Energy Policy 37 (2009) 4787–4796

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Energy saving and energy efficiency concepts for policy making

V. Oikonomou[a,*], F. Becchis[b], L. Steg[c], D. Russolillo[d]

[a] SOM, University of Groningen, PO Box 800, 9700 AV Groningen, the Netherlands
[b] POLIS Department, University of East Piedmont, via Duomo, 6-13100 Vercelli, Italy
[c] Faculty of Behavioural and Social Sciences, University of Groningen, P.O. Box 72 9700 AB, the Netherlands
[d] Fondazione per l' Ambiente 'T. Fenoglio', Via Gaudenzio Ferrari 1, I-10124 Torino, Italy

ARTICLE INFO

Article history:
Received 9 March 2009
Accepted 9 June 2009
Available online 5 July 2009

Keywords:
Energy saving
Energy efficiency
Energy policy

ABSTRACT

Departing from the concept of rational use of energy, the paper outlines the microeconomics of end-use energy saving as a result of frugality or efficiency measures. Frugality refers to the behaviour that is aimed at energy conservation, and with efficiency we refer to the technical ratio between energy input and output services that can be modified with technical improvements (e.g. technology substitution). Changing behaviour from one side and technology from the other are key issues for public energy policy. In this paper, we attempt to identify the effects of parameters that determine energy saving behaviour with the use of the microeconomic theory. The role of these parameters is crucial and can determine the outcome of energy efficiency policies; therefore policymakers should properly address them when designing policies.

1. Introduction

Energy efficiency is a term widely used, often with different meanings in public policy making. A clear distinction between energy efficiency and energy conservation is that the former refers to adoption of a specific technology that reduces overall energy consumption without changing the relevant behaviour, while the latter implies merely a change in consumers' behaviour. In psychology, this has been labelled as efficiency and curtailment behaviour (Gardner and Stern, 2002). Many aspects and influencing parameters on the total outcome of an energy system, from the demand and the supply side, have to be taken into consideration, hence energy efficiency improvement estimation demands analytical processes. In this respect, economic literature has frequently taken as given the microeconomic parameters affecting energy efficiency and energy conservation (Howarth and Andersson, 1993; Sanstad and Howarth, 1994; IEA, 1997; Mintel International Group Ltd., 1997; Howarth et al., 2000; Clinch et al., 2000; Poortinga et al., 2003; Sorrell, 2004; Bor, 2008). Nevertheless, actual practice demonstrates that economic and technological assumptions (of perfect information and absence of transaction costs) on these parameters do not necessarily hold in the market, which shifts energy efficiency patterns (Jaffe and Stavins, 1994). Policymakers often decide on specific policies and instruments on the ground of standardized assumptions of energy use and energy saving behaviour of end-users.

In many policy cases, energy efficiency improvement is set as an environmental target with strong assumptions on the rationality of end-users and their responsiveness to price signals, while such ex-ante assumptions should be verified with ex-post data, already appearing in the literature. Naturally, rationality of energy behaviour can be related to more parameters, as for instance effort, status, income, and many others. Energy efficiency policy instruments are mostly designed based on a normative perspective of market behaviour of economic actors, which are assumed to receive the market signals and act on the grounds of their own rationality. Still, the economic rationality in energy use and energy saving behaviours is an often entangled topic and depends on various parameters.

The purpose of this paper is to identify the relationships between various economic variables that determine the behaviour towards energy efficiency. More specifically, departing from the microeconomic theory, we attempt to unveil some parameters that should be taken into account by social planners, when designing policies for energy efficiency improvement.

The structure of this paper is as follows. In Section 2, we provide some basic definitions of somehow overlapping concepts of energy savings and energy efficiency. Section 3 refers to a microeconomic analysis of energy saving, rational use of energy, energy services, and the effects of time into energy savings. Furthermore, Section 4 deals solely with microeconomics of energy efficiency, incorporating concepts of rebound effects, real and shadow energy demand, the effects of time dimension in energy efficiency. Section 5 provides a discussion on energy saving and energy efficiency components as economic value reservoirs. Finally, in Section 6, we wrap up our theoretical

---

* Corresponding author. Tel.: +31 645380712.
E-mail addresses: vlasis@jiqweb.org, v.oikonomou@rug.nl (V. Oikonomou).

