the quantity of goods and services demanded or consumed were held constant*" [Madlener & Alcott, 2009:370-371]. So, for example, as light bulbs use less and less kWh energy input per useful output of lumens/m², society could choose to produce and consume no more of these things, or indeed other things, yielding real energy savings in any given time period[3] [Madlener & Alcott, 2009]. The aforementioned discrepancy stems from behavioural reactions of economic agents (changes in production and/or consumption levels) in contrast to keeping the status quo, particularly where the efficiency gains bring reduced costs. The rebound effect due to energy efficiency improvements may therefore be understood in terms of technical-engineering versus behavioural-economic phenomena [van den Bergh, 2011, p. 46].

In general, rebound effects are defined as non realized savings in the use of resources relative to expected savings in the use of these resources.

$$RE = \frac{ESR - ASR}{ESR} \times 100 = \left(1 - \frac{ASR}{ESR}\right) \times 100$$

Where $RE$ = rebound effects, $ESR$ = expected saved resources and $ASR$ = actual saved resources.

### 3.1.3. A novel classification of rebound effects

"*There is no standardized classification, terminology or even definition of rebound effect in the literature*" [Gavankar & Geyer, 2010:18]. Madlener and Alcott [2006] "*have counted approximately 28 different terms for rebound effects in the literature*" [id., ibid.

[3] Technically speaking, the ratio energy input to useful output [e.g., kWh per lumen/m²], is called 'energy intensity', the inverse of energy efficiency.

p. 3]. In addition, those definitions are overlapping. Hence, *"...achieving consistency across the literature is ultimately impossible"* [Jenkins et al. 2011:12].

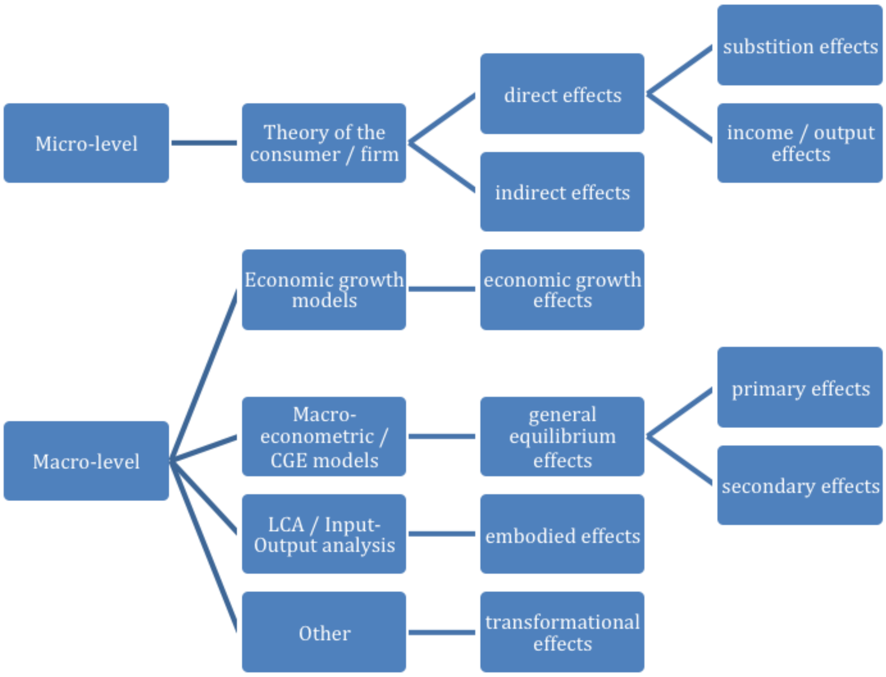



Figure 3.3. Categories of rebound effects

Rather than presenting a conventional 'taxonomy', figure 3.3 uses models in economic theory as a guide to classify rebound effects. For more traditional typologies we refer to Greening et al. [2000:390-392], Sorrell [2006:4], Jenkins et al. [2011:13] and van den Bergh [2011:47-48]. The main reason for choosing this classification is that our analysis is limited to rebound effects at the micro-level.

The rebound effects studied at the macro-level are what we previously called economy-wide rebound effects. They are *"macro effects that result from the interaction between different actors, both producers and consumers, in the economy"* [Hertwich, 2005:86], and as such they encompass all effects studied at the micro-level. The debate on the nature and magnitude of the rebound effect *"seems to concentrate especially on the macro-economic side of the issue"* [Dimitripoulos, 2007:6354], as it would appear that *"increased energy-efficiency at the micro-economic level, while leading to a reduction of energy use at this level, leads not to a reduction, but instead to an increase in energy use, at the national, or macroeconomic level"* [Herring, 1999:214]. However, at the macro-level, *"...empirical evidence is almost non-existent and there is no single widely accepted methodology that can depict rebound in higher levels of aggregation"* [Dimitripoulos, 2007:6354].

The rebound effects studied at the level of individual economic agents (households, firms) include the micro-economic effects that consist of the *direct* and *indirect* rebound effects. Direct rebound effects are so called because they refer to a change (increase) in demand for the energy service directly affected by the (energy) efficiency improvement. A classic example would be a homeowner who replaces a conventional boiler with a condensing boiler to increase the heating efficiency of his home, only to take advantage of the resulting decrease in home heating costs to increase the average room temperature, the amount of time the home is heated, and / or the number of rooms heated. The indirect rebound effects at the micro-level refer to a change in demand for other[4] goods or services (households) or for other factor inputs (firms), which themselves require energy to provide. For example, savings made through the more efficient heating of the home may be directed to extra overseas holidays. Our analysis focuses entirely on energy services in the household sector. For a discussion of rebound effects in other sectors (firms) we refer to Saunders [2011].

## 3.2. THE MAINSTREAM MICRO-ECONOMIC APPROACH TO REBOUND EFFECTS FOR HOUSEHOLDS

### 3.2.1. PRELIMINARIES – DELIMITATIONS AND DEFINITIONS

The estimated direction and magnitude of the rebound effects will partly depend upon how energy service, energy efficiency and (energy and total) costs of the energy service are defined.

Consumers admittedly[5] do not need (marketable) commodities[6] such as a boiler, a light fixture, a car, a washing machine or a TV, but rather they need thermal comfort, visibility (illumination), mobility, clean clothes or entertainment. These energy services are provided through energy systems that involve particular combinations of capital (K), labour (L), energy carriers (E) and materials (M). For example, the energy system providing the energy service 'lighting' is made up of lamps, luminaries and supporting systems such as power supplies and ballasts [Lima de Azevedo, 2007:1228], but also of passive daylighting sources such as conventional windows, clerestory windows, skylights, glass block walls, light shelves, tubular daylight guidance systems (TDGS), etc. Energy demand by households is thus a derived demand – energy is combined with other commodities to produce (or derive) the services households desire.

"*Energy efficiency is a generic term, and there is no one unequivocal quantitative measure of 'energy efficiency'*" [Patterson, 1996:377]. In principle, end-use energy efficiency concerns the technical relationship between on the one hand the maximum quantity of (useful) outputs of services (for instance, space heating, lighting, cooling,

[4] For this reason, the indirect rebound effect is sometimes called the "re-spending effect".
[5] But consumers may need the freedom and flexibility that brings about a washing machine compared to a launderette, of a TV set compared to a movie at the theatre, etc. In general, consumption is multifunctional.
[6] A commodity is defined as a particular good or service delivered at a specific time and at a specific location.

mobility, etc.) obtainable from a chosen and appropriately used technology, and on the other hand the (total) quantity of primary or final energy[7] consumed by that technology [Oikonomou et al., 2009]. The energy efficiency of an energy system is more formally defined as the ratio of useful output(s) to total energy input(s) converted to provide the useful output(s), or $\eta = S/E$, where $\eta$ is energy efficiency, S is useful output(s) and E is (converted) energy input(s). For example, the energy efficiency of an air conditioner may be defined as the amount of heat removed from air per kilowatt-hour of electricity input.

The scope of our research pertains only to the potential for rebound in response to so-called below-cost efficiency improvements, i.e. improvements that have the effect of decreasing the overall marginal costs of energy services. The marginal cost of an energy service is the change in total costs of producing (or delivering) one more unit of useful output of the energy service. For example, marginal costs could be the costs per additional unit of heating degrees provided in case of home heating; or the costs per additional lumen output for lighting. These marginal costs are also known as implicit or effective prices of energy services. Furthermore, a clear distinction must be made between the implicit or effective price of energy services and the market price of energy (e.g. cost per unit of heating fuel oil or per unit of electricity). The micro-level rebound effects are mainly driven by reductions in the implicit (effective) price (or marginal costs) of energy services. Changes in the implicit prices of energy services can occur even if there are no changes in the market prices of energy carriers [Jenkins et al., 2011:8]. At the macro-level, efficiency improvements may reduce aggregate demand for a particular energy carrier, leading to a possible reduction in market prices for that energy carrier, and this 'market price effect' may in turn drive a rebound effect in energy demand as consumers respond to now lower energy prices [Jenkins et al., 2011:8]. We will not concern ourselves with these macro-level effects.

### 3.2.2. MICRO-ECONOMIC ANALYSIS OF REBOUND EFFECTS IN THE HOUSEHOLD SECTOR

The most commonly used theoretical framework for micro-level analysis of the rebound effects in the household sector is the neoclassical model of consumer behaviour or 'rational choice theory'. This theory considers four basic elements: the consumer's available income, the prices of goods or services on the market, the consumer's preferences and the behavioural assumption of 'utility maximisation'. Given a limited income, a specific range of commodities to choose from, and a potentially infinite set of preferences, the consumer chooses commodities from those available in such a way as

[7] "Primary energy consumption refers to the direct use at the source, or supply to users without transformation, of crude energy, that is, energy that has not been subjected to any conversion or transformation process." [OECD, glossary of statistical terms] "Final energy is the energy supplied to the consumer in each end-use sector, which is ultimately converted into heat, light, motion and other energy services. It does not include transformation and distribution losses." [IEA, 2008:86] The 'primary energy equivalent' (of final energy) is an energy measure that accounts for losses in the production, transportation and distribution of final energy carriers (e.g. losses in electricity generation, transmission and distribution).

to maximise his or her subjective utility within the constraints of his or her available income [Jackson, 2005:30].

In our micro-economic analysis of rebound effects we deviate from the conventional textbook approach of consumer demand. In such an approach the object of interest would be commodities or energy carriers and their market prices. In our adjusted analysis the 'utility' of a household does not directly depend on market commodities, including energy carriers such as electricity, natural gas or gasoline. Instead, the household utility is a function of "energy services". Examples of household energy services are heating, space cooling, ventilation, domestic hot water, cooking, lighting, appliances and mobility. Because energy services in general produce more than one output, not all of them desirable (e.g. mobility by private car not only 'produces' passenger transport, but also noise and air pollution), we will explicitly refer to the "useful output of an energy service". Rather than quantities of goods and services (or commodities), we will only consider the levels of (useful outputs of) energy services. We prefer to describe the delivery of energy services as a "production household function" (see Becker [1965], Lancaster [1966] and Muth [1966]). To "produce" the useful outputs, the consumer has to purchase certain market commodities, which will serve as inputs into the household production function. Those inputs consist, amongst others, of durable (or capital) goods (e.g. a boiler for home heating or a car for mobility), energy carriers (such as electricity, natural gas, heating fuel oil, diesel or gasoline), and (market) services (such as boiler or car maintenance). In other words, we treat the demand of all commodities, including energy, as derived demands. Those demands are derived in the sense that these goods and services serve as inputs for the production of useful outputs of energy services. Our interest lies in analyzing how the demand for the useful output of an energy service changes, given an energy efficiency improvement in providing that energy service (e.g. by replacing a conventional boiler with a condensing boiler or by buying a more fuel efficient car). As a consequence, we are not at all interested in how demand for an energy carrier changes as a result of a change in relative market energy prices. On the contrary! A technological innovation improving the energy efficiency of an energy service makes the production of the useful output of that energy service "cheaper", not because of a decrease in market energy prices, but because one needs less energy to supply the same amount of useful output of that particular energy service. Therefore, to examine a change in demand for the useful outputs of energy services resulting from an energy efficiency improvement in the production of one of those outputs, we have to assume that all market energy prices remain constant (or for that matter, the prices of all other inputs needed to provide that energy service). So, instead of looking at changes in relative energy market prices, we have to consider changes in the relative "overall marginal costs of energy services", which we previously called "implicit" or "effective" prices. In our analysis, only the implicit prices of the energy services are relevant. Those implicit prices depend not only on prevailing market prices of the commodities needed for providing those services, but also on the (energy) efficiency of those services. Whereas in conventional analysis the budget set refers to the combinations (or 'bundles') of market commodities that a consumer can afford given his/her limited income (wealth) and the market prices of those commodities, in our analysis it refers to the combinations of useful outputs of energy services a consumer can afford, given his/her limited income (wealth) and the implicit prices of those energy services. The budget constraint means that the sum of the total costs of supplying the useful outputs of all energy services has to remain within the boundaries set by the household's budget.

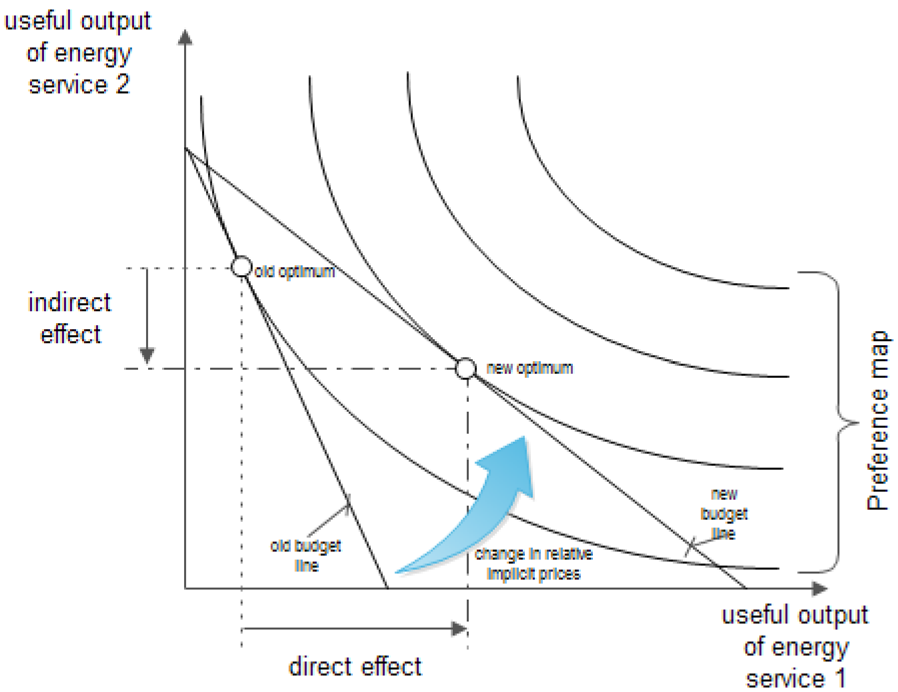



Figure 3.4. The direct rebound effect

The adjusted model of household behaviour can explain the rebound effect at the household level. An energy efficiency improvement leads to a change in the relative implicit price (or overall marginal costs) of providing the useful output of the energy service under consideration. This in turn leads to a shift of the budget line, and consequently to a new preferred (or 'optimal') combination of levels of useful outputs of energy services. It is important to note that, apart from the energy efficiency improvement and the household's subsequent change in consumption behaviour, everything else is kept constant, including income level but also all commodity prices (including market energy prices).

Given a certain change in relative implicit prices, both direction and magnitude of the direct and indirect rebound effects depend – ceteris paribus – strongly on the shape of the household's preference map (which, by the way, is also assumed to be constant). Because preferences can differ substantially from household to household and because preferences are not directly observable, it is extremely difficult if not impossible – on theoretical grounds alone – to accurately specify beforehand the direction and magnitude of these rebound effects.

The 'direct effect' in figure 3.4 shows the change (increase) in the demand for (the useful output of) energy service 1, as a result of an energy efficiency improvement of energy service 1, ceteris paribus. From this, it is straightforward to calculate both the "expected" (or engineering) energy savings and the "actual" energy savings. The direct rebound effect is the difference between expected and actual energy savings, divided by the expected energy savings.

Figure 3.4 also shows (on the vertical axis) the 'indirect effect', i.e. the change in consumption of the useful outputs of other energy services (the numeraire). This is an income effect, because after enjoying the (extra) quantity of useful output of the energy service whose energy efficiency has improved, there may be either less or more income to spend on the useful outputs of other energy services.

### 3.2.3. METHODS TO ESTIMATE THE DIRECT REBOUND EFFECTS IN THE HOUSEHOLD SECTOR

The extent of the rebound effects depends on parameter values whose determination is an empirical issue [Madlener & Alcott, 2007, p.3]. Two different approaches may be chosen in estimating the direction and magnitude of direct rebound effects for households: the quasi-experimental or engineering approach, and the econometric approach.

#### 3.2.3.1. THE QUASI-EXPERIMENTAL OR 'ENGINEERING' APPROACH

The quasi-experimental approach consists of measuring the actual saved resources (ASR) before and after an efficiency improvement, holding all other factors constant. The actual saved resources are compared with the expected saved resources (ESR), which – in principle – can be derived from engineering models (see also formal definition of the rebound effects). This methodology is mainly focused on household heating. There are two possibilities: one measures the change in demand for the useful output of the energy service before and after the improvement (e.g. measuring the change in heat output following the installation of a fuel efficient boiler), or one measures the change in energy inputs (e.g. the fuel consumed by the boiler). Sorrell, Dimitropoulos & Sommerville [2009:208-209] identify several weaknesses in (the application of) this methodology:

- The quality of most studies is relatively poor, the majority using simple before-after comparisons, without the use of a control group and without explicitly controlling for confounding variables;
- The methodology is vulnerable to selection bias, since households are not randomly assigned but rather choose to participate themselves;
- The sample sizes are typically small;
- The monitoring periods are often too short to capture the long-term effects;
- The relevant independent variables show large variations, both within and between studies (e.g. households receiving different types of energy efficiency measures, or combinations of measures);
- The researchers often fail to present the error associated with the estimates;
- The engineering estimates of the expected saved resources (ESR) are not always satisfactory. The installation may be deficient, the performance of the equipment could be inadequate, the energy efficiency improvement of household heating may change other physical factors (e.g. airflow) that may encourage other behavioural changes not directly related to lower heating costs, etc. Necessary simplifications in engineering models can result in overestimating savings by as much as 50%, especially for space conditioning [McKinsey, 2009, p. 33].

Also, different studies may use different terms for the same concepts as well as the same terms for different concepts [Sorrell, Dimitropoulos & Sommerville, 2009:208-209].

#### 3.2.3.2. THE ECONOMETRIC APPROACH

The more common approach to estimating direct rebound effects in the household sector is econometric analysis. In practice, direct rebound effects are estimated from either energy-efficiency elasticities or price elasticities[8]. These estimates require secondary data sources that include information on the relevant energy service, the demand for energy, and / or the energy efficiency of that service. Time series data allow the estimation of both short-run and long-run elasticities, depending on whether a fixed or variable stock of energy conversion devices is assumed. Cross-sectional data usually provide estimates of long-run elasticities. The choice of elasticity measure partly depends on data availability.

[8] A (partial) derivative is used to measure how responsive one variable $y = y(x_1, \dots, x_n)$ is to a change in another variable $x_i$. By weighting the partial derivative with the levels of variables under consideration, the scale effect is removed and a unit-free measure of responsiveness is obtained. This standardized derivative is called elasticity. The elasticity gives the percentage change in $y$ given a percentage change in $x_i$. Elasticity can be expressed in logarithmic form: $\varepsilon_{y,x_i} = \frac{\delta y}{\delta x_i}\frac{x_i}{y} = \frac{\delta \ln y}{\delta \ln x_i}$

Following $\eta = \frac{S}{E} \rightarrow S = \eta E$, the demand for the useful output of an energy service can be written as a function of the energy efficiency of that energy service, or $S = S(\eta)$. The efficiency elasticity of the energy service demand $\varepsilon_{\eta}(S) = \frac{\partial \ln S(\eta)}{\partial \ln \eta}$ gives the relative (percentage) change in demand for the useful output of the energy service following a percentage increase in the energy efficiency of that energy service. This elasticity [$\varepsilon_{\eta}(S)$] is taken as the immediate and most general measure of the direct rebound effect. The rebound effect will be zero [$RE = 0$ %] if and only if the demand for the useful output of the energy service remains unchanged following an energy efficiency improvement, i.e. if the efficiency elasticity of useful output equals zero [$\varepsilon_{\eta}(S)] = 0$]. In that case, the actual saving in energy consumption equals the expected energy savings from engineering calculations. A positive rebound effect implies that $\varepsilon_{\eta}(S) > 0$. Although the efficiency elasticity of the energy service demand should in all cases be the preferred, or in fact the only acceptable estimator of the direct energy rebound effect, insufficient data forces econometricians to employ alternative estimators.