0301-4215/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enpol.2009.06.035

analysis and come up with some recommendations for policy making.

2. Definitions

In this section, we provide a general overview of the terms met in the literature of energy efficiency, which can often overlap and create confusion. Consumer behaviour and lifestyle choices are strongly related to the concept of the rational use of energy, the end-use (final) energy saving and the end-use energy efficiency. Energy savings and energy efficiency refer to two microeconomic situations, which deserve to be differentiated. Energy efficiency concerns the technical ratio between the quantity of primary or final energy consumed and the maximum quantity of energy services obtainable (heating, lighting, cooling, mobility, and others), whilst end-use energy saving addresses the reduction of final energy consumption, through energy efficiency improvement or behavioural change.

In many studies, the energy conservation concept refers to the reduction of energy consumption associated with a frugal lifestyle that includes a form of regulation (i.e. speed limitations, reduced domestic heating, and so on) or spontaneous changes in consumers' preferences resulting in behavioural changes. This concept often implies a more moral aspect of behaviour rather than a strictly economic one, since effort is required from the end-users side in order to engage in energy saving. An extensive literature review on the matter of 'sufficiency' can be found in Alcott (2008) and on sustainable consumption in Jackson (2007). Nevertheless, energy conservation can be enhanced via changes in the context (including regulations and energy price increases) and changes in motivations of people (including environmental concerns, and feelings of moral obligation to reduce energy consumption). An exhaustive literature survey on the matter can be found in Herring (2004) and Steg (2008). Policies in this aspect can target either investments towards energy-efficient goods (as for instance subsidies) or behavioural changes (feed-in tariffs for energy savings, see Bertoldi et al. (2009)), or both.

In this study, strictly confined to the field of end-use energy demand, the two concepts of energy savings and energy efficiency are used in a specific and distinct way. In some cases, nevertheless, the energy saving concept is also used with its general and widespread meaning such as the reduction of energy consumption. As mentioned above, in this paper, strictly energy end-uses are considered: complex efficiency implications in the upstream phases of transformation, transmission, and distribution are beyond the scope of this paper.

3. Microeconomics of energy saving

In this section, we present the basic microeconomic variables and functions of energy saving, which describe the parameters influencing positively or negatively energy saving trends. These functions are built upon energy services, energy savings, and the effect of time horizon on energy efficiency.

3.1. Energy services

In order to analyze energy savings and energy efficiency, we start from a very basic model on energy services expressed in the following function:

$$Qs = f(Qe) \tag{1}$$

where Qs is the required energy services (measured in GJ) and Qe the final consumption of energy (measured in GJ).

The function f corresponds to an overall set of technology transformation processes and to the related boundary conditions in which these processes develop in order to accomplish energy end-uses in defined environments (houses, offices, etc.). One can omit the formalization of the relationship between these processes, the conditions of the defined environments and services produced, because investigating technology transformation functions, is out of the scope of the paper that is instead focused on the combined effect of energy conservation and energy efficiency actions.

At a second step, we express the final consumption as a function of energy services (Eq. (1))

$$Qe = f^{-1}(Qs) \tag{2}$$

The same function, with the strong assumption of linearity, can be expressed as

$$Qe = \beta Qs \tag{3}$$

where β is the technical parameter expressing the conversion efficiency of technologies in which we can add a disturbance factor, thus enabling us to take human behaviour into consideration

$$Qe = \beta Qs + \upsilon \tag{4}$$

where υ is the exogenous variable related to human behaviour and to organisational processes (measured in GJ of energy used).

Eq. (4) practically implies that final energy end-use is dependent on demand for energy services but forecasting its evolution must take into account social parameters. In particular, it can be noted that the linear relationship expressed with the parameter β, between the quantity of end-use energy consumed and the quantity of services obtained, is reasonable if we consider non-linear relationships as linearized (i.e. linear approximations): the first derivative of the linear approximation is a multiple-step function where the base of each step is the linearization range that has to be defined accordingly to each technology transformation. As stated before, the in-depth investigation of the technology transformation is out of the scope of the paper, but it may indeed represent an interesting development for further research, for instance focused on a specific sector like household appliances.