Because measures of the useful output(s) [$S$] and data on the energy efficiencies [$\eta$] of an energy service are very difficult or even impossible to obtain, empirical estimates of the direct rebound effect are often necessarily based on the energy price elasticity of energy demand of the relevant energy service. Assuming that 1) the demand for the useful output ($S$) of the energy service solely depends on its energy costs per unit of useful output ($C_E$); 2) energy prices are exogenous (i.e. $P_E$ does not depend on $\eta$); and 3) the energy efficiency ($\eta$) of the energy service is exogenous, i.e. energy efficiency is unaffected by changes in energy prices, it is shown that $RE \cong \frac{\partial \ln S(\eta)}{\partial \ln \eta} = -\frac{\partial \ln E(P_E)}{\partial \ln P_E} = -\varepsilon_{P_E}(E)$. The term $\varepsilon_{P_E}(E)$ is the own-price elasticity of energy demand, i.e. the relative (percentage) change in energy demand (total energy inputs for the energy service) following a percentage change in energy price. The rebound definition based on the own-price elasticity of energy demand is a very restrictive one, as it requires the validity of three preconditions. It was nonetheless this definition that was originally introduced by Khazzoom [1980:38] as the definition of the direct rebound effect.

For a more complete overview of elasticities used in econometric analysis of the (direct) rebound effect, we refer to Couder and Verbruggen [2012] and to Sorrell and Dimitropoulos [2008].

### 3.2.4. EMPIRICAL RESULTS

The most comprehensive, systematic overviews of econometric estimates of the direct rebound effect so far were made by the Energy Research Centre of the UK (UKERC) [Sorrell & Dimitropoulos, 2007] and the U.S. based Breakthrough Institute [Jenkins et al., 2011].

| End-use | Range of values in evidence base (%) | 'Best guess' (%) | No. of studies | Degree of confidence |
|---|---|---|---|---|
| Personal automotive transport | 3 – 87 | 10 – 30 | 17 | High |
| Space heating | 0.6 – 60 | 10 – 30 | 9 | Medium |
| Space cooling | 1 – 26 | 1 – 26 | 2 | Low |
| Other consumer energy services | 0 - 41 | < 20 | 3 | Low |

Table 3.1: Estimates of the long-run direct rebound effect for consumer energy services in the OECD (Sorrell, 2009).

The UKERC results suggest that "the mean long-run direct rebound effect for personal automotive transport, household heating and household cooling in OECD countries is likely to be 30 per cent or less and may be expected to decline in the future as demand saturates and income increases" [Sorrell, 2009:214]. However, the UKERC research team clearly indicates a number of important limitations of the evidence, including the neglect of marginal consumers, the relatively limited time periods over which the effects have been studied and the restricted definitions of 'useful output' that have been employed [Sorrell, 2009:215]. In developing countries, where unmet demand for energy services is strong, the potential for direct rebound effects may be much larger, in the order of 42% to 80% (albeit based on only two studies) [Jenkins et al., 2011:27].

The evidence remains sparse and inconsistent. Interpretation of the evidence is furthermore greatly hampered by the extreme diversity of the studies in terms of the definitions, terminology, notation, methodological approaches, and data sources used [Sorrell, Dimitropoulos, Sommerville, 2009:1356]. The most important caveats in empirical (econometric) estimates of the (direct) rebound effects at the household level can be summarized as follows:

- Most econometric (empirical) studies are partial, i.e. limited to a single energy service (notably household heating and personal automotive transport, but not both at the same time), and focused on developed countries, in particular the United States [Berkhout, 2000:429; Sorrell, Dimitropoulos, Sommerville, 2009:1356; Jenkins et al., 2011:8];
- Econometric studies should include the overall costs of the energy service, not merely the energy costs. In particular, the opportunity costs of time should also

be taken into consideration. *"This has not been included in the traditional rebound theories, in spite of the fact that the substitution between time and money is a central concern of consumer economics"* [Hertwich, 2005:88];

- Lack of suitable data. Data on energy consumption [E] and energy prices [$P_E$] are more readily available than data on the useful output(s) [S] of the energy service. Data on energy efficiency [η] are in many cases either unavailable or inaccurate [Sorrell, Dimitropoulos & Sommerville, 2009];
- The use of price elasticities instead of efficiency elasticities. The assumptions upon which price elasticities as suitable definitions of the direct rebound effect ($P_E$ does not depend on η and η does not depend on $P_E$) are not very realistic.

  Efficiency improvements may reduce aggregate demand for a particular energy carrier, leading to a possible reduction in market prices for that energy carrier. Empirical studies find that energy-efficient innovation is also significantly determined by changes in energy prices (See Popp et al. [2009] for a literature review).

There has been little effort to rigorously quantify the 'indirect' rebound effect (a.k.a. re-spending effect) at the household level, and the available evidence to date remains too limited to draw precise conclusions about the scale of these effects [Jenkins et al., 2001:21].

Experts contacted within the context of a study commissioned by the European Commission have suggested that, given the inherent uncertainty, "attention and efforts not be directed at additional attempts to derive a precise value for the rebound effect, but rather to focus on developing policies which will be effective despite such inherent uncertainty" [Maxwell et al., 2011: 39].

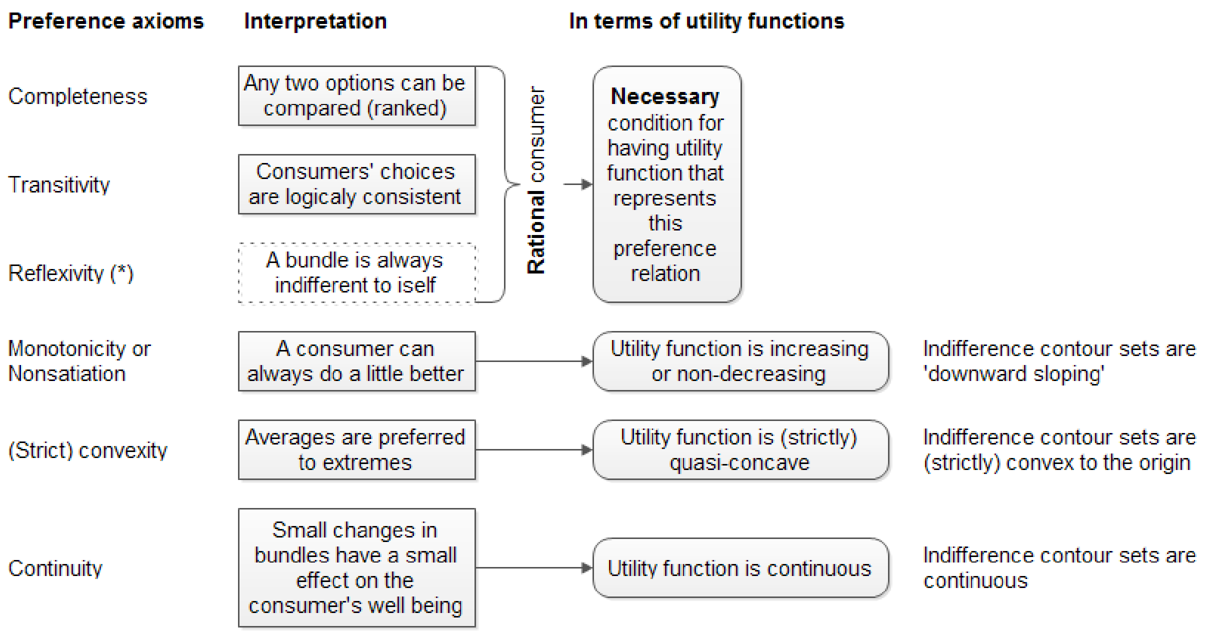
## 3.3. The need for a more complete model of consumption behaviour

### 3.3.1. Conceptual problems with mainstream theory of the consumer

The theoretical foundations of econometric estimates of the (direct) rebound effect are rational choice theory or its subjective expected utility (SEU) variant. The assumptions of traditional consumer theory may seem rather strange when it comes to explaining processes of long-term change [Linscheidt, 2001:5]:

- Preference orderings rely on formal axioms (fig. 6) which are ad hoc and do not conform to real-world situations;
- Preferences are assumed to be 'non-satiable', i.e. an individuals wants or needs are essentially unlimited;
- Preferences are assumed to be strictly convex;

- Consumers' preferences are assumed to be unaffected by their consumption in the past (preferences are specified as time-separable functions). This effectively excludes 'habit formation';
- Consumers' preferences are assumed to be unaffected by the actions of other consumers (there is no preference-interdependence), therefore excluding 'social factors';
- A consumer is a 'homo economicus', a hyper-rational person capable of processing massive amounts of information to make optimal decisions in his or her own interest. The implicit assumption that a consumer never makes mistakes in computation and choices excludes cognitive and affective limitations;
- Consumers (only) differ because of income[9], not because of skills, decision-making routines, etc. A 'representative consumer' represents different micro-agents (all sharing identical 'average' preferences) of the same (average income) class. A change in price would change the budget sets of all consumers, thus changing the behaviour of all consumers. In other words, there is no or very limited heterogeneity of consumers.




(*) Reflexivity is only required if the preference ordering is expressed as an indifference relation.

Figure 3.6. Axioms of rational choice theory

[9] In some neoclassical models all consumers even share the same income level.

The above "shortcomings" – described in more detail in Couder and Verbruggen [2012] – point to the need for a more complete model of (energy) consumption behaviour of households.

### 3.3.2. Rationale for models of consumer behaviour to study rebound effects

The key problem is that it is not possible to run historical "control" experiments on society to see whether total energy use is higher or lower than if there had been no energy efficiency improvements [Herring & Roy, 2007:198]. It is difficult or even impossible to conduct economic experiments on households let alone society. This necessitates the use of sophisticated models of (energy) consumption behaviour. Empirical research based on sound theoretical models may allow strong conclusions on the direction and magnitude of the rebound effect at the micro-level of households, without ever reaching absolute scientific certainty [Herring, 2008]. The value of such (hypothetical) models would not be so much the degree of realism of their assumptions, but rather the usefulness of the conclusions that can be derived from them. Computational models of consumer behaviour would allow conducting various simulations of household behaviours, which can be tested for the accuracy with which they represent reality.

In rational choice theory, consumers choose 'a bundle of commodities' in a consistent way, and therefore their behaviour is predictable [Kwan Choi, 2009]. If all consumers acted purely at random or if most behaviour could not be explained, it would not be possible to predict their behaviour. In order to fully understand the rebound effect(s) at the micro-level of households, it is necessary to understand how and why the various households consume. However, a solid understanding of specific mechanisms through which improvements in energy efficiency affect individual behaviours is still lacking [Safarzynska, 2011:6].

### 3.3.3. Why the need for an integrated model?

Since the mid-1970s, a succession of established disciplines has sought to develop theoretical models of human energy-related behaviour grounded in the perspective of each particular discipline [Parnell & Larsen, 2005:791]. Although existing models (rational choice model, attitude-behaviour model, folk model, categorization of energy users, diffusion of innovations) have been found to have merit in some though not all aspects of the human-energy relationship, *"...no overarching model to predict, influence, or categorize human behaviour on energy efficiency has emerged"* [Egan, 2001:12].

Recent literature has seen the emergence of a multidisciplinary approach to energy-use behaviour as part of the wider study of environmentally responsible behaviour (ERB) [Parnell & Larsen, 2005:792]. As stated by Ehrhardt-Martinez [2009:4], research on energy-efficient technologies and practices would clearly benefit greatly from the adoption of a behavioural toolkit. *"Such a toolkit would include the use of insights from a variety of social and behavioural fields including sociology, psychology, anthropology, demography, public policy, behavioural economics, marketing, and communications"* [Ehrhardt-Martinez, 2009:4].

In economic literature, the development of "sustainable" consumer demand models includes 1) the integration of psychological as well as sociological aspects; and 2) the detailed treatment of consumption as a complex process [Kletzan et al., 2002:137].

### 3.3.4. THE USE OF AGENT BASED MODELS (ABM) TO STUDY REBOUND EFFECTS

The main competitor of the mainstream perspective on consumer behaviour is evolutionary economics [agent-based models (ABM) of consumer purchase decisions]. Agent-based simulation is a relatively new bottom-up technique to model complex systems[10] composed of interacting, autonomous 'agents'. Agent-based models (ABM) can be used *"…to model social systems that are composed of agents who interact with and influence each other, learn from their experiences, and adapt their behaviours so they are better suited to their environment"* [Macal & North, 2010:151]. Agent-based models of consumer behaviour integrate economic, marketing, psychology, sociology, engineering and computer sciences. For example, de Haan et al. [2009] use an agent-based micro-simulation model of consumer choice of new cars to assess the potential occurrence of rebound effects, including potential direct rebound effects (more vehicles being purchased, increase in average car size, more kilometres being driven) but excluding indirect rebound effects (increased consumption of other goods or services). Lorentz and Woersdorfer [2009] use an ABM to study rebound effects for washing machines. They abandon the neo-classical concepts of non-satiation and optimization, and integrate the concept of consumer 'wants' into the body of literature on rebound effects. Households are modelled as heterogeneous agents. Their choices or "actions" include both purchases and utilization of washing machines. Those actions are driven by social standards of cleanliness and budget constraints. As social standards evolve, and energy efficiency of washing machines (exogenously) improves, consumption patterns change, in turn changing (decreasing) not only energy prices but also (increasing) social standards of cleanliness. They study the rebound effect by comparing potential energy savings, given technological progress, and actual energy savings. To study the rebound (backfire) effect at the economy-wide level, Safarzynska [2011] proposes an evolutionary-economic model, where consumers' preferences are interdependent and change over time as a result of a "snob effect" (i.e. a desire for distinction through special status commodities) and a "network effect" (i.e. imitation of

[10] A system is defined to be complex if it is composed of interacting unit and exhibits emergent properties, i.e. properties arising from the interactions of the units that are not properties of the individual units themselves.

others within their social networks). The analysis aims to provide – amongst others – insights to the role of technological change and status-driven consumption in explaining the rebound effect.

### 3.3.5. OUTLINE OF A NEW MODEL OF ENERGY CONSUMPTION BEHAVIOUR

Whether households will buy (and use) more energy efficient durable goods is the result of a complex choice process, involving income and time constraints, available information on the attributes of the new durable (including price and energy efficiency, but also 'comfort', 'social status', etc.), the consumption skills of the household (human capital), and the way the household "judges" that purchasing this particular good will contribute positively to the satisfaction of its "quality of life"[11], weighed against all possible other actions the household can take (e.g. spending the money on other market commodities). This judgement depends heavily on the perceived discrepancy between desired and actual satisfaction of certain wants (e.g. nutrition, clothing, sleep, safety, affection, social recognition and 'self-realisation'). Purchasing and consuming a good is supposed to add to the actual satisfaction of a weighted combination of wants, whereas the actual satisfaction of those wants may also depend on the consumption of (many) other commodities. The desired satisfaction in turn depends on personal characteristics of the household, including socio-demographic variables (such as household size, age, gender, education level, etc. of the household's constituent members) and psychological factors (for instance 'personal motives' or 'beliefs'). The latter can and will also be influenced by the environment in which the household operates, in particular the socio-cultural framework. This institutional framework includes social networks (interactions with family, friends, colleagues ...), social norms, etc. This is important, because it means that society not only influence consumer behaviour through market and regulatory instruments (prices, taxes, subsidies, technological standards, etc.) but also through soft policy instruments like sensitisation campaigns, 'energy education', etc.

A new conceptual model should allow simulating the conventional micro-economic approach of analyzing the rebound effect at the level of households. Even if the more energy efficient durable is more expensive (higher capital costs) than similar goods, the household – using its consumption skills and the available information on the attributes of the good – may still judge it worthwhile to buy that durable, because using that good will either allow the increased satisfaction of a particular want (e.g. thermal comfort) without having to sacrifice the satisfaction of other wants ("direct" rebound effect), or it will allow maintaining the same satisfaction level of that particular want, and free additional real income which may be used to pursue the increased satisfaction of other

[11] Hofstetter and Madjar (2003) see *happiness* as the affective (emotional) aspect and *life satisfaction* as the cognitive (realization) aspect, whereas *subjective well-being* combines both aspects. Quality of life combines subjective parts (well-being) with objective parts (measurement of explicit standards like wealth). [id., ibid. p. 15]

wants through purchasing other market commodities ("indirect" rebound effect, a.k.a. re-spending effect).

It would also allow simulating the time rebound effect. Purchasing a time-saving device permits a household to dedicate the saved time to other activities, which it "believes" will increase its overall level of quality of life. Whether this will lead to an net increase in the energy consumption of the household not only depends on the energy efficiency of the time saving device (less, equal or more than similar non-time saving devices), but also on the "energy intensity" of the other activities the household decides to engage in.

At the moment, this "new" model is little more than a concept. The energy rebound effect is an emergent phenomenon. It is the result of very complex processes, not only within households themselves but especially between households and all other agents in society. The proper way to study this phenomenon would probably be the use of an agent-based model (ABM). Time and resources in this project were far too limited to construct a full-fledged ABM. Further research is needed.

# 4. MENTAL ACCOUNTING AND THE REBOUND EFFECT

## 4.1. INTRODUCTION

As we have seen in the previous chapter, the neoclassical economics narrative of the consumer's rebound effect likens individuals and households to kinds of deterministic automata (Turing's machines) that react automatically to changes in their environment according to a predefined, fixed program. All the environmental changes are reflected in variations of prices and/or incomes to which the machine adapt itself by adjusting its demand function according to fixed parameters, namely price and income elasticities which allow maintaining a given level of overall utility or, if changes are significant enough, a higher but identical in nature (unchanged preferences, just 'more is better') one. If such a sketchy model of consumer's behaviour has proven useful for some purposes, it is clearly insufficient to give account of the way real people act and therefore to inform realistic, plausible public policies. In particular, it says nothing about the real behavioural mechanisms at work (or not) in the supposed consumer rebound effect and how to counteract them efficiently. A lot of 'fleshing out' (at least) of the mainstream economic model is mandatory if one wants to understand and influence household behaviour. Behavioural economics and social psychology are two disciplines which are currently actively and productively engaged in working out a more realistic and comprehensive picture of the way we take economic decisions and manage our resources and purchases. The concept of "mental accounting" has been adopted by these disciplines for describing and explaining the mechanisms through which real people make use of their money, or better, of their monies.

## 4.2. ELEMENTS OF MENTAL ACCOUNTING

"*Mental accounting is the set of cognitive operations used by individuals and households to organize, evaluate, and keep track of financial activities*" (Thaler 1998, 183]. In the same way that organizations record their financial transactions in books and separate accounts for different uses in order to control their expenses and keep track of their activities, households also need to record, summarize and analyse their financial transactions. However, in so doing they do not comply with the model of formal rationality underpinning standard microeconomics and decision theory. In what has quickly become – rather unexpectedly – an international bestseller, Thaler and Susstein [2008], contrast the creature of standard microeconomics, which they call Econ, with the only real creature, called, naturally, Human. They argue that, contrarily to Econs, Humans are guided not by the perfect logic of a super-computer that can analyse the cost-benefits of every action but by their very human, sociable, emotional and sometimes fallible brain.