In the short-term, with given domestic technologies, parameter β is exogenous. Nevertheless, as shown later, it is affected by investments in energy efficiency and endogenized in the model. Moreover, this parameter depends on the considered sector (heating, lighting, cooling, mobility, and others). Hence, a family of sectoral parameters can be imagined: $\beta_a, \beta_b, \beta_c, \beta_d, \ldots, \beta_n$.

Subsets of parameters in the same sector can be expressed as follows: $\beta_{a1}, \beta_{a2}, \beta_{a3}, \ldots, \beta_{am}$ (for example, different kinds of lamps in the lighting sector).

The exogenous term υ expresses the effect of human behaviour and the organisational practices on end-use energy. For instance, the attention paid to switch off lights left carelessly on, the regulation of heating or cooling, the personal driving style, the usage of a certain device, the habit of managing indoor air comfort conditions with outdoor air (opening doors and windows). This parameter gains significant attention by policymakers and should be always targeted by policy instruments. The values of this parameter are quite hard to quantify and they depend on the types of services (for instance, in cheaper technologies where energy saving is not very obvious, this parameter is expected much higher than in more expensive technologies). Here, we make use of a typical 'rationalist information deficit model[1]'

---

[1] Rational information deficit model supposes that energy savings can be promoted by informing people about the need to do so as well as ways and means to achieve that. The main assumption here is that a lack of knowledge prevents

(Burgess et al., 1998) in order to explain this behaviour, but we also acknowledge and take into account, at a very small extent, parameters that determine the behaviour, beyond market failures: awareness, trust, and commitment, moral obligation, cultural norms, routine practices, and habits, social networks and fashion (Owens and Driffill, 2008). In other words, Eq. (4) demonstrates that the energy services obtained Q_s are not equal to those maximum obtainable using a given quantity of final energy Q_e, because a part of this energy savings is wasted through careless or thoughtless behaviour.[2] This behaviour still could be explained by the social dilemma theory,[3] since reducing effort can be an individual benefit but not a collective one. To this end, if costs of individual benefits are lower than collective ones, maybe in a normative aspect, people can choose for the former, and this can lead to negative externalities as social costs are not incorporated in private costs' decisions. Policies based on this principle fall are mostly information campaigns, as imposing a cost on individual behaviours does not necessarily lead to common action, while internalizing the common benefit by proper information in individual decisions concerning energy use can indeed lead to energy savings in the long-run. Alternative policies that can target at a certain extent this social dilemma could involve a form of market trading, where negotiations in the form of price arrangement for energy saving take place, as for instance, in case of White Certificates (WhC). As shown later, energy saving affects final energy consumption through this factor (υ), whilst energy efficiency acts upon the parameter β. To this respect, our analysis focuses on the concept of final energy savings and parameters that influence them. In the next section, we explain more in-depth how the exogenous variable υ manifests and produces its effects.

3.2. Energy saving

We already specified that energy saving reduces the unnecessary final energy consumption which does not correspond to the production of utility and services. The fact that this unnecessary consumption emerges as a by-product of the required consumption is not completely new in the economic theory of rational behaviour. In fact, levelling the energy consumption to the exact minimum quantity necessary in order to obtain the desired energy services is not a costless activity. On the contrary, it requires a *noticeable* effort in terms of resources and information. As a result, an end-user can simply not desire to undertake this effort, even at the cost of consuming more energy than necessary.