Before Thaler and Susstein introduced behavioural economics to a large audience, two important psychologists had already demonstrated that people depart routinely from rationality as conceived by mainstream decision theory in very crucial aspects. Kahneman (who has been honored a Nobel prize in economics for this) and Tversky are renown for having worked out 'prospect theory', a model of decision making and economic behaviour which retains important characteristics of rationality but account for observed, regular departures from formal rationality in people real behaviour. In order to explain these oddities, they put forward a different image of man that the one which underpins neoclassical economists and decision theorists. Contrarily to *Econs*, Human are not fully consistent, homogeneous wholes. In fact, they are best described as composed of loosely coupled, more or less independent systems. Using a metaphor we owe first to the Buddha, the psychologist Jonathan Haidt [2006] compares human being to the association of a wild elephant and a driver. The driver – which looks so small and feeble compared to the elephant – represents the logical, rational component of man which tries to control and educate the immensely more powerful and stubborn component responsible for the non-logical, non-reflexive, automatic responses to environmental stimuli. Actually, the human self is divided in several ways: there is the division between the body and the mind, between the left and the right brain, between the oldest and the newest elements of the brain and, finally, between the automatic and the controlled systems. The latter distinction is well known in psychology as the System 1 versus System 2 distinction. System 1 – the elephant – is automatic, quick, and mostly effortless, System 2 – the driver – is conscious, slow and generally painful. As Kahneman [2011:415-416) states it: "*The attentive System 2 is who we think we are. System 2 articulates judgments and make choices, but it often endorses or rationalizes ideas and feelings that were generated by System 1….System 1 is indeed the origin of much that we do wrong, but it is also the origin of what we do right – which is most of what we do. Our thoughts and actions are routinely guided by System 1 and generally are on the mark*".

It follows, as Thaler and Susstein [2008] suggest, that in order to obtain behavioural changes, it is sometimes more effective to act on the environment of the decision than on its motivations or others more conscious elements of the decision situation. They call this activity "choice architecture". Indeed, the physical environment plays also an important role in shaping our choices and decisions. For example, the way the different foods are displayed and arranged on the self-service line desserts influence how the customer will compose their dinner. It is possible to make them eat more healthy food through an adequate arrangement of the different foods. In particular, the consumption of desserts will vary significantly according to their position in the line: at the beginning, at the end or even on a separate line. Clearly, infrastructures in general are part of the environment of choices and contribute greatly to their framing. An example of the way infrastructure influences behaviour is given by the intervention that aimed at (and succeeded in) reducing driving speed at a especially dangerous place by painting onto the road a series of white stripes that are initially evenly spaced but get closer together as drivers reach a dangerous curve. This gives drivers the impression that speed is increasing even if it does not really change. [Thaler and Susstein 2008:37].

To return to mental accounting, we may present it as a model of the usual outcomes of interactions between System 1 and System 2 when involved in economic decision making. The main building blocks of mental accounting are a) The value function; b) Framing and c) labeling or "earmarking". The value function captures how outcomes are perceived and evaluated. Framing refers to the way the decision context is understood or, most often, constructed. Labeling or earmarking refers to the way incomes and expenses are categorized, how different "mental" or physical accounts are created, etc.

In what follows, we present each of these topics in a non-technical way, our objective being to raise interest in categories we believe could provide a fresh, fruitful new look at rebound effects.

#### 4.2.1. THE VALUE FUNCTION

The value function is to Kahneman and Tversky's prospect theory what the utility function is to standard decision theory. It expresses how events are perceived and coded in mental decisions and provides a frame for mental accounting and decision making. It has the following characteristics, fundamentally different of the classical utility function features:

- It has gains and losses (i.e. changes) as domain, instead of end states like the utility function. Whereas utility theory assumes that the economic agent (*Econ*) decides on basis of expectations about absolute quantities of wealth, prospect theory states that human makes decision on basis of prospective changes (gains or losses) in wealth. Furthermore, changes in wealth are evaluated with respect to references points. As Kahneman and Tversky explain: "Strictly speaking, value should be treated as a function in two arguments: the asset position that serves as reference point, and the magnitude of the change (positive or negative) from the reference point. [Kahneman & Tversky, 2000:32].
- The value function passes through the reference point. It has two domains: a gain domain, located above the reference point and a loss domain, under the reference anchor. It is s-shaped and asymmetrical, being concave in its positive portion and convex in its negative one. This means, for instance, that the difference between 10€ and 20€ seems bigger than the difference between 1000€ and 1010€.

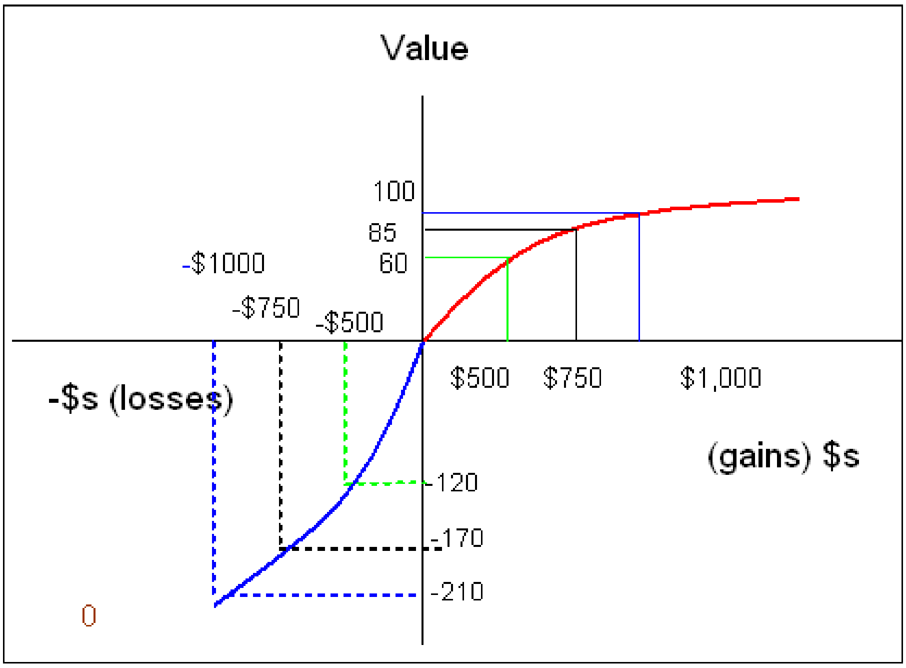



Fig. 3.1. Display of the characteristics of a typical value function

- Losses are weighted more than gains ("losses loom larger than corresponding gains"), a feature known as "loss aversion" which appears to have tremendous influence on mental accounting. For instance, it hurts more to lose 100€ than it yield pleasure to gain 100€.

### 4.2.2. Framing

According to Kahneman and Tversky, there are three different ways to frame outcomes and, therefore, choices: minimal accounting, topical accounting and comprehensive accounting. Comparing two options in a minimal accounting frame entails looking only to the differences between the two options. Comparing them in terms of topical accounting means relating the consequences of the possible choices to a reference level determined by the context within which the decision arises. Comprehensive accounting entails considering all possible consequences of the different options in terms of wealth, future earnings, other alternatives, etc. Comprehensive accounting is characteristic of *Econs*, but human are more comfortable with topical accounting

An example illustrates this. Suppose you are about to purchase a jacket for €125 (or alternatively €15) and a calculator for €15 (or respectively €125). The calculator vendor tells you that the calculator you are considering buying is on sale for (€10)[€120] at the other branch of the store, located 20 minutes drive away. Would you make the trip to the other store?

Most people would make the trip for saving 5€ if the calculator was priced €15 and the jacket 125 but not if it was the reverse (the jacket at 15 and calculator at 125). If they were using a minimal accounting frame they would ask themselves if it is worthwhile to drive 20 minutes for saving 5€ and give the same answer in either version. The same holds for comprehensive accounting. But, most people use the topical accounting frame.

The psychological mechanisms in the calculator and jacket example, consists of comparing not absolute values but relative ones: 5:15 is compared to 5:125. In other words, what matters is not the value of the difference but the difference of values. Formally, if v(x) is the value function of prospect theory, then it is true that $v(x) + v(y) \neq v(x + y)$: the sums of the values of two outcomes can be different from the value of their sum.

Thaler derives some interesting conclusions from this inequality regarding the way to combine different outcomes in a common account, that is: to frame a decision context. Two options are possible: integrating them [(x +/- y)] or segregating them [(x) +/- (y)]. Taking into account the shape of the value function (concavity above the reference point, convexity beneath) and the loss aversion, he submits that, in order to maximise welfare (what he calls 'hedonic framing'), we should:

- Segregate gains: that is presenting gains as separated instead of aggregating them (Question: Who is happier? A who wins a single 75€ lottery or B who wins at a 50€ lottery and also at a 25€ other one?)
- Integrate losses;
- Integrate smaller losses with larger gains (to offset loss aversion);
- Segregate small gains from larger losses.

These recommendations are made in a "marketing" perspective, as ways to maximize the perceived attractiveness of products or services. Of course, if, as is our concern here, the aim is to minimize the attractiveness of consuming energy, we should take the reverse: integrate gains, segregate losses, etc.

Another example of the importance of framing is given by Larrick and Soll [2008]. As is well known, the fuel consumption of cars is expressed in USA as miles per gallon (*mpg*). Larrick and Soll [2008] show that this way to express fuel consumption is leading to what they call the '*MPG* illusion'. The following snippet illustrates what they mean [Kahneman 2011 : 372]:

- Adam switches from a gas-guzzler of 12 mpg to a slightly less voracious guzzler that runs at 14 mpg.
- The environmentally virtuous Beth switches from a 30 mpg car to one that runs at 40 mpg.

Who, from Adam and Beth, is making the greatest effort in favor of the climate? Most people would answer Beth, not only because she has been presented as "environmentally virtuous" which certainly has some influence but because it seems that she is reducing her consumption from 10 units (instead of 2 for Adam) and of 1/3 against 1/6 for Adam. However, this is misleading. Suppose they both drive 10000 miles in a year. Adam will consume 714 gallons instead of 833 and save 119 gallons. Beth's fuel consumption, on the other hand, will go from 333 gallons to 250, a difference of 83 gallons.

Larrick and Soll conclude that the mpg frame is misleading and suggest replacing it with the gallons-per-mile or liters-per-100 km unit[12] in the commercials and information sheets on cars, as is the case in most countries.

Epley & Gneezy [2007] have conducted several experiments that highlight the importance of framing in decision making. They studied how the way windfalls (unexpected income) are frame can influence the way people use them. Their point of departure is the observation that the costly operation of tax rebates led by the American government in 2001 in order to stimulate consumption and foster economic growth had been rather deceiving. Far from spending it, people saved most of it, which didn't help boosting the economy. Epley and Gneezy put forward the hypothesis that what refrain people to spend their check of $300, $500 or $600 (depending on their reported annual income) is the fact that the windfall has been framed as a rebate, a return to a status quo and not as a bonus.

"*Despite being objectively identical, a "bonus" describes a positive change from the status quo whereas a "rebate" subjectively describes a return to the status quo. If people evaluate income comparatively rather than absolutely, they may feel like they have more income to spend – and therefore be more likely to spend at least some of it – when described as a gain (e.g. as a bonus) than when it is described as a returned loss (e.g. as a rebate).*" [Epley & Gneezy, 2007:39].

This is clearly an application of prospect theory according to which people react to changes in income, not to absolute levels and assess changes against a reference point.

They checked their hypothesis by launching several experiments wherein people were given a $50 windfall presented either as a bonus or as a return. All the experiments confirmed the hypothesis. In one of them, 73% of the participants in the rebate condition reported spending none of their $50 check compared to only 36% in the bonus condition. In fact, those in the bonus condition reported spending on average 2.5 times more than those in the rebate condition. Different variants of the experiment have been settled in order to control for possible bias in self-reporting behaviour. All of them gave still more significant differences between the two groups of participants. Epley and

[12] Which is now mandatory in the USA, thanks to Larrock and Soll paper. However, they complain it is still in too small characters to be salient enough.

Gneezy checked also for alternative explanations of the difference in behaviour. For example, they looked at the possibility that rebates, being interpreted as compensations for preceding losses, could be valued more than bonuses, a statement compatible with another component of prospect theory: loss aversion. However, they could not validate this explanation.

#### 4.2.3. Earmarking

Epley and Gneezy's work brings ample evidence that people indeed "label" their incomes and use them differently according to the way they label them. Indeed, labeling or earmarking is a fundamental feature of mental accounting. There are three ways in which money is labeled: expenditures are grouped into budgets (housing, leisure, food, clothes...), wealth into accounts (checking, pension, emergencies...) and income into categories (regular, exceptional, unexpected, earned, inherited, received ...).

Heath and Soll [1996] have explored the mechanism of labeling from a consumer point of view and shown that people generate two kinds of labels that affect their decisions as consumers: first they label money as relevant for a certain class of goods, second they label the goods as relevant for a certain pool of money. Heath and Soll call the first "budget-setting", and the second, "expenses-tracking". They distinguish two stages in the tracking-expenses process: (1) expenses must first be noticed (= "booked") and (2) then assigned to their proper accounts (= "posted"). The latter poses the problem of categorizing items and expenses, i.e. assigning them to one or another account. This can be made on basis of the goal (items that concur to the same or similar goals), the magnitude ("things you can have for 5 dollars"), the location where it is made, etc. As for every cognitive category mental accounting and posting categories are best represented by some items, which are therefore considered more "typical" of their group. As an example, attending a play is for many people typical of an entertainment expense even if it is a rather infrequent event. It follows that typical expenses will be easier to book and to post than less typical expenses.

Heath and Soll arguments are that:

1) Consumers budget portions of their total resources to separate mental accounts and they track expenses against the budgets. As expenses are incurred, they deplete the funds available in their account, which makes future purchases less likely. When a particular budget is depleted, they resist further expenses on items in that category. Note that many small routine expenses are not booked at all.

2) Budget setting leads people to over-consume some goods and under-consume others. Because budgets are set before consumption opportunities arises, they sometime overestimate, sometimes underestimate the money required for a particular account. They write: "*We hypothesize that when the predetermined budget earmarks too much*

*or too little money for a particular class of expenses, people stick closely to their budget and resist transferring funds across accounts… When people budget too little money, they may underconsume goods they desire. When they budget too much, they may overconsume goods that they desire less"*. (42).

3) Expenses tracking imply that some expenses are more likely to produce over or under-consumption. Expenses that are relatively easy to categorize (those that are more typical examples of a category) will be the most subject to the rigors of budgeting.

The explanation provided by behavioural economists and psychologists to mental budgeting of revenues and expenses is that it makes cognitive calculations easier and, more importantly, it helps monitoring self-control efforts. In short, people label because they want to control their economic behaviour. Budgeting helps making rational trade-offs between competing uses of funds and act as a self-control device. For instance, there is the tendency to intentionally set some budgets at a too low level in order to help restraining expenses of the category, or to buy "sinful" products (alcohol, cigarettes, candies...) in small packages even if it involves paying a price premium. As Wertenbroch (cited by Thaler 1999:195) puts it "To control their consumption, consumers pay more for less of what they like too much".

Likewise, wealth accounts can usually be ranked in a hierarchy arranged by how tempting it is for a household to spend money in each. The most tempting is the "current assets" one such as cash in hand and checking account. Next comes the "current wealth" account which includes savings and liquid assets in general, etc. In fact, the money in these different accounts has a different mental life-cycle or life expectancy which translates in differing marginal propensities to spend each unit of them: from 1 to current expenses account to near 0 for future income accounts.

In short, most of people think of money as sitting in different "mental budgets" – salary, savings, expenses, etc. Spending is constrained by the amount sitting in different accounts and people are reluctant to move money between such accounts…This means that policies may encourage people to save or spend money by explicitly 'labelling' accounts for them, without removing their control over exactly how the money is used. The impact of particular expenditure could be boosted by linking it to one mental account instead of another.

### 4.2.4. OTHERS FINDINGS ON MENTAL ACCOUNTING

#### *4.2.4.1.* TRANSACTION UTILITY

Many purchasing behaviours we observe everyday are not understandable if we take into account only what can be called acquisition utility. Acquisition utility is the pleasure the consumer gets from having the good. In technical, microeconomics terms it could be defined as the value the consumer would place on receiving a good as a gift (i.e. the pure possession utility) , minus the price paid for it (the sacrifice for having it). It is more or less equivalent to what standard microeconomics calls the consumer surplus. Transaction utility is the value of a deal, which corresponds to the difference between the "reference price" for a good and the amount really paid. The reference price is the one the consumer expects to pay for a product or a service. As Thaler (1999:189) explains: "*The addition of the transaction utility to the purchase calculus leads to two kinds of effects in the marketplace. First, some goods are purchased primarily because they are especially good deals. Most of us have some rarely worn items in our closets that are testimony to this phenomenon. Sellers make use of this penchant by emphasizing the savings relative to the regular retail price (which serves as the suggested reference price). In contrast, some purchases that would seemingly make the consumer better off may be avoided because of substantial negative transaction utility*."

#### *4.2.4.2.* OPENING AND CLOSING ACCOUNTS

The analysis of the selling behaviour of investors has shown that they rather sell the stocks which value has increased rather than the other ones [Odean 1998]. The generalization of this behaviour is that people are reluctant to close (an account, an investment…) on losses even if it is clearly more rational in terms of wealth. Until shares of stocks are resold, they have only 'paper' value, which can go up and down. They get a real value only if and when they are sold. Odean's observation is that if investors can afford paper losses while remaining adamant, they are reluctant to close a stock on a real loss. This is why they prefer selling winners (that is, shares which value is higher than their acquisition cost) than losers. Once again, the loss aversion of prospect theory is at work here…

#### *4.2.4.3.* SUNK COSTS

The problem of when to open and close an account is linked to the well-known 'sunk costs" phenomena. Sunk costs are retrospective (past) cost that have already been incurred and cannot be recovered. Normally, only prospective costs (those not already paid) and benefits should be taken into account in rational economic decision, not past ones. However, this axiom of rationality is frequently violated. In some way, including sunk costs in a decision context mean that the account in which they were included has not been closed, that it is still open. Keeping open accounts which should have been closed is a manifestation of mental accounting. The situation is frequent when a purchase is made well in advance of consumption. In such a situation, anything that could impede the consumption would turn a cost into a loss, which is aversive. Suppose you bought in September a theatre ticket for a play in December. This amounts to open an account which will be closed only in December, after having attended the play.

Suppose, however, that at the date fixed for the spectacle, a winter storm makes difficult and dangerous to ride to the theatre. Giving up – which would be the reasonable thing to do – would mean closing an account on a loss. Most people would take the risk to attend the play, something they would never even consider if they had received, instead of bought, the ticket.

Kahneman and Tversky [1984] have also pinpointed an irrational behaviour in a similar quasi-experimental context. They observed that people having bought in advance a theatre ticket and having lost it would be less prone to buy another one and attend the play that people having loss an equivalent amount in cash. As Thaler [1999:190] comments: *"In the theatre ticket example, buying a second ticket is aversive because it is included in the mental account for the theatre outing, but the loss of money is not."*

However, they are temporal limits to sunk costs. Thaler gives an illustration of the fact that payments depreciate in time with the following thought experiment. Suppose you buy a pair of shoes you find perfectly fitting in the store. The first day you wear it they hurt you. A few days later, you try again and they still hurt you. What are you going to do? The predictions are the following:

- The more you paid for them, the more times you will try again to wear them.
- Eventually, you stop wearing them but you do not throw them away. You keep them in your closet. The more you paid them, the longer you keep them there.
- At some point later, you throw them away, regardless of what they cost.

#### 4.2.4.4. PAYMENT DECOUPLING

Another aspect of mental accounting relates to the link between payment and consumption. When sellers have the choice between flat rate pricing or piece-rate pricing, they generally prefer the former as is the case at the Club Mediterannée where the clients pay a fixed fee that includes meals, lodging and recreation. The formula of "all inclusive" has two advantages. The first is that the (relatively modest) extra costs of including the meals and recreation in the total bill goes mostly unnoticed for the customer, being immersed in a whole dominated by the costs of accommodation (and sometimes travelling). The second advantage is that, in the opposite case, each additional expense looks large by itself and is likely to carry a negative transactional utility (see above) taking account of the prices usually practiced in these kinds of resorts. This is also why high standing restaurants prefer proposing 'prix fixe' menus. Would every meal of their multi-meal dinner be paid separately, the customer would be more upset by the small quantity of food each of them amounts to for the price!

When everything is paid separately, the link between the payment and the consumption is more salient, something sellers find undesirable. However, this largely explains why most urban dwellers still own a car when it would be far better for them, from a financial a point of view, to sell their car and use a combination of taxis and car rentals. As Thaler [1999:192] observes: *"However, paying $10 to take a taxi to the supermarket or a movie is both salient and linked to the consumption act; it seems to raise the price of groceries and movies in a way that monthly car payments (or, even better, a paid-off car) do not."*

The importance of decoupling for fostering consumption is best demonstrated by credit cards and the fact that stores are willing to pay 3% or more of their revenues to the card companies. The "advantage" brought by the credit card is twofold: first, it separates the payment from the purchase[13] and, second, it mix every payment with all others in a monthly bill. Clearly, from a psychological point of view, 50€ paid separately or added to a 850€ bill weights very differently.

#### 4.2.5. CONCLUSION ON MENTAL ACCOUNTING

All the experiments and observations which underpin behavioural economists and psychologists substantial conclusions are not immune against some methodological criticism and should be taken, as every scientific result, with some caution. However, most of them are confirmed by everyone, personal experience. We recognize oneself in the picture of that human who hates losses more than he enjoy gains, puts his revenues in (mental, physical or virtual) envelopes, owns a car even if it would be far more rational to use taxis, etc.

Would we want to summarize in a single statement the principal message of behavioural economics, the following would do: "In mental accounting, money is definitely not fungible". All the examples and discussions above illustrate and document this affirmation. Whilst for *Econs* one € is one € whatever its source or its destination, it is not the case for real people. The actual, psychological value of any € depends on a lot of economic, social, cultural and psychological circumstances. Of course, this contributes to complicate tremendously the problem of the rebound effect. Behavioural economics teaches us that the money saved on a electricity bill will be valued and used differently according to the way it is framed (for instance, as a bonus or as a rebate?), the way it is labelled (as a windfall? as an earning?), the mental budget to which it will posted (provided it has been first booked), etc. Therefore, in order to be able to predict if it will be spent on additional unities of the same good or service ("more of the same": direct rebound effect), or on other goods and services ("more of something else": indirect rebound effect) or not spent at all, but saved (no rebound effect at all), we need to know much more than what standard microeconomics can offer. If for standard

[13] The fact that the payment occurs after the purchase is not seen necessarily as an advantage for the consumer. Generally, the consumer prefers paying before than after, except for those who have some liquidity constraints.

microeconomics, the existence of a rebound effect follows straightforwardly from changes in relative prices, from a behavioural economics perspective, the nature of the rebound effects and even their very existence remains problematic. It depends on the answers we can give to several empirical questions, notably:

- In how many mental budgets do most people track their expenses? Do expenditures on electricity, fuel, cards expenses, travels, etc. belong to the same budget or to different ones, and if so, which ones?
- How flexible or inflexible are the different budgets that people make?
- Are people aware of their savings – if any – in energy budgets after having installed more efficient appliances?
- Do people usually overconsume or underconsume energy because of budget inflexibility?
- How do people frame the savings – if any – in energy-related expenditures coming from better efficiency of appliances, vehicles, etc.? Are they considered as bonus, which could explain their spending on "luxuries" such as airplane travels?

However, if behavioural economics has been successful in highlighting the existence of mental accounts and some of the consequences of their existence for decision making, it has not much to say on the way individuals and households build these accounts and how they allocate their resources to the different expenditures envelopes. We have to look on the side of others social sciences to expect finding answers to these questions. One possible source of inspiration is Viviana Zelizer's research on the changes in the public and private use of money in the USA between 1870 and 1930. A historian and sociologist, she also shed much light, in her 1994 book titled 'the social meaning of money', on the phenomena of non-fungibility of money deriving from the tendency to earmark incomes and expenses. In particular, she gives an extensive account of the different ways people earmarked money during that period. Most commonly, they segregated monies *spatially* using all sorts of physical containers (labeled envelopes, colored jars, stockings, piggy banks). Another very common practice of earmarking consisted in segregating by uses. For instance, a child's income could not be spent as parents' ones. It was designated for specific purchases, generally on child's entertainment and clothing. The source and the nature of the income mattered enormously. It was the case with child's income but it was true also of woman's compared to husband's incomes, of inherited compared to earned money, of earnings compared to gifts or reliefs, etc. In sum: "*People deploy a social lexicon of monies…earmarking certain monies for particular uses, distinguishing others by how they were earned, designating special users for particular exchanges, inventing new* *names for distinct uses of official currencies, or converting non monetary objects into media of exchange*". [Zelizer 1994:200].

In short, Zelizer clearly demonstrates that:

- Money, apart from its existence as the key rational tool of market economies, exists outside the sphere of the market and is influenced by social and cultural structures.
- Monies differ in uses, divisibility, fungibility, portability and subjectivity.
- "There is no single, uniform, generalized money, but multiple monies: people earmark different currencies for many or perhaps all types of social interactions, much as they create distinctive languages for different social contexts." [Zelizer 1994:18-19].

Reflecting on her 1994 book in a recent paper [2007] she added the following comment: "*These days, I would state the book's main theme more polemically. Here, for example, is an obvious point I took for granted but did not dramatize sufficiently: Monetary phenomena consists of and depend on social practices*." [Zelizer 2007:1063].

### 4.3. THE IMPORTANCE OF NORMS

It is tempting to advocate that the way people label and earmark their incomes, wealth and purchases have something to do with what they believe about the prevailing social norms in their social and cultural group and in society in general. Social psychologists have two concepts for reporting the way people refer to social norms: **descriptive** norms and **injunctive** ones. The first one refers to what people consider the most frequent (modal) behaviour. As Goldstein, Cialdini and Griskevicious [2008:472-3] put it: "*When consumers learn that seven out of 10 people choose one brand of automobile over another, that teeth-whitening toothpaste has become more popular than its less functional counterpart, and that nearly everyone at the local cafeteria steers clear of the "spamburger surprise" entrée, they are getting information about social norms. Specifically, they are getting information about descriptive norms, which refer to how most people behave in a situation*." Note that very often (especially for somewhat 'touchy' matters such as alcohol or drugs consumption) people generally have mistaken conceptions of the norm. Although they are devoid of any explicit normative content, people have a tendency to conform to descriptive norms. **Injunctive** norms, on the other hand, refer to what people perceive as being socially approved or disapproved. Both kinds of norms motivate human action; people tend to do what is socially approved as well as what is popular.

The power of the need to comply with others has been beautifully demonstrated by Solomon Asch (about 1950) in a famous experience where people were asked to identify the longest of different lines appearing on a screen, a task absolutely obvious. However, at some point in time, one of the participants (in fact, an assistant of the experimenter) begins to give false answers with much apparent self-confidence. Others assistants then agree with him despite the evidence. Eventually, most of the genuine guinea pigs change their mind and give also the false answer. More precisely, in Asch's experiments, 75% of the participants altered their answers to concur with the incorrect answers of others in the group. Furthermore, they upheld this incorrect answer in following sessions where there were no assistant of the experimenter but a new group of subjects.

Social norms are an important component of the social marketing toolbox. One well-known example of a successful resort to social norms in order to foster environmental behaviour is the use, in hotels room, of towel reuse cards informing the room guests that " x %" (generally more than 50) of past guests of this hotel have reused their towels". It has been demonstrated that when a hotel room contained a sign that asked people to recycle their towels to save the environment, 35.1% did so. When the sign used social norms and said that most guests at the hotel recycled their towels at least once during their stay, 44.1% complied. And when the sign said that most previous occupants of the very same room had reused towels at some point during their stay, 49.3% of guests also recycled.

However, invoking the social norm in social marketing program can be a mixed blessing. For instance, in programs aiming at reducing energy consumption, informing households about the mean consumption entails a double outcome: households above the mean decrease their consumption, which is the expected outcome but those already below the average are driven to increase their own consumption in order to comply with the norm! Note that, when the norm corresponds to a socially desirable state for some ethical or health related reason, it should not necessarily be hidden, even if doing so comes at an environmental cost.

# 5. REBOUND EFFECTS AS EMERGING FROM SOCIAL PRACTICES

## 5.1. INTRODUCTION

After having seen how behavioural economics and social psychology question the assumptions underlying the neoclassical account of the consumer behaviour and, therefore, of the rebound effect, we describe in this section how rebound effects can be interpreted within the framework of a sociology of practices that includes the dynamical aspect of transition. Improving energy efficiency spurs economic growth and higher standards of living. As causes and effects are intertwined it is not easy to tell if striving for comfort is the effect or the cause of economic growth. The impossibility to properly measure the (behavioural) effects of energy efficiency improvements when technology changes lead us to consider the coevolution of technology and social practices. We have then to adopt a theoretical framework that explains how energy efficiency improvements are linked to the transformation of the sociotechnical system.

The underlying idea of re-thinking the dynamics of rebound as a socio-technical transition of practices is to transform an abstract reflection into a heuristic model of diverse determinants relevant in everyday life. If models necessarily simplify the real world, case studies such as home heating and personal transport can put flesh on the conceptual bones of practices in the socio-technical transition of energy efficiency improvements.

The objective of this section is to broaden the analysis of rebound with insights gained from qualitative and quantitative resources. In the course of the project it became obvious that sufficient and consistent quantitative data could not be obtained. Socio-economic statistics had to be retrieved from a variety of sources that rely on widely differing definitions and assumptions. We have therefore complemented the collection of quantitative data with more qualitative methods. At the micro-level, we conducted several in-depth interviews with household members in their home settings. This qualitative study aims to provide a better understanding of past trends.

The sample was selected according to the various income levels. It was also focused on the differences between gender and dwelling location in Belgium (big city, small town, suburb, countryside) within the same income bracket. All respondents were older people who were already of age during the sixties of the previous century. Their common experience constitutes the starting point for increasing our knowledge of past and present practices.

To the extent possible we perform the analysis grouped by socio-economic profiles of the households. We also examine other important drivers of household energy consumption. For example, land occupation links different types of urbanisation, periurbanisation and countryside land-use, to mobility and the various types of housing constructions. To create a long term view on the socio-technical transition of energy related practices, it is imperative to cast a glance at the past. In order to map the evolution over the past forty years, three key years (1961, 1981, and 2001) were chosen to represent specific changes in development. We tried to set up the different analyses focussing on these key years, to make the search for data and the comparison between the various energy consumptions more feasible. However, as not all sources allow concentrating on these years only, it is important to treat the key years as ‘indicators’ within a time period.

Our intention is to explore and interpret some main trends in the long term in order to learn from the differences and similarities both between the 1960’s and the decade 2000-2010 as well as between home heating and personal transport. Both case studies provide the basic data and background information in order to reflect on the practices in transition behind the idea of rebound effect.

### 5.2. Some insights from interviews and focus group

At the beginning of the research we conducted eleven in-depth interviews with various actors who are familiar with households and their day-to-day energy consumption. These Belgian professionals belong to the following four sectors : housing (an architect, two energy auditors and an advisor for the energy performance of buildings), consumer goods (an energy advisor for *Test-Achat* and another for *ConsoEco*), mobility from home to work or leisure (the general secretary of Belgian Tour Operators’ association, the director of carsharing in Brussels, a researcher for an association of biking and an engineer in mobility plans for firms and cities) and social services (an energy advisor for poor households). This qualitative survey of intermediary actors showed that little is known about the rebound effect. The interviews revealed neither professional observations of nor meaningful reflections on the phenomenon of rebound. We explain that by the fact that the observation of rebounds needs a long-term perspective since the phenomenon refers to the consequences of prior energy savings. As a result, rebound effects appeared out of touch with the segmented reality of the professional actors.

The second step of our qualitative research was a focus group with eight individuals selected according to criteria based on household income, composition, age, gender and dwelling location (big city, small town, suburb, countryside). All respondents stated to save energy at home. In order to avoid as much as possible any bias, households were defrayed (40 euros per participant). It was hence easier to involve low-income household members of the population and people who are not interested in the question of energy conservation for environmental reasons. The energy efficiency of their equipment was used as an opening question in a questionnaire focused on their energy savings and expenditures. The idea behind the questions was an exploration of spontaneous representations linked to the rebounds in everyday life. In the questionnaire, several questions were asked to evaluate the level of knowledge about the rebound phenomenon. Without imposing a scientific definition, the purpose was to survey the ordinary experiences of rebound viewed from the angle of households. The diversified panels are convenient to maximize the investigation of different perspectives within a group setting. Indeed, the principle of collective interviews is that collective discussion can help people to clarify how they save energy at home, but also what their thoughts on the matter are and why they think that way.

As a first result of the focus group with households, the qualitative method applied to energy saving and spending enabled to explore how consumers link energy efficiency gains with other expenses. If individuals do not precisely calculate how much they save thanks to their investments in and rational use of efficient appliances, the various efforts made to this end lead some households to spend more money on leisure activities (home cinema, DVDs, video games, equipment for sports, going on holiday by plane or by personal car, rides in motorbike during week-ends). Therefore they consider money savings from energy conservation as a bonus. In other words, energy savings appear here as fungible.

From the households' point of view, we can speak about rewards for the economic, social, cognitive, mental and physical efforts revolving around the adoption of material equipment in energy efficiency. This kind of interpretation refers to what was recently called "mental or psychological rebound effect" [Girod et al., 2011]. Precisely, this emerging category of rebounds underlines that technical innovations that reduce environmental impact can have take-back effects on behaviour because people "feel good" or "less guilty" about their choices and they pay less attention to consumption. Regarding this "diminished concern", the collective interview of households has shown that the respondents consider energy consumption as a right. In their discourses, the spending of energy savings was described as a compensatory dynamic. In energy economics' terms, these practices of leisure evoke what is called "indirect rebound effect". The method allows to identify some characteristics of this phenomenon. The focus group with households manifested the importance of both material and socio-cultural dimensions at stake. The observation also suggests a close link between the level of energy consumption and the energy bill. People are firstly concerned with the stability of their global energy bill.

Figure 5.1 confirms such a pattern of household energy consumption. We can even observe a slight decrease of the energy (heating fuel + electricity) share in the total household budget, from 5,9 % in 1958 to 5 % in 2001, notwithstanding important differences between low income (quartile 1) and high income (quartile 4) households.

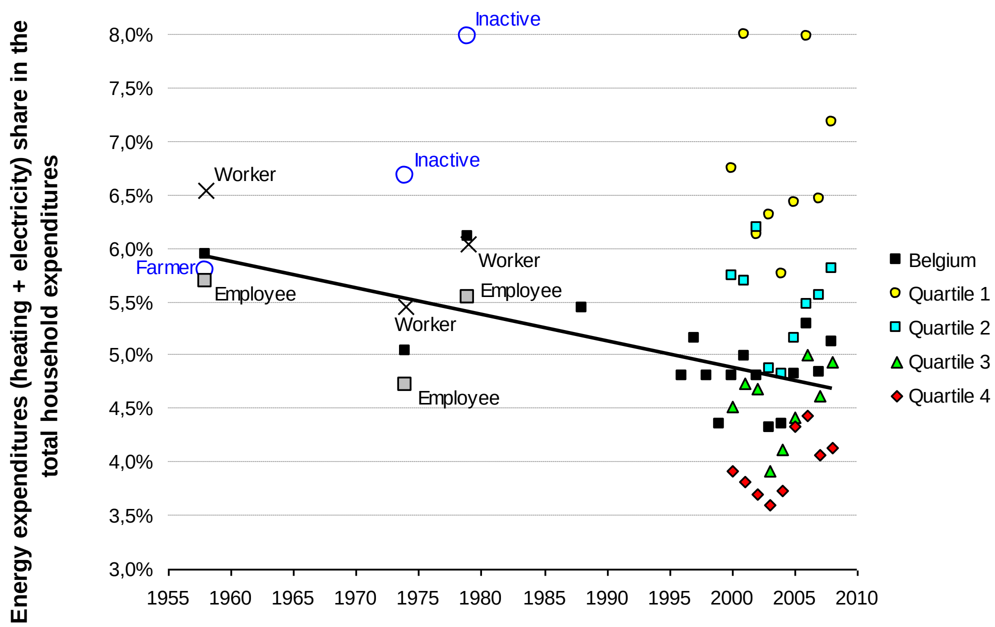



Figure 5.1. Energy expenditures share in the household total budget

Insofar as the energy bill represents a relatively small — it remains around 5 % in the last 50 years — and decreasing share of the total household expenditures, there is no economic reason for citizens to try to mitigate their energy consumption. The decrease in the energy share in the overall budget is largely due to the fact that household incomes have increased (see figure 5.1). The results from the focus group show then the tensions between the pursuit of well-being and the need to remain within ecological limits.

### 5.3. Rebound effects seen from a practice perspective

Some human sciences are good at describing internal aspects of individual decisions like consumer's cognition, but fail to reflect the importance of contextual or situational variables and vice versa. Making sense of behaviour inevitably requires a multi-dimensional view which incorporates both internal and external elements. We turn now to a model that analyses practices and their interactions (influences, consistency, exclusion, integration, etc.) with more energy efficient equipment. If we take the social organization of daily life as the focus point, it is immediately apparent that rather than concentrating on 'resources' like energy, the key issue is primarily to understand the services these resources make possible: heating, washing, lighting, cooking, etc. and how these services change. The interest of social practice and technological theories consists in inspiring new ways of seeing embedding energy consumption in domestic practices, closer not only to what is occurring at home but also to the concrete challenges of technological markets. The first step consists then in defining the appropriate unit of analysis to map how the material, cognitive, institutional and symbolic factors interact in influencing the significance of rebound effects at the household level [Némoz, Wallenborn, 2012].

If Schatzki [1996] and Reckwitz [2002] are both authors who are the most often quoted in reference to this approach, its sources of inspiration are multiple as well as diverse. Indeed, practice theory is a promising approach rather than a conceptually achieved theory. One of its conceptual interests rests on the articulation of traditionally separated concepts in sociology such as those of Bourdieu, Giddens, Lyotard, Charles Taylor, Garfinkel, Foucault, Latour,... The integrated analysis of their different sociological insights offers a multi-dimensional view of consumer behaviour, closer to what occurs in ordinary life. The basic principle of the practice centred framework postulates that its unit of analysis is the smallest in social sciences. As Reckwitz specifies, two senses need to be distinguished in the term of practice: on the one hand, it means human action as a whole (*Praxis)* and, on the other hand, practices (*Praktik*) refer to a "theory of social practices". In this last sense, « A 'practice' (Praktik) is a routinized type of behaviour which consists of several elements interconnected to one other: forms of bodily activities, forms of mental activities, 'things' and their use, a background knowledge in the form of understanding, know how, states of emotion and motivational knowledge. » [Reckwitz, 2002: 249). This « new » approach has the explicit ambition to take important elements into account that are neglected in the psycho-social models based on attitudes and individual behaviours (more or less rational), without necessarily adopting a holistic approach where the social structures are considered as causal, nor an epistemological relativism. Social order and individualities result from practices which can be identified and described as having an intrinsic value for "practitioners". If the processes of imitation are crucial for the creation and the reproduction of social facts, it is important to note that an agent does not imitate another individual as a whole but a practice adopted by this individual [Røpke, 2009].

At the moment, different authors are debating to determine the number of dimensions which should be taken into account by a practice theory [Gram-Hanssen, 2010]. We can discern the following components: materiality, infrastructures and objects; competences, skills, know-how and practical understanding; norms, procedures and institutionalized knowledge; engagement, symbolic meanings and representations. Beyond the number of elements involved in a practice, what matters is their way of being present and linked to each other. Thus, the conceptual framework of practice theory can be sufficiently integrative to encompass most of the data coming from a lot of disciplines and other field studies. By consequence, another interest in applying this theoretical approach to rebound effects consists in keeping in mind all the dimensions of problem. In the case of domestic energy consumption, the practice centred theory has several advantages presented below. To the extent that households do not consume energy, but use a series of appliances and resources which provide them different services [Wilhite H. et al. 1996], it makes sense to take practices as unit of analysis. Indeed, a practice theory approach to rebounds is able to move away from an expert understanding of reality and to approach the lay household's one.