The drivers behind the motivation of a consumer towards saving energy from a psychological perspective are explained in a study by Abrahamse (2007), which employs the theory of planned behaviour and the value-belief-norm theory. The theory of planned behaviour assumes that attitudes, subjective norms and perceived behavioural control determine intentions, which can predict behaviour (Ajzen, 1985; Ajzen and Fishbein, 1980). In terms of energy use, this theory takes as granted that people make planned, rational decisions (based on a typical cost-benefit rationality approach) and that behavioural choices are motivated by self-interest (in terms of hassle, time, and social approval). An alternative explanation is provided by the value-belief-norm theory (Stern, 2000) stating the general values of people determine environmentally oriented behaviour. Such values are categorized in egoistic (concern for own self), altruistic (concern for others), and biospheric (concern for the biosphere). Based on this theory, energy saving measures are accepted by the public when they have strong altruistic and biospheric values (Poortinga et al., 2004; De Groot and Steg, 2008). More specifically, values influence awareness of energy problems and the extent to which individuals feel responsible for these problems, which in turn influence feelings of moral obligation to do something about it and increase the acceptability of energy policies (Steg et al., 2005).

In our model, the variable υ in Eq. (4) is tied up to costs that an end-user must sustain in order to eliminate unnecessary consumption. In this paper, we group together these costs in a variable that we name "effort" (σ). This variable represents the disutility associated with "virtuous behaviours" of energy saving, essentially in terms of opportunity cost of time (the time necessary to acquire information and apply it to individual behaviours and organisational practices), as well as costs of effort, discomfort, and reduced status. It can be measured in 'utils' originating from cardinal utility in quantifiable terms (Varian, 2003).

As with all forms of disutility, an end-user can be disposed of sustaining a certain level of effort σ in exchange for compensation. The compensation that best fits our case is represented by the return in terms of income (Y) (expressed in €), which is the main reward (in terms of monetary savings in energy bill) for those who save energy. Nevertheless, we acknowledge that more psychological compensation parameters beyond the financial one trigger energy saving effort (for instance, feeling proud or being praised for doing the correct thing). The compensation can be stimulated furthermore by policy, when a direct reward for the energy saved on a short-term basis takes place (e.g. monthly) in order to provide the correct stimulation of longer-term energy saving behaviour and adaptation of energy needs (otherwise, if the financial reward is applied on a yearly for instance basis, end-users miss the insight of their actual daily consumption and cannot easily adapt their behaviour in the following period). Fig. 1 represents the indifference curves (u_1, u_2, u_3) between effort and return. These curves demonstrate that the higher the bill reduction, the higher the willingness to invest in energy saving effort in order to achieve this reduction.

Economic theory dictates that on any indifference curve the utility of the consumer does not vary; hence the slope of the indifference curve indicates the incremental return that is able to compensate an end-user for an incremental effort of energy saving, maintaining the constant overall utility. The linearity of the functions is justified with the hypothesis that, in return, interval values defined by the possibility of saving energy, the marginal preferences do not change. The arrow indicates the preference direction with increased levels of utility.

One more intuitive way of representing the indifference curves between effort and monetary compensation is to take into account the overall energy bill rather than the return

$$B = QePe$$

where B is the total energy bill for end-user, also incorporating the avoided income return (expressed in €); Pe the end-use electricity price.

Fig. 2 shows how an energy end-user exchanges incremental efforts with the reduction in energy bills, the slope being the

---

(*footnote continued*)
people from acting pro-environmentally. Nevertheless, we acknowledge that many studies have revealed increasing knowledge is not sufficient to promote energy savings, so this model is not validated in several studies.

[2] An important clarification is that the exogenous term υ should not be confused with the much documented rebound effect, which is exclusively dependent on income and substitution effects.

[3] The social dilemma theory explains situations in which private interests are at odds (e.g. comfort and convenience) with collective ones (e.g. environmental quality). Social dilemmas are defined by two properties: (a) each person has an individual rational strategy with a best pay-off, when not cooperating, at least in the short-term. However, if everyone acts at their own interest, collective interests will be seriously harmed. To this end, the second property (b) assumes that if all individuals pursue this strategy it results in a deficient collective outcome, hence everybody would be better off if they had cooperated.