From a scientific viewpoint, it is particularly obvious that there is a lack of studies investigating the matter of rebound from the perspective of the people concerned; focusing on their energy practices, conditions of action, and coping strategies. As a matter of fact the rebound effect describes the discrepancy between expected (engineering) and actual (realized) energy savings, which stems from behavioural reactions of economic agents in contrast to keeping the status quo [Lorentz & Woersdorfer, 2009]. More broadly the fact remains that people give sense to practices. Cooking, bathing, chatting on the web, are activities whose individuals have both practical and discursive consciousness [Giddens 1984]. In other words, a competent "practitioner" is an agent able to appropriate a group of elements in order to reach a precise goal, who has the possession of adequate tools, and whose behaviour needs a certain degree of attention. Furthermore, the eminently material characteristic of consumption is immediately included in the analysis of practices. Their sociological approach extends the psychosocial view of consumer behaviour to incorporate both internal and external elements of psychological disciplines. Even if many theories in psychology offer insights into the relevance of factors other than economic ones as regards the micro-level of energy consumption such as attitudes and values, psychological as well as economic approaches rely on individualist models for consumer behaviour which are not socially embedded and neither take into account the socio-cultural context nor the infrastructural conditions of actions like those of the built environment.

However, homes, offices, domestic appliances and other material objects play a major role in our lives. The predominant effect of habits and routines explains that not many of us question exactly how and why we perform so many rites associated with everyday use of energy technologies. A practice theory approach gains insight into these factors of behavioural inertia, by explicitly considering them through tacit knowledge and practical consciousness required by the accomplishment of a task. Furthermore, the enactment of a practice is actively linked to heterogeneous elements which imply forms of resistance to change. Indeed, our practices are enrolled not only in the material environment, but also in social norms and routines which reinforce each other. As Shove [2003] has shown, social norms and conventions constitute a key factor of explanation for the development of practices such as the case of weekly bathing which was replaced by daily showering in a few decades. In Shove's analysis, there is clear evidence supporting the view that routine consumption is controlled by conceptions of normality and profoundly shaped by cultural and economic forces. Expectations of comfort, cleanliness and convenience have changed radically over the past few generations. If they evoke different needs, they also refer to a social trend that can be adapted. This movable perspective is the last advantage of practice theory for re-thinking the dynamics of consumption labelled “rebound effects” in energy economics. Viewed from this sociological angle, practices are differentiated and dynamic in an intrinsic way. Both dimensions have been underlined by Warde [2005]. It is a social fact that individuals accomplish a same practice in very various ways. We can even observe resistances to the accomplishment of some practices and the emergence of alternative ones. In other words, our practices evolve. They have a history with a beginning, a development and an end. As the implementation of a practice requires an interconnecting link between distinctive elements, we can understand how these components chain to each other, by accumulation at certain periods or by dispersion another time.

### 5.4. Transformations induced by energy efficiency seen from the technological transition theory

To analyse the evolution of energy-related practices whose significance of rebound effects is relatively well-known among energy economists, the renewal of their conceptual model is not only based on the practice theory, but it also borrows from the “theory of technological transitions” its main concepts: socio-technical regime, niche, landscape [Geels 2002]. If the practice theory leads us to a comprehensive approach to heterogeneous components of rebound effects and no longer strictly focused on energy efficiency, the transition theory is good at describing the multi-level interactions of such elements whose timing of change are variable. The socio-technical regime of given sector (mobility, energy, food, etc.) is defined as a series of institutions whose connections can display the link between production and consumption: industrial networks, scientific and technical skills, sectoral policies, markets and users, technology, infrastructure, culture. All the relations between actors make up the socio-technical regime as a dynamically stable whole. A socio-technical regime is actively created and reproduced by different social groups. The production and reproduction of relationships between actors stabilize the entities of the system. The concept of technological niche describes the starting level of innovations. These novelties constantly emerge, but their forms are unstable until they have not been integrated into a regime. The performance of new technologies is generally weak with regard to the norms of the regime, and innovations disappear before being stabilized. It is why these niches should be protected, “sited on” if we want to give them a social future. Finally, the socio-technical landscape refers to the environment changes that occur during a very long time. At this level, external variables frame the possible evolutions of the regime: international and national policies, macro-economy, demography, climate change, cultural mutation, etc. This three-level approach is effective to follow the dynamics of transition from one socio-technical regime to another. An innovation can develop in a unique or several niches thanks to various processes: training, improvements (notably in performance), price decrease and support for powerful groups of society. The irruption of an innovation disturbs the socio-technical regime in place and recomposes it by transforming for instance the relationships between actors. At the level of landscape, changes can also pave the way for the development of innovation at the level of the regime. The new socio-technical regime is stabilized when the innovation is broadly adopted and when the set of practices become an identifiable configuration.

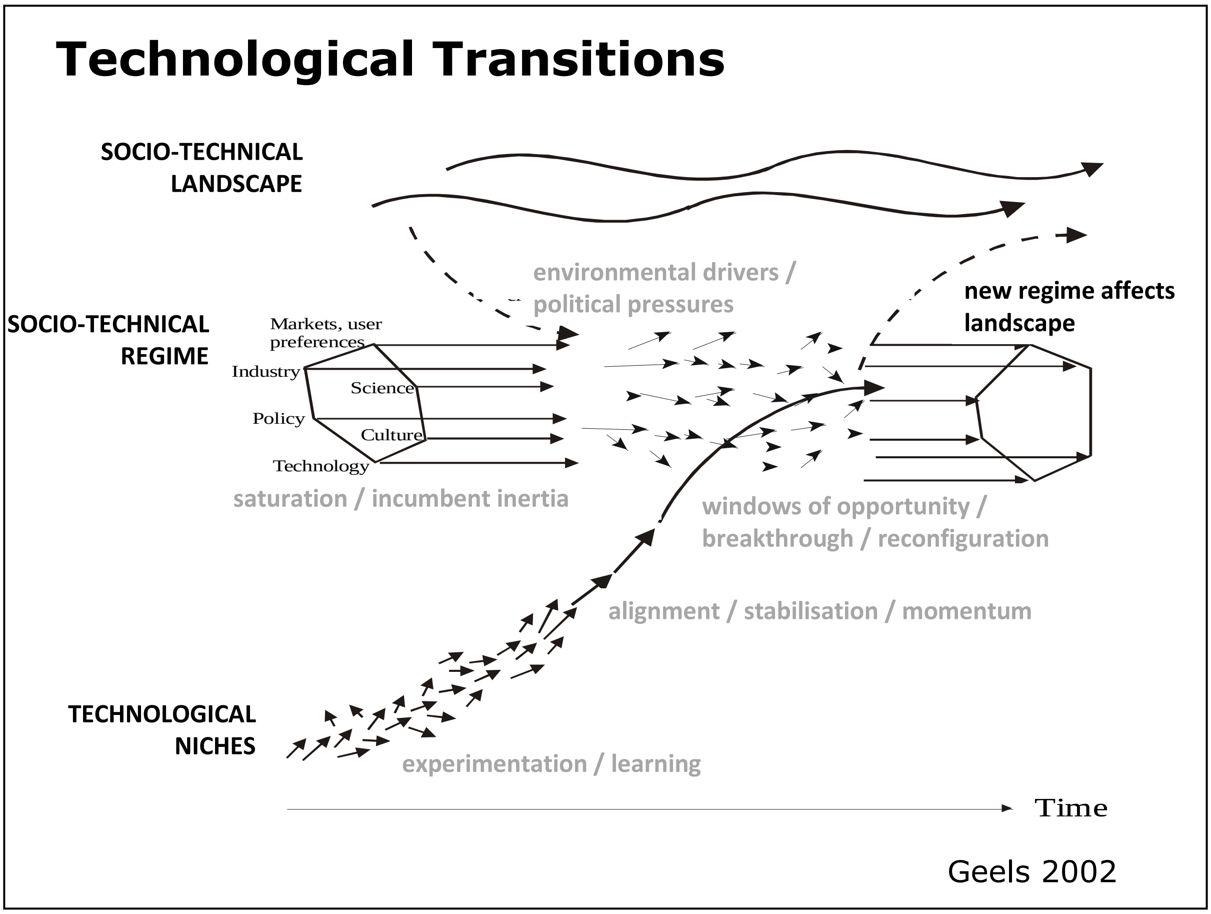



Figure 5.2. A typology of socio-technical transition pathways (Geels 2002)

In this integrated approach, we substitute technological innovations for practices, whereas social norms are located within the landscape. Indeed, social norms tend to concern several given sectors and they evolve in a slower way than technologies. Nevertheless, new social norms can emerge and favour the multiplication of new niches. On another hand, the sociotechnical regime is characterized by users' habits and routines which point to a great variability of uses within the same practice. To the extent that a practice is performed through the cohesion of heterogeneous elements and that a practice is varied in an intrinsic way, the novelty of a practice cannot be as easily identified as a technological innovation. But the case study of domestic energy consumption, in particular home heating, can be followed through the evolution of some indicators.

### 5.5. REBOUND EFFECTS IN HOME HEATING

Innovation development is commonly seen as the linear progression or diffusion from research to engineering and applied development, and then to commercialisation. Nonetheless, looking at how demand for new energy-using products and services develops, innovations are not turned out to be purely technological. Practice theory offers an alternative to (macro-economic) growth theories as it analyses the social uses and processes of co-construction of technology and society, given the many variables involved over a long timescale.

In the following analysis, the long time perspectives of emerging energy related practices are scrutinized through both material and socio-cultural dimensions. According to the multi-dimensional perspective of our alternative framework, we propose to examine how transitions come about through interactions between heterogeneous processes. In order to establish which aspects of rebound phenomena have received insufficient attention until now, and how we might go about in covering them, we endeavour to develop a deeper understanding of heating practices and their patterns of resource consumption associated with more efficient equipment. The ambition of this first case study is to develop a model that links practices and observable variables.

To be recognized as a practice, a certain degree of repetition is needed. It is the regular performance of a practice, of its doings and sayings, which maintains a practice as an entity. Social interactions are framed by a variety of constraints that, in turn, strongly contribute to the regularity of communication, resource allocation, preference formation and problem solving that characterise most social phenomena. Behavioural changes linked to energy use are no exception — whether successful or not. What has happened in the case of home heating?

Nowadays, Belgium energy consumption per square meter in residential buildings is more than 70 percent higher than the European average (Denis et al., 2009). If we compare the current situation of space heating in Belgian dwellings with what was common in 1961, we can observe that central heating has been progressively appropriated to the detriment of coal stove. In 2001, more than 70% of inhabitants in Belgium had a central heating contrary to only 10% in 1961. Although central heating is reputed to be more efficient that coal stove — and this obviously depends greatly on how the system is managed —, efficiency was not the reason of the introduction of central heating. It was introduced mainly for improving comfort and convenience. Furthermore, the heated area is generally increased and even if the energy efficiency (measured as heated volume per energy consumption) is improved, the total energy consumption can increase. The average area of Belgian dwellings increased significantly from 71 square meters in 1961 to 108 square-meters in 2001. Houses got bigger and rooms can be dedicated to different domestic functions.

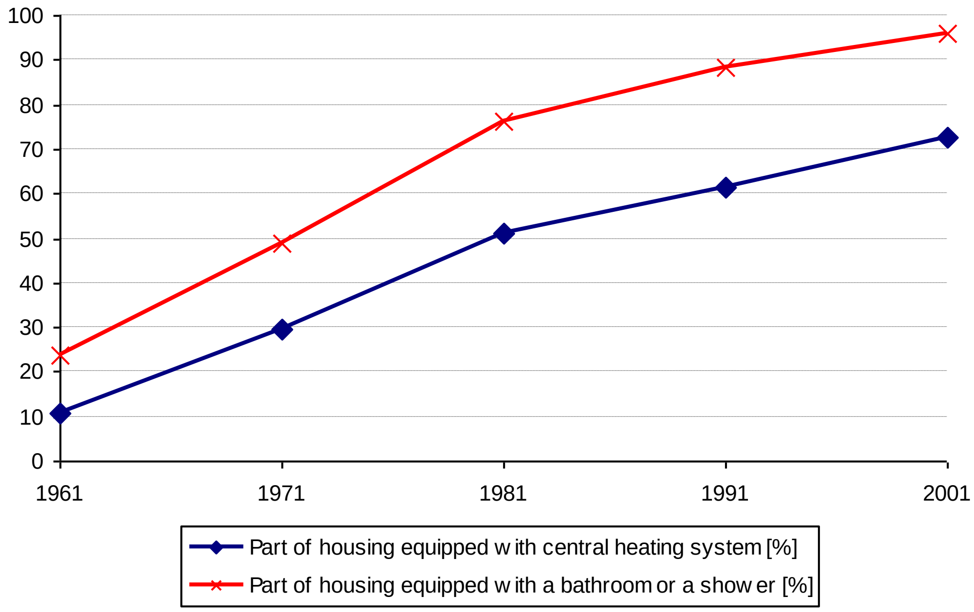



Figure 5.3 Co-evolution of central heating and bathroom penetration rates from 1961 to 2001.

In figure 5.3 the growing penetration rates of central heating systems and bathrooms from 1960 to 2001 seem correlated. However the replacement of the residential stock is slow and not yet complete. When one examines the energy intensity of heating a living space, one has to bear in mind two components: the volume of the living space that is heated and the heating system (including fuel type). In addition, the energy quality of the building is important, since compactness, airtightness and insulation of walls and windows have an influence on the amount of energy required to heat the building. Belgium's dwellings are relatively old, partly due to a low demolition rate (at 0,75 percent a year one the lowest in Europe) and to a slow growth in the building stock (only 1 percent, compared to a 1,5 percent average among Belgium's neighbours) [Marbaix & van Ypersele, 2009]. It is an element at the landscape level that innovations act very slowly. Insulating materials were used since the 1970s, although its use was not yet widespread. The same may be said about double glazing. These technological innovations were still at a starting level, in a niche among others related to the socio-technical landscape of residential buildings in Belgium. Thus, the infrastructural conditions of an efficient heating were not sufficiently present: energy efficiency was not the main motive for the introduction of new equipment. The evolution of household infrastructure can be explained by a steep rise in income, and the energy consumption increase results from new expectations of comfort.

Different fuels and different heating systems can be considered when looking at the case study of the heated living space. Nevertheless, the evolution of absolute energy consumption for home heating and its share in the total energy consumption of households, are not analysed by the study due to the lack of historical homogeneous data. However the relative importance of energy carriers show a clear transition in the housing heating system.

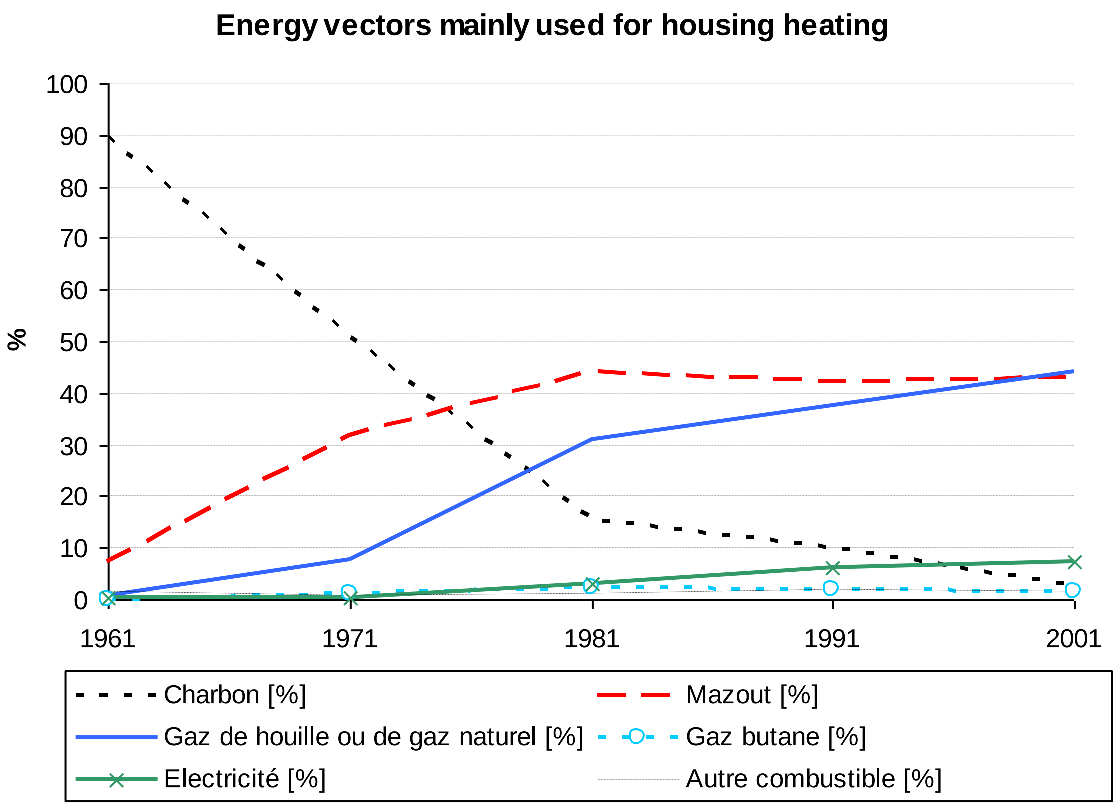



Figure 5.4. Evolution of energy carrier penetration rates.

Since 1961, coal has been progressively replaced with oil and gas, made possible by the development of distribution networks of oil and gas. In 1961, more than half of the Belgian population used a stove and coal for heating the house. This implies that only one room of the house was heated regularly. During the winters in that period, indoor temperatures ranged between 25 degrees C in the 'living' room and 15 degrees C in other rooms. Nowadays, the heating can be turned on in almost every room and homes are routinely heated to 21 or 22 degrees Celsius. This is what households come to expect and any other heating regime would be considered odd. The volume of the heated living space increases dramatically in the twentieth century. Although central heating is very common today, Belgian households also use electric heaters and open fires as secondary heating. Therefore, heating practices are also affected by the social norms of thermal comfort.

The cold part of the year no longer signifies having to put on various layers of clothes (that was, in most cases, at least two pairs of warm socks, sometimes even long underpants, and several layers of garment on the upper part of the body), even inside the house. Whereas central heating is now integrated into daily life and is almost everywhere, concentrating the warmth in one single room as well as using clothes and blankets to preserve body warmth in a cold housing is contrary to the current trend and its conceptions of normality. Thus, the practice of home heating has evolved and contemporary regimes of comfort are constituted through a range of regulations and technical procedures, knowledge of thermostat's functioning, understandings of ordinary indoor clothing, global building materials and air-conditioning industries, conventions of ventilation, sweat and smell, and actual built environments designed and run in a particular way.

A bringing-in of in-depth interviews with elderly households gives an overview of past daily routines regarding home heating. As competent "practitioners" of coal stoves in the 1960's, the accounts given by them are very instructive about the skills, tacit knowledge and habits enrolled and required for accomplishing that task. Thus, we can rediscover several 'rites' associated with everyday use of a coal stove and how they performed the former practice of heating.

*"In the past, I warmed myself by the fire after a great deal of effort. I had to carry the coal bucketful from the cellar. Every week I poured water on the pile of coal to avoid too much dust and dirt at home. Then, in the living room, I used wood and paper for the ignition. It didn't switch on automatically like our current thermostat! The fire was not going to stay alight if I didn't pay attention to the stove. Every time it was cold, I added coal. The stove was also useful for keeping hot coffee and for ordinary cooking. During that period, we had not yet a water heater; or white goods. To take a bath, we used a big metallic bowl once a week. With the same bowl, I washed the dishes as well as socks and underwear. The coal stove was multifunction at that time!"* (Paulette, 88 years old, a retired dressmaker, Grand Reng).

Figure 5.5 is an attempt to measure the evolution of household energy consumption for different uses (based on the expenditures). It shows that in a first step (1981), systems from coal stove to central heating, the thermal comfort improvement and its associated energy efficiency increase (in terms of heated volume per kWh) heating have been counterbalanced by more cubic metres of the heated living space. In a second step, we observe the effects of energy efficiency measures following the oil crises, although the decrease is also partly explained by the decline of the average number of people per household (from three individuals in 1961 to two individuals in 2001). The supposed increase in energy efficiency is then counterbalanced by different factors. The period of time a house or room is heated, the average outside temperature and the average comfort temperature all have an influence on the environmental impact of the heating of the living space. Beyond the eminently material characteristic of consumption, our multi-dimensional view of consumer behaviour offers a focus on the evolutions of norms, procedures and informal competences embedded in the practices in transition.

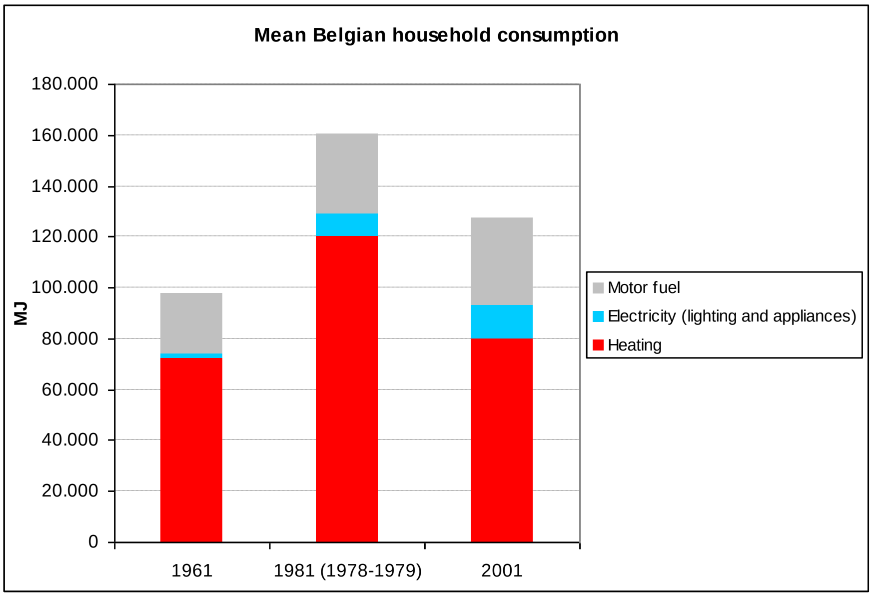



Figure 5.5. Mean Belgian household consumption

Energy efficiency saves not only money but also time and physical efforts. Thus, the introduction of a new appliance does not necessarily change the patterns of practices in the sense of more energy efficiency. Our modelling of rebound effects as practices in transition allows us to observe that the diffusion of central heating implies a radical shift in the daily organization of domestic tasks. In parallel, it is interesting to study how social norms co-evolve.

Beyond perceptions, feelings or sensations, an important shift of social images is remarkable in the rising of both power and efficiency provided by central heating, compared to coal stoves. Indeed, practices of heating are enrolled not only in the material environment of spacious housings equipped with a bathroom, a washing machine, or even a dishwasher. The practice of central heating is also favoured by a social norm of hygiene which separates the different purifications of ordinary dirt in several specialised, heated and sanitized rooms. Moreover, the ignition of glowing embers in a unique room was formerly an opportunity to bring together all the members of family around only one seat and to share together different practices in everyday life. Between promiscuity and conviviality, cooking, washing bodies and clothes, keeping an eye on the ignited, were all the women responsibilities [Stephany, 2006].

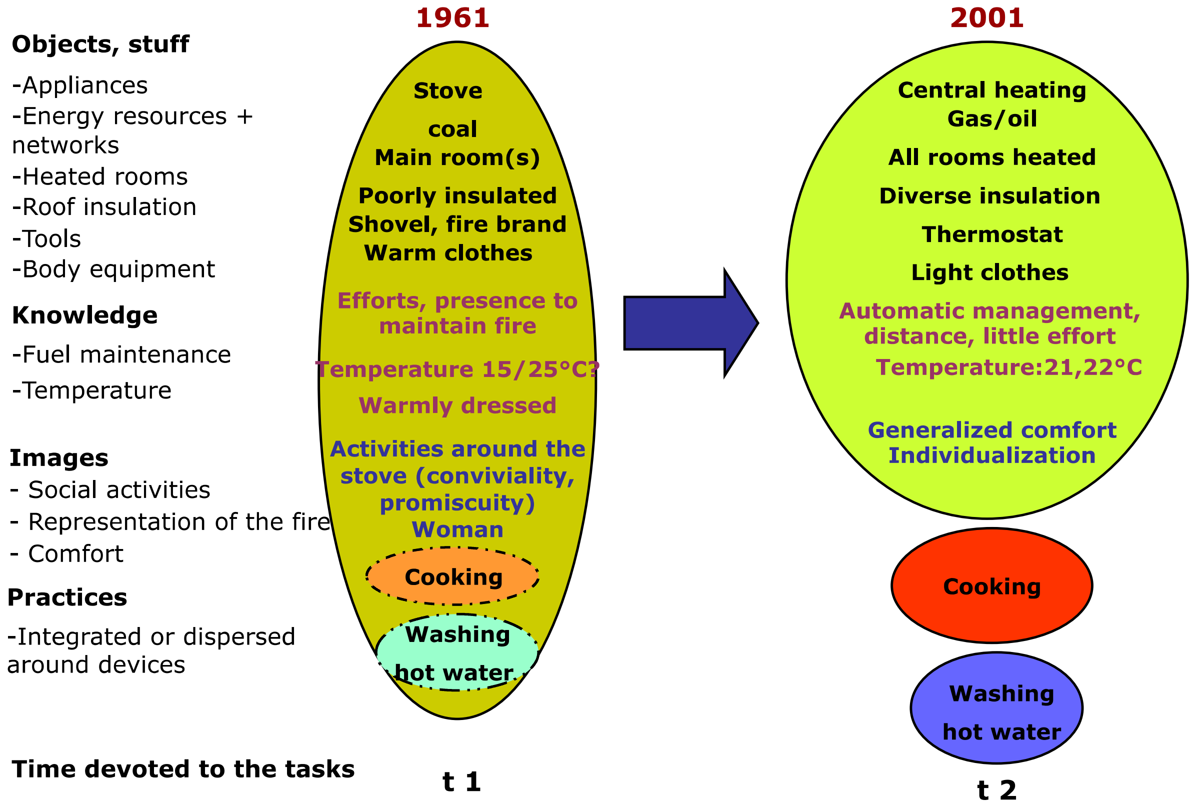



Figure 5.6. Summary scheme for the evolution of heating practice

The introduction of gas boiler, or electric radiator, deeply disrupts our connections with domestic space and time, leading to the dispersal of energy-related practices at home. Cooking, showering, washing, all these practices revolved around the same device, but are now compartmentalised in different household activities, segmented by everyday life and domestic spaces. Figure 5.6 summarises this shift in heating practice. Not only objects and appliances have changed but all the envelope of buildings and body protection should be considered when describing the evolution of practices. Practices while integrated around the coal stove are now dispersed around different devices and in diverse rooms. Skills and competences have evolved, and the meanings of heating and other practices have developed along. Time devoted to this practice has been reduced ($t2 < t1$) meanwhile comfort has increased. Even if energy efficiency of the different services delivered individually by the appliances have increased, the overall energy consumption may also have augmented.

It is important to stress that this drawing of practices as entities is not only visible to analysts. These entities make sense to the practitioners themselves. According to several witnesses, the generalization of central heating devices gives a better comfort level to inhabitants and it echoes to the modern expectations of convenience and cleanliness. The improvement of the standard of living is unmistakable. Heating became more economically and socially sustainable from the second half of the twentieth century. However, these developments provoked an unsustainable development of energy consumption and environmental emissions.

The socio-technical transition of heating practices was made possible by an increase in household income faster than the budget devoted to domestic energy. During the period 1961-1981, the trigger of the sociotechnical transition of heating practices in Belgium is the steep increase in household incomes. This allowed people to invest in new equipment as long as the energy carrier system changed accordingly. Larger heated volume and new appliances acquisition were made possible among others because the energy budget share remains at the same level and even declines for the majority of the population (figure 5.1). When energy prices soared in the 1970s, energy efficiency improvement enabled household to keep their energy budget at the same relative level. Without energy efficiency improvement household would have had probably to compromise between the acquisition of new equipment and other purchases. New appliances have resulted in a multiplication of practices once integrated around fewer devices. In turn, the use of these appliances has increased electricity consumption.

As regards the heating practice, the dynamic of rebound effects is more largely the consequence of a shift in the material, cognitive and symbolic system of practice which makes possible the current energy use not only spatially extended, but also concomitant with other energy-related practices. Even if new individual appliances are most efficient that the former ones, in reason of the multiplication of the appliances the total energy consumption has increased.

The multi-dimensional and movable perspectives of this conceptual framework reveal the synergy of factors implied in the increased energy consumption of Belgian households at home. The reasons are diverse. If heating of private living space is technically done in a more energy efficient way, the volume of the living space that is heated has been significantly enlarged. In parallel, the household average size fell from 3 to 2 persons per household. The energy efficiency of households' heating systems should increase faster than the growth of the households' number to avoid a global increase of energy demand in this sector. Another explanation of rebound effect is that the central heating saves not only money but also time and physical efforts which allow a multiplication of energy related practices as well as an expression of the modern norms associated to comfort, convenience and cleanliness.

Over the last decades, Belgian household have come from one heated room with a coal stove to a housing heated as a whole with a central system of heating. This routine consumption is profoundly shaped by both economic and cultural forces like the more 'individual' way of life, or the growing demand for sanitary security. The matter of rebound from the perspective of the people concerned does not make sense in terms of energy consumption. The approach to households' practices rests on their material conditions of action, symbolic images of wellbeing and tacit knowledge and practical consciousness of time and space required by the accomplishment of their daily tasks. This interpretation of rebounds brings insight into these factors of behavioural inertia.[14]

### 5.6. Understanding the components of rebounds in personal transport

This section is dedicated to personal mobility, another important driver of household energy consumption that needs to be examined in parallel to land use and the development of road infrastructures. We study the heterogeneous elements linked to the fulfilment of commuting between home and work and to what extent they imply forms of resistance to change. The case here differs from domestic consumption because we have passed from a more energy efficient system of mobility (train, bike and walk) to a least efficient one (automobile) although mobility efficiency (in terms of kilometres/hours) has increased. We show that the new distribution of practices is related to infrastructures and that cars play the role of an integrating devices of these practices.

The fuel efficiency of private cars has increased since the 1990s (Zachariadis 2006) and has led to a fuel cost reduction by kilometre. At the same time, more cars with higher mileage have resulted in greater fuel consumption. In Belgium, fuel consumption per passenger-kilometre in road transportation is one the highest in Europe, and the trend is not declining (Denis et al., 2009). The dynamics of rebounds in personal transport follow a different process from the movement of compartmentalisation analysed by the case study of energy efficiency improvements in domestic heating.

Commuting practices have been deeply transformed in Belgium since 1961. From walking, biking or travelling on the vicinal railway in 1960 to driving a car in 2010, fuel consumption has considerably increased. There was a structural shift in activities and an economic growth effect in the car industry. Indeed, this is mainly due to the diffusion of car transport. In the 1960s the car was not a representative means of commuting between home and work. Contrary to the case of white-collar households, the average practices of blue-collars did not refer to the use of this personal and motorized vehicle. Our interviews with some elderly people have confirmed and related this past trend.

*"No, I didn't drive my first car after the Second World War. In the sixties, I began to be given a lift by office clerks to commute between home and work… But, generally, I used the railway and the tramway because my company was located too far and it was long and difficult for biking or walking after work. Later, I bought my first car but it was*

[14] We have tried to quantify these rebounds by analysing different socio-economic profiles of Belgian households. However, due to gaps in historical data and changing methodologies in collecting data, that proved impossible.

*not before the seventies. The Belgian roads were no longer so bad in that time!"* (Arno, 76 years old, a retired blue-collar, Molenbeek)

In our approach based on qualitative and quantitative data, the macro-economic rebound effect in personal transport means a shift in the socio-technical landscape of mobility infrastructures in Belgium. New roads can improve the efficiency of mobility (in terms of kilometres per fuel litre) in reducing congestion, but they can soon increase traffic as well. A milestone in the history of the car occurred in the second half of the twentieth century. Figure 5.7 illustrates a fivefold increase of the number of motorized vehicles between 1960 and 2010.

Figure 5.7. Evolution of road transport consumption since 1960. Source: Wolrdbank, SPF Economie

In Belgium, the number of passenger-kilometre by car has been multiplied by six between 1950 and 1980, and then again by two between 1980 and 2010. Numerous scientists like Ascher (1995), Dupuy (1995), Kaufmann and his research team (2001), or Newman and Kenworthy (1985), have underlined that the evolution of built environment is highly correlated with the steep rise of private cars, inducing some slackening of strains in commuting. Inferring from such a statement, Wiel defined "urban transition" as a structural process which re-spreads cities in the long term under the impact of car mobility (1999: 56).

By consequence, from a short way to go to work in the sixties to longer distances through the current motorway and highway network, households' commuting has changed in a radical way. On Figure 5.8 we can notice that the increase in the number of private cars is highly correlated with an important extension of highways network from 1950 to 2007. The building of new roads first improves the mobility efficiency, but is soon overcome by the increase number of journeys.

The inter-urban transport has been reconfigured by the amplitude of Belgian highway system. In the material field of social practices, cars replaced the rail in households' experiences of commuting between home and work. After World War II, the number of private motorized cars exploded and this continuous growth was only slowed down a bit by the 1979 oil shock. The road came more and more in competition with the railway network as they were built alongside each other. From vicinal rails to a personal car, an elderly inhabitant interviewed in the rural area of Wallonia described the material transition of his mobility during that period.

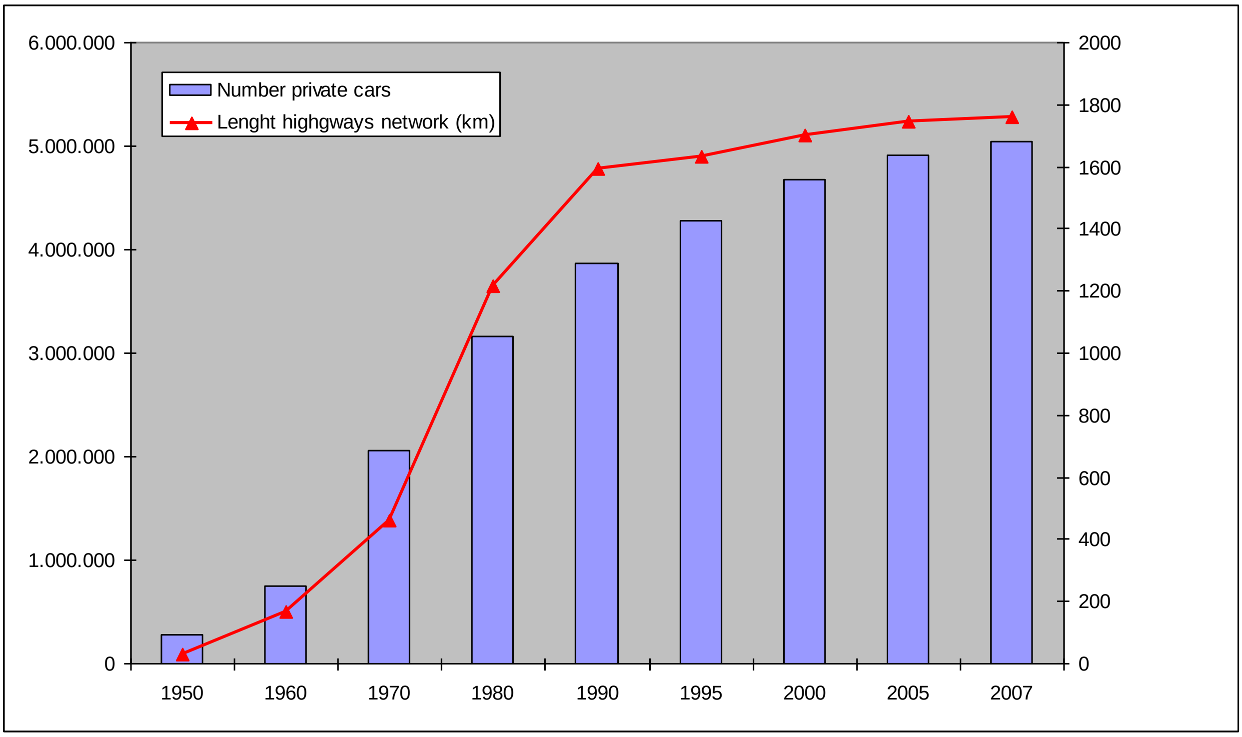



Figure 5.8. A co-evolution between the number of private cars and the extension of highways network in Belgium from 1950 to 2007

*"I was born in this village, and I can tell you that around 1960, the share of bicycles and motorcycles was largely higher than the share of private cars. Most inhabitants of Fontaine l'Evêque travelled on the vicinal railway network. I remember many train stops within the village and my father's commuting between home to the mine with all his colleagues by rail. I used the same means of transport to go to my work in the army. Today, the streets are saturated by the road traffic at the beginning and at the end of a day. It contrasts with the afternoons when the streets are almost inhabited! In the sixties, there were many shops and a cinema in the village. It was so lively! At present, when I want to go to the cinema, I have to drive my car until Charleroi."* (Hubert, 71 years old, a retired career soldier, Fontaine l'Evêque)

This quotation explains to what extent the local environment have varied over the last fifty years. Since 1960, the length of highways rapidly increased without completely supplanting the decline of SNCB railway network in Belgium. This profound transformation of mobility infrastructures is significant in the socio-technical landscape of practices. The figure 5.9 presents the quasi symmetric evolution of both infrastructures over the last past centuries.

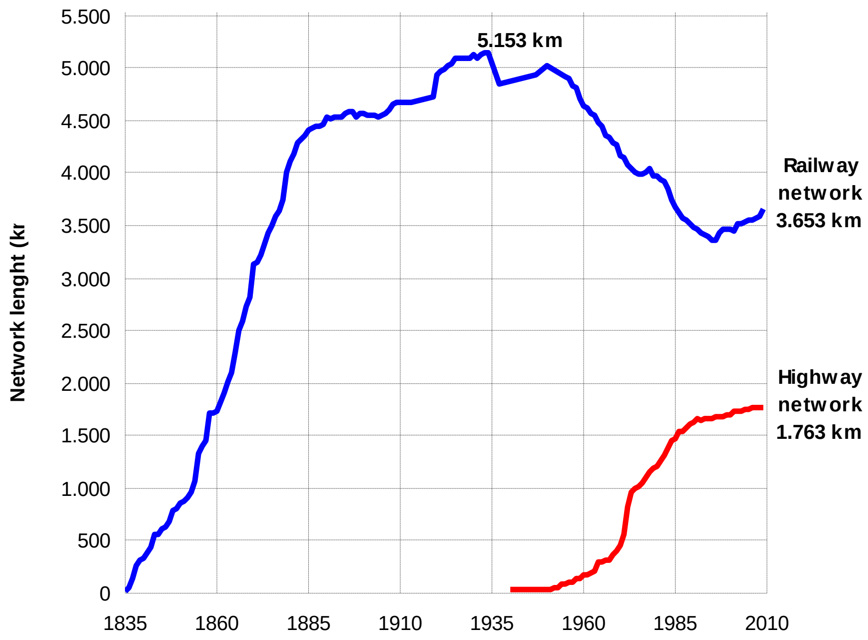



Figure 5.9. Evolutions of railway network and of highway network in Belgium over the last centuries

This can been seen as a technological transition from a rail landscape where the highway network was limited to a niche of innovation in 1960 to a car regime of everyday mobility whose socio-technical landscape is less dominated by the rail infrastructures. This decline constitutes a serious loss, as these broad networks could have constituted a part of the needed solution of oil-free mobility, especially for what concerns the vicinal railways network for local and short distances mobility needs. Indeed, global road fuel consumption sharply increased since 1960; it has been multiplied by a factor 5 in fifty years. This evolution is highly correlated with the constant increase of the number of private cars. The more or less polluting fuels supply motorized journeys since the cars quickly won the race and represent the major share of the road traffic. If the material infrastructures contribute to a favourable environment for the growing penetration of cars in the everyday practices of mobility, the cognitive, institutional and symbolic factors cannot be left behind.

During the twentieth century, car industry was seen as a major component of a national Belgian economy, with a privileged role for goods and persons transport. Funds were raised through toll taxes to allow the building of roads, first in the most prosperous provinces (West Vlaanderen, Oost Vlaanderen, Hainaut), and then to access to the most isolated regions (Limburg, Luxembourg). In other words, those of transition approach to technological innovation, the socio-technical niche of private cars had been protected and promoted by public authorities. A new regime of transport was actively created to the extent that the link between production and consumption of motorized vehicles was supported by the political planning of highway and motorway networks. Without this kind of material infrastructures, the performance of car motors would be weak with regard to the norms of rail regime in commuting between home and work.