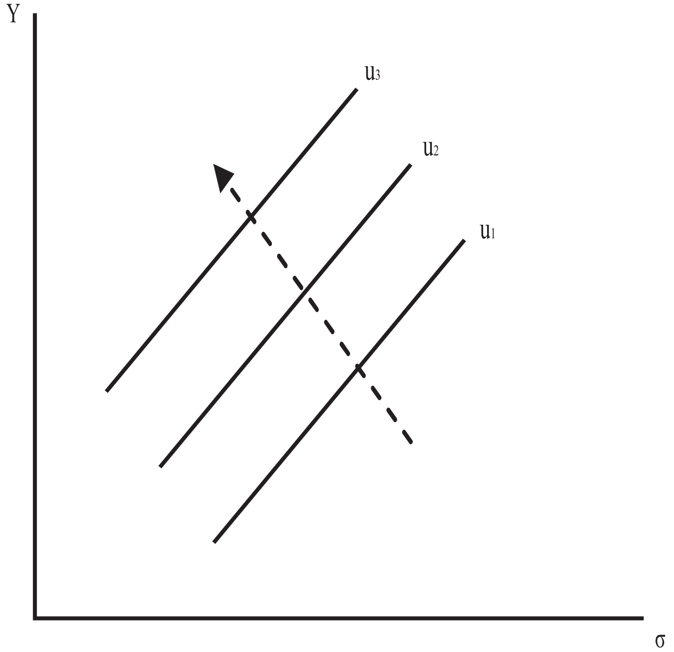

Fig. 1. Indifference curves between effort of energy savings (σ) and income (Y).

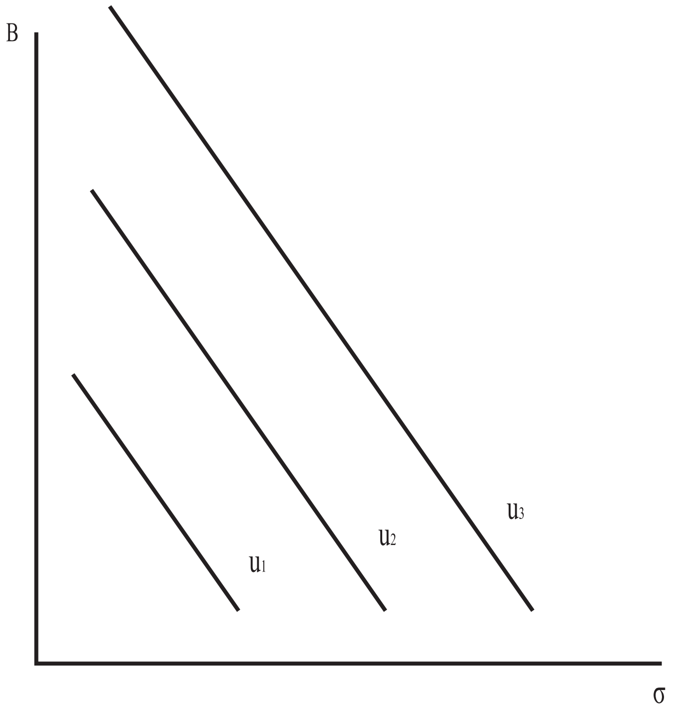

Fig. 2. Indifference curves between the effort of energy saving (σ) and energy bill (B).

marginal rate of substitution, here given as a constant due to the relative little impact of energy bill saving on income and preferences. Fig. 2 also represents an interesting case of indifference curves between two "bads", instead of the usual representation between two "goods". In other words, the end-user faces the trade-off of reducing energy bill and putting in effort for saving energy, where, based on these curves there are indifference points because of the small impact of bill saving on preferences.

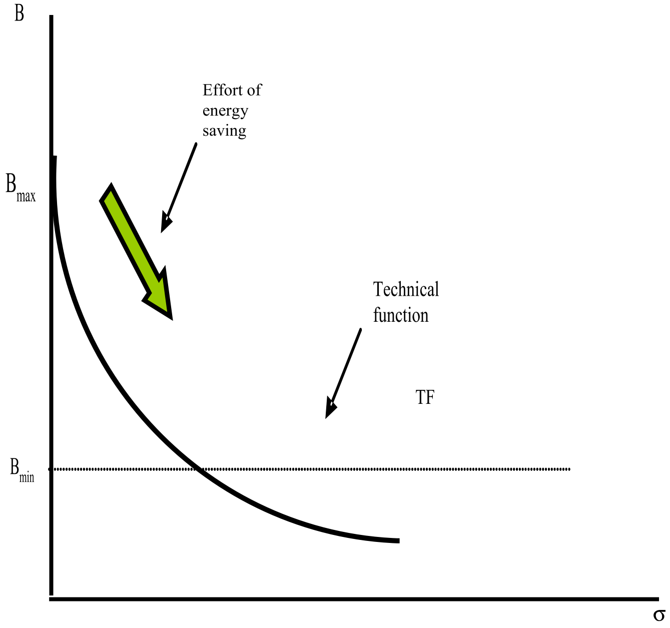

Fig. 3. Technical function of energy saving.

So far, we defined the preferences of an end-user with respect to the disutility of the effort and the utility of energy bill reduction, and the moral happiness of reducing a collective environmental and energy problem. However, it is necessary to examine how the effort of energy saving influences its effective energy consumption. In other words, to investigate the function of the production of energy saving, expressed by the technical relationship between the effort (the time dedicated to the acquisition of information and to its application in generating ES behaviours) and the result, i.e. the reduction of final energy consumption.

A technical function, represented in Fig. 3, expresses the relationship between the effort of saving energy (σ) made by subjects with virtuous behaviour, and the results in terms of monetary savings in energy bills (B), with energy services being equal. In other words, it unveils the opportunity cost of investing in a new energy saving technology to paying a higher bill for energy consumption. The values of both costs can be compared when discounted, since the upfront cost of an energy saving technology does not entail any immediate profit in the short-run. If the relationship is linear then for each € decrease of the energy bill a sacrifice of one util is required (increased effort, which can also be translated as a € increase of the investments in energy saving technologies).

The profile of the curve reminds us, intuitively, that when we start from a situation in which no care is taken in energy consumption, thus ending with a maximum energy bill ($B_{\max}$), interesting marginal energy savings can be obtained with little effort. In this case, the marginal cost of saving energy increases. This is the standard rule with marginal abatement costs, where under no effort cheaper abatement options are present and these costs increase along the marginal abatement cost curve (Tietenberg, 2000). In other words, the results of the effort of energy saving continuously decrease, until they become insignificant (levelling of the technical function) and approach the technically minimum possible level of final energy consumption, the required energy services being equal, which corresponds to the minimum energy bill ($B_{\min}$). To enhance energy savings below the intersection, as to change the optimal levels of energy savings, specific incentive policies are required, targeting at reducing the sunk costs of an investment.

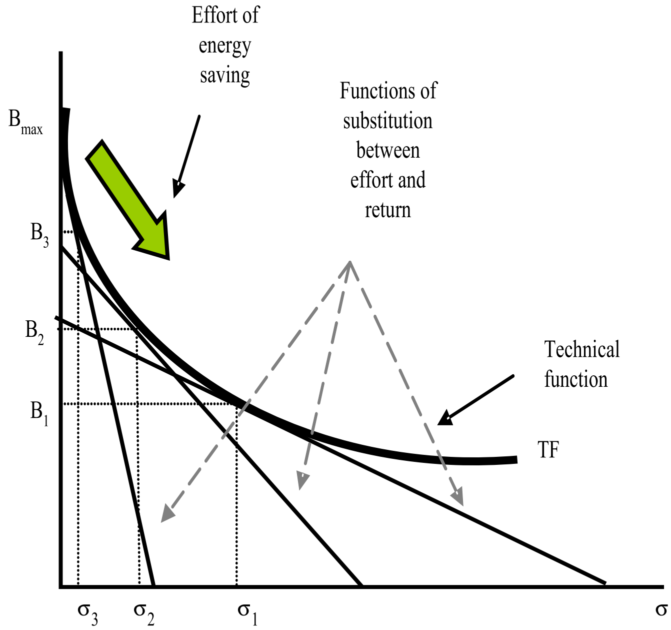

Fig. 4. Technical function of energy saving and indifference curves between effort of energy saving (σ) and energy bills (B).

Combining indifference curves between return and effort and the technical function enables us to represent the optimal choices of energy saving, which is found at the point of the curves' intersections.