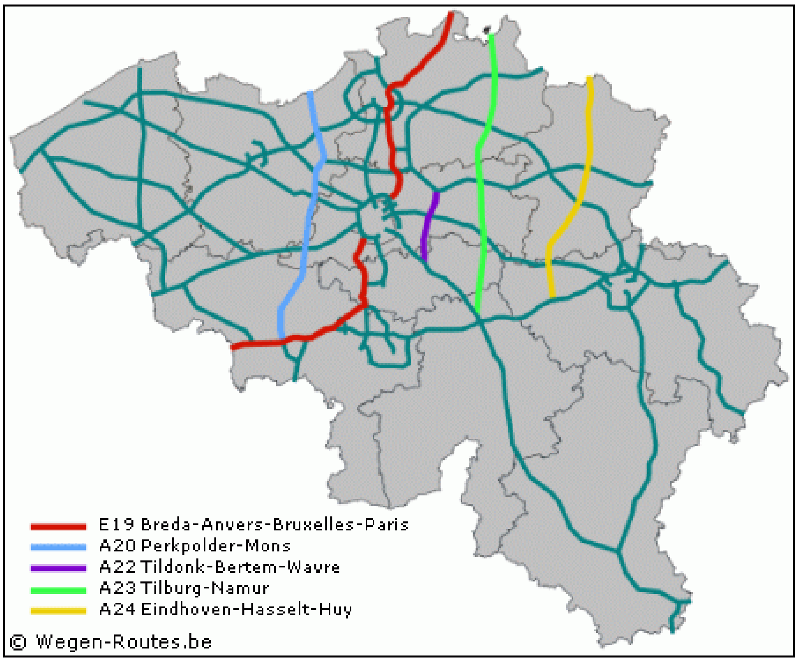



Figure 5.10. Belgian highway program in 1972 (2394 km planned)

However, in the institutional field, a first highway program was decided in 1937, including a route between Brussels and Oostende (construction started in 1940). Political discussions and annual budget constraints only allowed the construction of around 100 km of highways by 1955. From that year, growing financial resources were allocated to the highways programs, and the forecasts of the motorized vehicles park evolution were still on the increase. A new program arose with around 1500 km of highways and a modernization of all the other roads foreseen. The period 1965-1973 was the golden age of Belgian highways (PFS Mobility and Transport): the number of kilometres tripled from 304 to 960 (650 km were constructed), in 1972 all the main cities were interconnected and all the regions were crossed, and finally a total network of 2400 km was foreseen in the 1972 plan (more conform to a grid model, figure 5.10).

The highways network development was then slowed down, several were replaced by express roads, but despite all those elements, the growth of the private cars' park and the road traffic continued almost imperturbably. The 80s' were mainly marked by the State reform of 1980 (the land planning became a regional competence) and by a long period of drastic and general savings. In that period were achieved only the construction of highways in the more isolated regions of Belgium (Ardennes), of urban bypasses and boulevards, and to the modernization of "ordinary" roads. In 1989, the construction and management of roads and highways became the competence of the Regions, and the highways faded into the background. In 2008 the Belgian highways network "only" extends to 1763 km and is represented on figure 5.11.

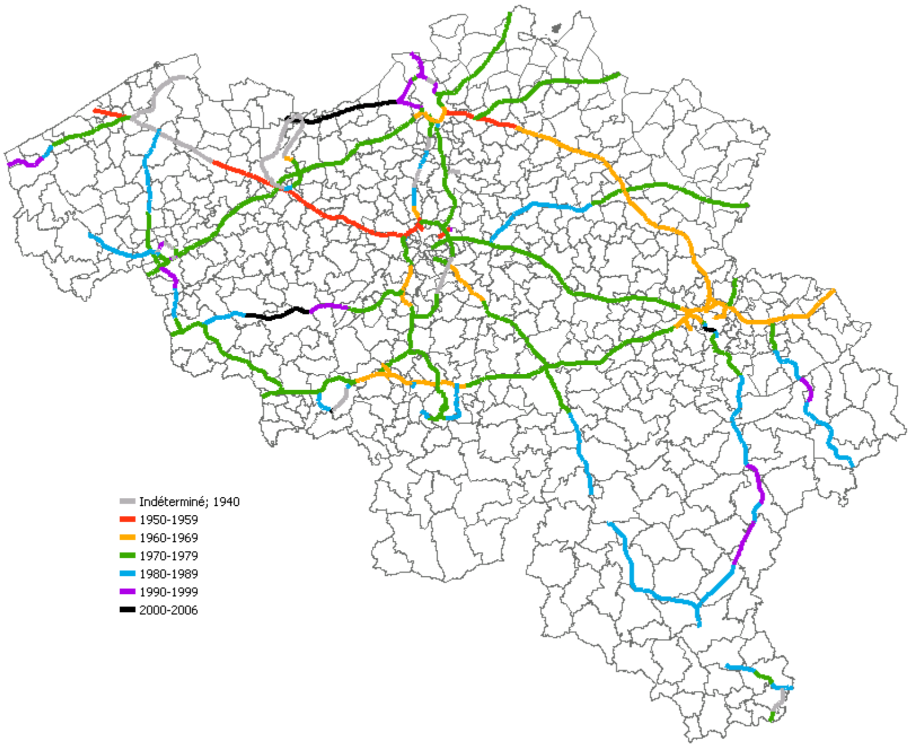



Figure 5.11. Belgian motorway network in 2008 (1763 km)

At the level of Belgian households, the normative dimension of automobile regime is also noticeable. Unlike largely tacit knowledge about pedestrian routes, or vicinal railway network, individuals have developed a new ability linked to the practical understanding of driving a car and to the training of Highway Code. Nowadays, all these competences are officially recognized by MOT test. What matters is the road safety. This social representation structures the norms of personal motorized mobility. Viewed from a socio-cultural angle, how does the unreasonable growth of this energy related practice make sense in everyday journeys between home and work?

To take into account the socio-cultural context of mobility practices in transition, one has to bear in mind that only young, rich people owned a car in the 1960s and they mostly used it for leisure. Nowadays, this has radically changed at the memory of a retired blue-collar who took part in our survey.

*"When I was young, I dreamt about driving my car! But I had to be patient in the 60s. I explained you that I bought my first vehicle in the 70s. So I envied for a long time the office clerks who gave me a lift. I was fascinated by racing drivers and I wanted to imitate the rich guys who could afford such leisure! Later I didn't become an car ace, but a crazy driver who had no idea of road hazard. In the 1980s, I used to driving my car for more and more long distance trips. With my family, we had good holidays on the French Riviera. As for the Belgian coast, we liked this destination on the occasion of*

*a sunny weekend. In the sixties I could not imagine that the next month I would spend time in Morocco to rest. It makes a change from the past when low cost tickets had no existence. Other changes are clear in everyday life. For instance, my daughter has numerous activities after work. She drives to the school of her children, she goes to the shopping centre and she brings me ready-cooked meals, and then she comes back to home. Formerly, work and transport took up all my time and my parents had to take care of my children."* (Arno, 76 years old, a retired blue-collar, Molenbeek)

This story offers insights into the shift of mobility culture which occurred over the last generation. Nowadays, the MOT test evokes a sort of passport for freedom and no longer a social distinction associated to a luxurious way of life. The feelings of speed can be exiting. Indeed, private cars represent a fast, flexible and relatively cheap form of transport and it is not regional limited as explained during our interview with a retired blue-collar. His experience of past mobility with a first private car suggests a dangerous artefact compared to the current standards of road safety. This growing preoccupation has led to heavier vehicles whose energy efficiency progresses are prone to be counterbalanced by this technical characteristic.

As the mechanism of rebound was analysed in the case of home heating, driving a car for commuting between home and work has contributed to transform the temporal and spatial dimensions of personal transport. However, in the last case, the result is not a new division of practices but a new chain that is to say: a successive coordination between commuting, shopping, children's journey until the school, and even other journeys like a call on grandfather for instance. Driving a car can save a considerable amount of time which constitutes a source of commodity in everyday life, not to mention the comfort of a car box to be filled in comparison with arms. Mobility efficiency has been improved, but to the detriment of the total private fuel consumption. Meanwhile fuel consumption by household per year has decreased from 41 GJ in 1981 to 34 GJ in 2001 (table 4a in Annex). This is explained by the decreasing size of households. At the same time fuel consumption has slightly decreased in the budget share of households (figure 2.4). But the overall mobility expenditures have significantly increased on the same period (figure 2.5). That means that households tend to use more the equipment in which they have increasingly invested whereas the apparent running cost remains approximately the same. Thus, the dissemination of cars in the practices of mobility has many direct rebound effects due to the integration of journeys formerly distributed among the activities of different households' members.

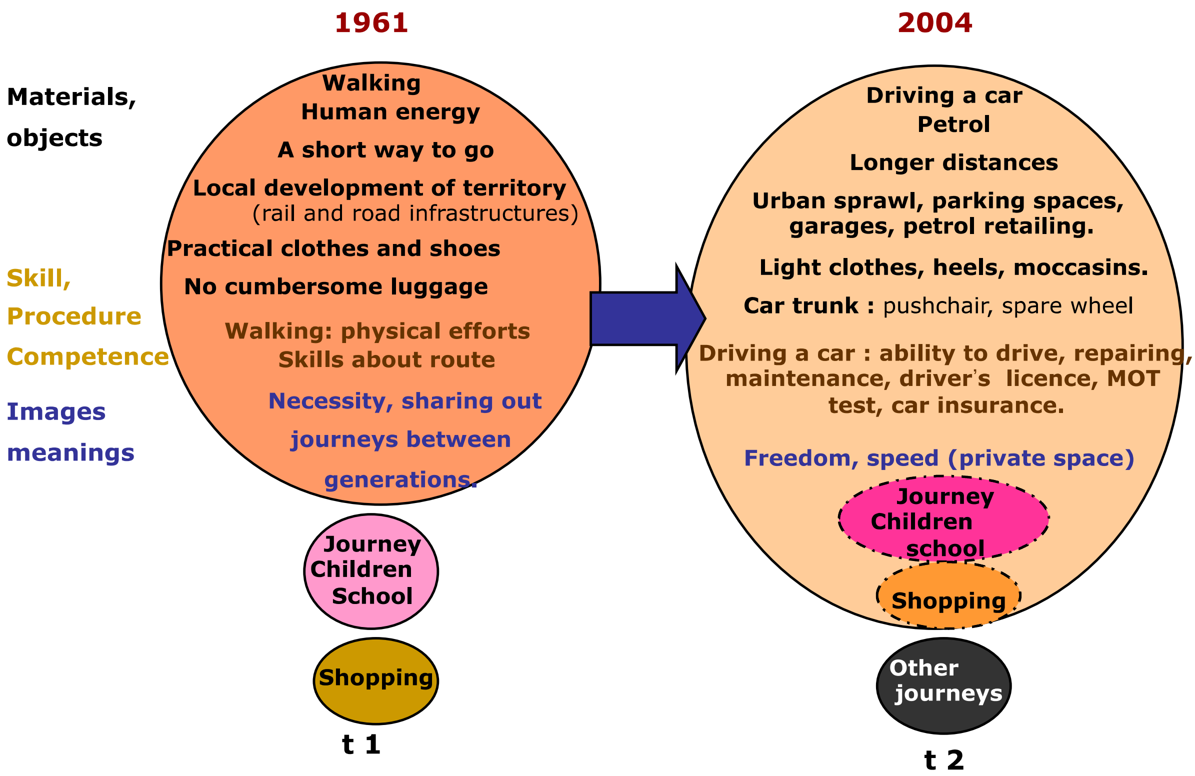



Figure 5.12. Summary scheme for the evolution of heating practice

Furthermore, the current images of motorized mobility go beyond the perceptions of fast and convenient commuting between home and work. The temporal and spatial dimensions of transport have been extended to international distances and spare time. More broadly, the fact refers to direct as well as indirect rebound effects in energy economics. Other lessons can be learnt and presented from our approach to these practices in transition through the multi-level interactions of both material and cultural components.

In order to make fair comparisons over all the years, given the available data, we had to make a trade-off between what can be measured and what makes sense at the household level. As a matter of fact, it is impossible to quantify every aspect of a system of practices. The quantitative indicators have been combined with the data of our qualitative interviews with Belgian households. Thus, this multi-dimensional analysis of the transition in home heating and personal transport aims at opening new perspectives on energy consumption and path dependency, closer to what is occurring in everyday life.

The integrated analysis of the dynamic interrelations between the diffusion of energy technologies and everyday uses through the theories of practices and technological transitions leads to formulate a new hypothesis about the underlying drivers of currently observed rebounds. The indirect rebound effects are encouraged by the energy efficient equipment which disconnect a series of existing practices. In the case of domestic practices, the multiplication of devices is made possible by the improvement of energy efficiency that allows households to keep their energy budget at a constant relative level. Delegation of tasks to efficient appliances gains time and comfort. In the case of automobile, the direct rebound effects are understood as the possibility to multiply mobility practices with the same device while letting its budget share at the same level.

# 6. POLICY IMPLICATIONS OF REBOUND EFFECTS

## 6.1. INTRODUCTION

The existence of rebound effects is used as an argument against policies based only on the improvement of energy (or any other resource) efficiency. Rebound effects can be defined as the unintended increase in consumption of a resource due to the increase of the efficiency of this resource. A recent report to the European Commission (DG environment) makes interesting policy recommendations to counter rebound effects [Maxwell et al. 2011]. They show the existence of rebound effects through an exhaustive state of the art, and deliver a catalogue of measures that could be taken to suppress the adverse consequences of resource efficiency improvements. These policy recommendations are generally presented as a 'mix', but what is a good mix is left open.

We review quickly the main advantages and limits of different policy instruments that counteract rebound effects. We do this by summarising the different dimensions of rebound effects we have encountered in this report (section 6.2). Information and economic instruments are necessary but not sufficient to act on all these dimensions. We describe then the scope of economic instruments (6.3). We conclude with a very tentative proposition of complementary currency for energy purchases by households (6.4). This energy currency would be adjustable to different parameters: income, past energy consumption, political aims.

## 6.2. THE DIFFERENT DIMENSIONS OF THE REBOUND EFFECTS

As saving energy means saving money, rebound effects can be described as well as an unexpected consumption of energy as an expense. Counteracting rebounds would mean to get a grip on this unexpected process. We have seen however that rebound effects are not easily quantified. "It is hard to measure and varies depending on the intervention (policy, technology, practice), the type of products/services/resources investigated (energy, food, transport, etc.), as well as other related factors e.g. income level, productivity, price elasticity, saturation, location and time (Sorrell, 2007; UKERC, 2007)." The difficulty of quantifying indirect rebound effects is due to the impossibility to make a clear link between a gain in a service A and the expense in the service B.

Economics is not only concerned with prices but also with *values*. Rebounds have an obvious economic dimension for it is the transaction between income and energy use. How would it be possible to give different values to energies? Today, from the point of view of the service provided, any kWh or MJ (for a given energy carrier) is similar to any other kWh or MJ (of the same energy carrier). With an electrical kWh I can do very different things, some very useful and basic, others more superfluous or even extravagant. Energy is not valued as regards the provided service. Moreover, we have to remember that energy is cheap when the provided services are considered. For instance, a human body consumes through alimentation around 400 to 3000 MJ per year, depending on the sort of performed activity. By contrast, an average Belgian consumes around 100.000 MJ per year for heating, electricity and motor fuel. While the former energy costs 15% of her budget, the latter gets a half of this share. Obviously one does not eat petrol or gas and food is a qualitatively different form of energy, but this example shows how much energy we use through engines and appliances and at which level we pay it.

People interest towards energy consumption is diverse and relatively low. People conserve energy for many different reasons: economic, environmental, management of one's household, autonomy, search for reward or avoid risk, etc. [Wallenborn et al. 2006]. The criteria to provide new values to energy belong to the sustainable development agenda. Policy measures should be socially fair and environmentally sound. From a sustainable point of view, economy is a mean to increase wellbeing while reducing environmental impacts. The consistent objective is an overall reduction of consumption that can only be achieved through changing the activities and practices that people prefer. Sustainable consumption can be reached through changing our consumption patterns by a combination of the three strategies of consuming more efficiently, consuming differently and consuming less [Boulanger 2010].

Improvements in energy efficiency have not compensated the increase of number and use (for almost every product category). And new energy-using products have appeared. Energy uses relates directly to ways of life, to everyday practices, to consumption patterns. As Herring [2011] states, "whilst there has been some energy savings on the micro level (rebound is less than 100 %), on the macro level energy use has continued to increase despite large increases in energy efficiency. This is because we choose to convert the financial savings from energy efficiency into greater consumption." Herring interprets rebound effect through the lenses of comfort, cleanliness and convenience [Shove 2003]. Therefore rebound effects have to be tackled through policies that target everyday practices and sustainable lifestyles.

Rebounds in general result from increased activity (consumption / production) levels that improve e.g. comfort (heating more rooms), are the result of time gains (private car), or that provide more pleasure (long distance holidays abroad). 15% of (thermal) comfort taking is considered as standard in the UK and is incorporated in the models that forecast energy conservation following the implementation of new heating systems. Comfort and social norms can be modified, but it is not clear whether they can be steered in a desirable direction. Sound recommendations are to prevent people of performing bad habits, but what are bad habits? The distinction between basic services and luxury is not easy always to do in practice.

In modern life, rebounds are often the effect of time gains. Practices have multiplied and diversified. Several practices can be performed at the same time thanks to technology. I can cook, listen to the radio while my clothes are being washed by a machine. Multi-tasking allows extending one day up to 43 hours [Shove 2009]. This strategy of multitasking is linked to the easy access to appliances. Policy recommendations tend then to reduce the access to individual objects (car sharing, public transport) and to share commodities. Another way is to redistribute wealth and working hours. Reducing working hours enables to take back energy use from mobility. What could work for rebound is probably the same that makes society resilient for carbon taxes or energy price increase. Therefore mitigation and rebound policies are aligned. "On the sustainable consumption and growth agenda – we need to ask what is the goal of our society. At present the priority is for maximum growth in consumption and production. This is a conflict. Less working days and less productivity are important solutions as are lower environmental impact activities e.g. spending time with family and potentially cultural (fine arts) vs. productive (commerce and industry) related." [Maxwell et al. 2011]

### 6.3. Power and limits of economic instruments

If we consider that rebound effects are the result of changes in relative implicit prices of energy services, it is then sensible to try to apply new economic instruments. We explore in this section the different economic instruments that have been proposed.

#### 6.3.1. Taxes

The straightforward workable policy option to counter rebound effects is to increase energy prices (e.g. through carbon pricing policies and / or energy taxes), to keep the implicit price of the energy service whose energy efficiency has improved approximately constant. At the macro-level, this would "*likely require substantial and rising energy prices over time and sustained over the multi-decadal periods relevant to climate policy, such that rising energy prices keep pace with the improvements in energy productivity*" [Jenkins et al., 2011:53] Ecological economists like Wackernagel and Rees [1997] suggest that in a globally inter-linked economy we can afford cost-saving energy efficiency "*only if efficiency gains are taxed away or otherwise removed from further economic circulation*" [Id., ibid.:20].

The idea to increase progressively tax has already been applied successfully to fuel. Fuel tax escalators have proven to be effective in influencing consumer behaviour: « ... two historical examples of fuel tax escalators can be seen as proof of effectiveness. The British escalator on petrol taxes was introduced in 1993, and the German ecotax reform came six years later. In both cases the fiscal duty increased year by year by very small amounts, which by itself would have hardly any steering effect. But the certainty of future steps to come had a major effect on customer behaviour. » [UNEP, 2011: 70].

The product of the taxes has to be carefully analysed. If the yield of the energy taxes is reintroduced in the economy as public consumption or as wages or social security allowances this would entail a growth of energy consumption in particular knowing that there would be a transfer from the better-off households to the least well-off. In order to avoid rebound effects through redistribution policies, the tax product should be directed only towards investments that help reduce energy consumption.

### 6.3.2. UNIFORM TAXES?

Shift from labour tax to energy (and 'green') taxation has been argued for several decades now. However, uniform economic instruments (either a harmonized global tax rate or a global carbon emission permission market) are no suitable instruments for tackling climate change, because *"reality is too diverse and dogged in diversity..."* [Verbruggen, 2010:10]. Although overlooked in literature, a similar remark applies to the micro-level. Uniformly raising energy prices would not only affect the demand for energy services whose energy efficiency has improved, but also the demand for all other energy services, possibly leading to an overall decrease of the household's "utility". This particularly applies to appliances, where electricity is effectively the only relevant energy carrier. One way out could be the use of "intelligent appliances" in the context of smart micro-grids, where energy pricing would not only depend on energy supply conditions but also on the energy efficiency (and perhaps other attributes) of the appliance itself. However, it is not obvious what (other) incentives households would retain to choose energy efficient technologies, if the share of energy expenses in the household budget remains constant. Hence, this suggestion could in principle work at the level of individual appliances, but not at the level of the individual consumer.

### 6.3.3. ENERGY POVERTY

Another issue to be addressed is the heterogeneity of households, and in particular the problem of "energy poverty". Boardman [2004] defines energy poverty or "fuel poverty" as occurring when a household has to spend more than 10% of its income to provide an adequate standard of warmth and other energy services (hot water, lighting, etc.) The consequences of energy pricing policies will differ considerably across households with different income and other characteristics. Studies indicate a tangible relationship between high rates of energy poverty, low level of domestic thermal efficiency and reduced health and comfort status [Clinch & Healy, 2003:565]. Low-income households are to some extent prepared to *"...accept lower temperatures, intermittent and/or partial heating regimes, lower hot water consumption and lower use of energy for other uses (lighting, cooking and appliances), in order to have lower energy bills"* [Clinch & Healy, 2003:565] A number of ex-post studies evaluating thermal efficiency improvement programmes estimate that for lower income households (especially those living in energy inefficient dwellings) 25% to 30% of potential programme benefits are taken as increases in thermal comfort, and 'only' 75% to 70% as energy cost savings. Higher income households, on average, would appear to translate the benefits of improving the thermal efficiency of their dwellings into a relatively larger reduction of their energy expenditures [Milne & Boardman, 2000; Sheldrick, 1998; Skumatz, 1996; Energy Saving Trust, 1994]. This might suggest that energy pricing policies should be different with and adapted to the income status of households [Milne & Boardman, 2000:422]. From an equity point of view, the impact of increased energy prices will depend on how revenues are returned. For example, revenues "could be partly used to bring energy efficiency improving technologies to the market" [Koerth-Baker et al. 2011: 11]

#### 6.3.4. BEHAVIOUR CHANGE LIMITS

In the search for more sustainable consumption patterns, "behaviour change" has become a motto. Up to now however behaviours have rather changed towards more resource demanding practices. If "behavioural failures" lead to sizeable rebound effects, policy instruments addressing market failures (e.g. price or income taxes) may not be well suited to mitigate the rebound effects. Mainstream economics does not consider the option of changing the preference map (indifference curves) and / or the "choice mechanisms" (utility maximization) of the household. Shifts in preferences would change the rebound effect. Reverting consumer behaviour from consumerism to a more sustainable lifestyle may be an effective option to mitigate the rebound effect. This might entail consuming differently, i.e. shifting consumption towards "greener" goods or services with a lower environmental impact or increasing expenditures on services rather than goods, or simply consuming less or "downshifting". Energy conservation policies could try to direct re-spending decisions to (relatively) energy-extensive goods and services [van den Bergh, 2011, p. 55]. Wilhite and Norgard [2003] advocate policies aimed at reducing absolute energy consumption, e.g. by discouraging the demand for more and even bigger homes, appliances, cars, etc. Ouyang et al. [2010:4274] suggest that if (Chinese) households set their requirements for the "high quality life" a little lower, the rebound effect could be mitigated to some extent. The widespread adoption of a "sufficiency"[15] ethic faces numerous psychological and socio-cultural obstacles and is unlikely to develop through voluntary action alone [Sorrell, 2010:1793-1794].

[15] Sufficiency is a social organising principle that builds upon restraint and modification to provide rules for guiding collective behaviour [Princen, 2003].

### 6.3.5. CAP OR RATIONING?

The difference between efficiency and sufficiency strategies lies notably in their relative or absolute approach of energy consumption. Energy efficiency considers the relative level of consumption: it is measured as the relative gain obtained through a technological improvement. Energy sufficiency is translated in absolute indicators: a service should not use more than a given quantity. For instance, the energy consumption of a TV can be measured as the energy/square inch or by its total consumption. In the former case, the energy consumption can increase as the screen sizes get bigger. A first step is therefore to use absolute indicators in regulation in general and at levels where the responsibility is. Energy labelling of appliances has begun to adopt this approach, although the efficiency indicator is still indicated in a bigger format than the absolute energy consumption indicator.

A straightforward measure of sufficiency is rationing energy, namely to allocate a maximum energy quantity by person by year. This approach is however flawed with many questions: how to measure it? Should every person be equal in energy use? How to distribute the rations between household members? Personal carbon allowances and other quotas are instruments that have been extensively studied [Parag and Strickland 2009]. Beyond the restraining aspect of these instruments, the main argument against them is their high transaction costs. Carbon trading is also sometimes promoted at the individual level. This approach has no advantage in terms of equity [Starkey 2012]. Economists therefore tend to prefer pricing interventions to quantity restrictions, because price- or tax-based interventions selectively induce those who can adapt most readily and at lowest cost to do so, and because pricing policies generate revenues that can be used to mitigate adverse wealth effects for those who suffer under the higher price of a desired activity. Regulation of activities can neither selectively identify the efficient adjusters, nor generate any revenue to soften the wealth impact of the restrictions [Pozdena, 2009: 10].

### 6.3.6. PROGRESSIVE TARRIFS

Due to fixed costs, energy delivered in homes has today a degressive price: the more a household consume the cheaper the additional unit of energy is. In other words, households with a high energy consumption are advantaged. To the extent that access to energy is a right, electricity consumption corresponding to the basic needs should be delivered at a low price possibly financed by those that consume well beyond the average. Beyond a given threshold (or multiple thresholds) the kWh price should steeply increase. This kind of progressive tariff exists already for electricity and water in some European regions.

### 6.4. WHERE HOUSEHOLDS AND ENERGY USE MEETS: ENERGY COMPLEMENTARY CURRENCY.

In this last section we present a tentative proposition of a new energy currency. This proposition is not a policy recommendation *per se* but as thought experiment that deserves further investigation. It can be seen as an elaborated taxation, more comprehensive, that tries to avoid pitfalls of cap and trade instruments. It could for example be considered as a possible 'transition experiment' that could be tried at a local level.

A conclusion of the findings of behavioural economics and social psychology is that any public policy aiming at decreasing lastingly energy consumption and GHG emissions by households should benefit from:

- Taking stock of the recent results of behavioural economics and social psychology on mental accounting, loss aversion and the importance of social norms;
- Combining different measures and policy instruments in order to address not only the rational, controlled element of the self but also the automatic, uncontrolled one; in others words: to speak not only to System 1 but also to System 2;
- Taking a "choice architecture" perspective: acting on the environment of choices in such a way as to facilitate the decisions that are the most compatible with sustainable development;
- Addressing the "energy poverty" problem. As explained here above, 'fuel poors' have to spend 10% or more of their income on energy in order to reach acceptable levels of warmth and comfort. Some rebound effect is welcome if it allows poor people to live in more healthy and comfortable conditions.

The scenario sketched here below is an attempt to meet these requirements. It is a policy mix composed of regulation, incentives and information, based on the insights from social psychology and behavioural economics, especially mental accounting and the role of social (descriptive and injunctive) norms. It is provided not as a "take it or leave it" proposal but as a basis of discussion, a kind of mental experience intended to help taking a fresh perspective on policies aiming at influencing consumers behaviour and identifying and counteracting microeconomic rebound effects.

As van den Bergh (2011:46) argues: "When households or firms undertake energy conservation activities these may cause additional energy use within their own sub-system, even without them being aware of it. One policy response could therefore be to make agents conscious or aware of rebound effects occurring within their own realm". Therefore, the idea is to induce consumers to build a single "mental account" for all energy-related expenses: heating and cooling, household appliances, car fuelling, airplane travels, etc., through the creation of a special energy currency in which all expenses should be expressed. The hypothesis is that the creation of a special currency for all energy-intensive purchases will induce people to book and post all these expenses in the same mental account, helping them becoming aware of the importance of energy in their overall budget.

In practice:

1) The government creates a new complementary currency exclusively devoted to energy payments. It settles an “energy bank” which has the monopoly of emitting the energy currency.

2) Every household receives an energy account number in that bank and as many “energy payment cards” as adults members in the households. All the household’s payments for energy will pass through this account.

3) In order to pay their energy expenses, households must trade Euros against the energy currency. They do so at an exchange rate varying according to their wealth, composition and past consumption.

4) The exchange rate between € and the energy currency is calculated according to the following formula :

1 ENERGY CURRENCY UNIT = 1 EURO * (1 + *IncomeCoeff* + *ConsCoeff* + *PolCoeff*), where

- *IncomeCoeff* is a coefficient depending on households’ income (the higher the income the higher the coefficient);
- *ConsCoeff* is a coefficient depending on the amount already changed during the last year (the more has been already changed, the higher the rate for future changes);
- *PolCoeff* is a policy coefficient depending, for instance, on macro-economic improvements in eco-efficiency and decoupling and/or on a program of steady increase in energy tax. In the latter case, *Polcoeff* should be from the start announced as intended to increase slowly but regularly, as in the case of fuel tax escalators (see 6.3.1).

5) All expenses are paid on the spot through the payment card. If the account is insufficiently funded, the bank immediately informs the buyer of the need to refund his/her account and of the new exchange rate he/she is facing. The payment is delayed until the customer has refunded his/her account.

6) The government keeps the benefits accruing from the differences in exchanges rates in order to finance the system and for other uses if any surplus exists. However, it will be considered non fungible, staying (mentally) in energy currency so that it cannot be turned back to the normal economy but devoted exclusively either to development aid programs or to energy and climate related investments or programmes.

7) Every month, each household receives a summary of its energy account: expenses and possible losses in exchange rates (triggering the aversion for losses) together with different information, for example the current level of the descriptive norm (for those who are above it) and a recall of the injunctive norm.

8) The system is transparent and neutral for energy sellers. Whatever the price paid by the consumer for the energy currency, sellers will trade with the energy currency bank at a 1:1 ratio.

This proposition of a new currency may look like a ‘thought experiment’, but it expands on the idea of qualitative values and benefits from research in behavioural economics. The proposal makes use of the complementary currency as a means to activate a property of mental accounting highlighted (see 4.2). It obliges people to move resources from one mental account (in €) into another (the one in energy currency), an operation we have seen that they were generally reluctant to make. It is expected that, as Heath and Soll have shown, this will lead people to under-consume energy-related products and services. The under-consumption effect can probably be enhanced by limiting the maximum amount that can be exchanged in a single energy currency acquisition. This could go hand in hand with restrictions on the maximum quantity of energy the consumers could buy in a single purchase.

Such a proposal is in line with a recent trend of using complementary currencies systems as policy instruments for environmental purposes [Seyfang 2009, Joachain and Klopfert 2011]. Yet, hitherto, we know only of three actual large scale examples of this trend: the *NU-Spaarpass* system in Rotterdam between 2002 and 2003, the still ongoing *E-portemonee* operation in Belgian Limburg province, and the Belgian “ecochèque” system. However, our proposal is different from these experiments in two crucial respects.

1) First of all, it would be compulsory, not voluntary. This eliminates the issue of motivating people to participate. Joachain and Klopfert calls “regulatory model” complementary currencies (CC) systems in which participation is mandatory and they observe that (Joachain and Klopfert 2001: 9-10): “ *Since no CC system based on a regulatory model has been deployed yet, it is only possible to conjecture what would be a key point would such a system ever exists in the future. In this respect, the way to*

*calculate how many CC units are due by the citizen (or the quotas) allotted to the citizens) seems absolutely crucial. Since a regulatory model would relate the use of CC to a tax system, criteria to do the actual calculation should be based on objective data and perceived as fair and socially acceptable by the citizen."* We argue that the exchange rate system we propose meets the latter requirements: objectivity and fairness.

2) Second, while *Nu-Spaarpas* and *E-portemonnee* can be characterized as "rewarding systems" insofar as they consists of rewarding the searched-for behaviours, our proposal can be characterized as a "penalty system" insofar as it boils down to penalize by increasing transactions costs the consumption of energy. Reward systems rely on the utility of gains, penalty systems on the disutility of losses. If behavioural economics is right, penalty systems should be more effective because "losses loom larger than gains". It is also hypothesized that rewarding systems are more likely to induce a rebound effect than our proposed scheme because the loyalty points earned by adopting environmentally friendly behaviours[16] are likely to be interpret as bonus and spent therefore in a less responsible way.

3) It is not blind to differences in incomes, family composition and needs in general. Contrarily to the other systems, our scheme marries ecological efficiency and social justice through the income coefficient of the exchange rate, which allows combining fighting energy poverty and excessive consumption by better-off households. .

We see also in our proposal additional benefits with respect to past and current experiments and also to other scenarios such as "Personal Trading Quota" schemes, notably:

- The energy-related expenditures of every household are known and they can be linked to information on their income and wealth, location, education level, household composition, etc.
- The government can at any moment adapt the exchanges rates according for instance to the evolution in energy efficiency, actual consumption, new commitments, market prices, etc.
- Our system leaves more space for individual freedom and diversity in preferences and choices than a "Personal Trading Quota" scheme and it doesn't provide for the possibility to trade pollution rights, a property of trading quota systems that meets deep opposition from ONGs and many people as well. However, it can lead in a smooth, progressive way to a quota system if necessary.

[16] For instance, in *E-portemonnee* using 100% green electricity is worth 300 points per year, etc.

- It opens the door to possible real scale social experiments through manipulation of the changes rates, the content of the monthly account, mixing with quotas or whatever.
- It is relatively easy and cheap to settle and manage. It should even be possible to use free open source software (such as *Cyclo*[17], for instance) for operating it.

We are aware of the very sketchy and incomplete character of the proposal but as already stressed, it is only through vivid discussions between policy makers, stakeholders and scientists that such ideas can develop into workable, plausible plans and programmes.

The general idea is to consider a currency as a technology, or better, as a technological cluster. As Bob Swann (1981, quoted by Longhurst and Seyfang, 2011:3) remarked: '*from a technological point of view, money is a tool. Like any other tool it can be shaped to perform in different ways. Just a both a scythe and a combine are tools for cutting wheat, so money may be designed to perform in different ways with different objectives.*'

According to Longhurst and Seyfang (2011), complementary currencies can contribute to sustainability in the following different ways: stimulating economic localization, building the "informal" economy, reducing ecological footprints (as is the case for loyalty cards systems like Nu-Spaarpas or E-Portemonee), credit for small/green business, providing investment mechanisms for green technologies, and embedding economic activity with ecological limits. In general, the complementary currencies referred to are grassroots initiatives. Our proposal departs from most complementary currencies initiatives in that it would not be a grassroots initiative but a State-based one. However, we assume it could share some of the functionalities of those alternative moneys: reducing ecological footprints thanks to the disincentive role of the progressive exchange rate and contributing to the development of green technologies thanks to the non-fungible character of the surplus collected by the energy bank. However, its major originality with respect to comparable propositions, lies in its psychological and behavioural roots, and particularly its justification by the psychological processes of mental accounting, framing and loss aversion.

### 6.5. Discussion

This sketchy proposition of an energy currency has the advantages to tackle directly the issue of micro rebound effects while being theoretically socially equitable. However political discussions about energy consumption are displaced and concentrated in the determination of the coefficients.

[17] See : http://project.cyclos.org/index.php?option=com_frontpage&Itemid=1

The main practical disadvantage of the energy currency is its transaction costs (additional administrative overhead costs). We can however argue that the price to be paid for the implementation of this system is a way to internalise the specific values of energies.

The income acquired by the bank has to be used carefully in order to prevent rebound effects. The investments should be directed to green technologies but also to programmes of building insulation and other infrastructures that will help to reduce energy consumption. A special attention should be given to infrastructures and the way housing and mobility are linked. Special programmes to support measures addressing fuel poverty could be funded through the energy bank.

Many practical issues have also to be fixed:

- Is the refund of energy accounts automatic or not?
- What is the energy unit? Primary energy? How to include wood?
- What is included: only direct energy consumption? Flights? How to make the difference between private and professional consumptions?
- How to protect privacy? Energy providers should not know the different coefficients of its customers. How to protect the access to the bank data which has big economic value?

In conclusion the energy currency proposition should be further investigated. Comparisons to other complementary currency systems should be performed. In order the feasibility of the energy currency, different scenarios should be developed.

# 7. DISSEMINATION AND VALORISATION

## 7.1. COMMUNICATION AT CONFERENCES

Némoz S., "To break unexpected phenomena of energy efficiency markets, an in-depth approach to rebound effects in dynamics of domestic practices", $6^{th}$ *international conference on Energy Efficiency in Domestic Appliances and Lighting,* EEDAL'11, Copenhague, 24-26 mai 2011.

Némoz S., Wallenborn G., "Interpretations of the rebound effect at the household level", *Addressing the rebound effect in policy. Stakeholder meeting*, DG Environnement, Commission Européenne, Bruxelles, 28 février 2011.

Némoz S., « To go beyond the assumptions of energy efficiency: a sociological understanding of rebound effects », MILEN International Conference *Visions and strategies to address sustainable energy and climate change*, Université d'Oslo, 25-26 novembre, 2010.

Némoz S., « The meaning of rebound effects in the energy-related practices of households », *$7^{th}$ Biennal International Workshop "Advances in Energy Studies 2010,* Barcelone, 19, 20, 21 octobre 2010.

Némoz S., Wallenborn G., « Comment infléchir la demande d'énergie ? Une approche socio-anthropologique des pratiques d'usage », Colloque *Pour une socio-anthropologie de l'environnement*, CETCOPRA, Université Paris I – Panthéon Sorbonne, Paris, 23 et 24 septembre 2010.

## 7.2. SEMINARS

Némoz S., « Policies to overcome rebound effect », *International Workshop "Energy Efficiency Policies and the Rebound Effect"*, University of Stuttgart, Carnegie Mellon University's Climate and Energy Decision Making (CEDM) center, Tsinghua University and the International Risk Governance Council (IRGC), Stuttgart, 13 et 14 octobre 2011.

Némoz S., "Potentials & limits of rebound effects in design", *Designing household energy practices. A workshop bringing together designers, companies and academics*, Centre d'Etudes du Développement Durable (IGEAT – Université Libre de Bruxelles), Bruxelles, 27 avril 2010.

Némoz S., « Energy efficiency policies and adaptive practices: how can the rebound effect be curved in favour of social justice ? », *Workshop on Low carbon cities, resilience and social justice*, Interdisciplinary Cluster on Energy Systems, Equity and Vulnerability; and the University of Birmingham's College of Engineering and Physical Sciences, Birmingham, le 17 octobre 2011.

## 8. PUBLICATIONS

Némoz S., Wallenborn G. « Comment comprendre les effets rebonds dans la consommation domestique d'énergie. Pour une socio-anthropologie des pratiques en transition », in *Pour une socio-anthropologie de l'environnement*, L'Harmattan, coll. « Socio-anthropologiques », to be published in 2012.

Némoz S. (2011) "To break unexpected phenomena of energy efficiency markets, an in-depth approach to rebound effects in dynamics of domestic practices", 6$^{th}$ *international conference on Energy Efficiency in Domestic Appliances and Lighting,* EEDAL'11, accessible sur le site internet European Commission Joint Research Centre – Institute for Energy.

Némoz S. (2011) "To go beyond the assumptions of energy efficiency: a sociological understanding of rebound effects" in Actes du colloque *MILEN International Conference Visions and strategies to address sustainable energy and climate change*, Université d'Oslo, accessible sur le site internet du Conseil Européen pour Economie Efficiente en Energie.

Némoz S. (2010) "The meaning of rebound effects in the energy-related practices of households" in Actes du colloque *7$^{th}$ Biennal International Workshop "Advances in Energy Studies 2010"*, Universitat Autònoma de Barcelona, Barcelone.

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