In Fig. 4, the three linear functions represent three profiles of an indifference curve. The three profiles correspond to three hypothetical subject groups, characterized by different preferences, represented by different substitution rates between effort and return. Every group makes more of an effort in ES until the point of equilibrium, where the marginal cost of the effort is equal to the marginal benefit.

To this respect, different levels of energy saving correspond to different structures of end-users' preferences. The group with the greater substitution rate between return and effort, for example, manifests little effort, equal to $\sigma_{3\,,}$ which is completely reasonable when taking into account that this group associates a high cost to the effort (indifference curve with a bigger slope); on the contrary, the group with a lower substitution rate between return and effort will manifest a higher effort level, equal to σ_1, justified by the relatively low cost that this group associates with the effort (indifference curve with a small slope).

Based on this reasoning, we form Eq. (4), which shows that different levels of σ generate different levels of energy bills and thus of energy saving, when incorporating the value of the exogenous variable υ.

$$ES = (B_{\max} - B_n)/Pe \qquad (5)$$

An important point with this respect is derived from the goal-framing theory (Lindenberg and Steg, 2007). Because energy savings generally imply that people have to give up personal advantages (e.g. comfort) in order to reach a collective goal (security of energy supply and reduction of GHG emissions), it is unlikely that people will be triggered to save energy solely based on individual benefit discounting. However, people do not only strive for maximising individual benefits. The goal-framing theory proposes that three goals govern behaviour: hedonic goals "to feel better right now", a gain goal-frame "to guard and improve one's resources", and a normative goal-frame "to act appropriately". This implies that people not only consider comfort and costs of energy savings, but also moral aspects such as environmental quality and future generations. The substitution rates indicated in Fig. 4 are likely to vary with goal strength, that is, when normative goals are strongest, substitution rates are likely to be lower as compared to situations in which gain or hedonic goals are strongest. In many cases people are tempted to act on the grounds of personal interest, while collective interests play a less important role. However, some people do take into account moral considerations and thus collective objectives. Energy savings will generally follow such collective concerns (since the benefits in energy bills are generally low) and this can be explained as moral normative behaviour. Similar concerns on moral social concerns and pro-environmental behaviour (including energy savings) are raised by De Groot and Steg (2008). A study of Abrahamse (2007) unveiled that household energy use is related to socio-demographic variables (Brandon and Lewis, 1999; Gatersleben et al., 2002), which are completely different from the drivers of energy savings. For instance, households with higher incomes or larger in size often use more energy, while psychological variables are less adequate to explain energy consumption patterns, since the latter are determined by socioeconomic barriers and opportunities. Nevertheless, from a different angle, households with higher income can relatively promote easier energy saving measures (e.g. purchasing-efficient technologies or installing insulation domestically). Results for intention to conserve energy detect a direct association with psychological factors, whereas socio-demographic characteristics do hardly come into play. Especially, attitudes towards energy conservation and perceived behavioural control could explain the variance in intention to conserve energy. To this end, higher levels of perceived behavioural control and positive attitudes towards energy conservation can drive towards greater energy savings. Behavioural control and attitude change can also be triggered by policies of self-monitoring, such as introduction of smart metering in the market, where end-users can be aware of their actual energy behaviour and in the medium long-run get adapted to modifying this behaviour or reducing unnecessary energy use.

3.3. *Energy saving and time*

Based on the definition used for the choices of energy saving in this paper and considering the typical approach of cost-benefit analyses, the cost of the effort and the benefit in terms of financial savings through reduced bills can be considered like two instantaneous flows (the time lapse between the two flows can be measured in a few weeks, indeed a negligible lapse of time for actualization purposes). Thus, the cost of time can be disregarded as one can imagine that the subject does not apply to the end-user's own choices by any actualization of the cost and benefit flows. The same does not apply to energy efficiency as a result of investment in new equipments with a life cycle of several years and corresponding financial returns in terms of reduced bills.

4. Microeconomics of energy efficiency

In this section, we deal exclusively with issues concerning energy efficiency, differentiating from the background of energy savings. More specifically, we refer to the relationship between energy efficiency and the rebound effect, the real and shadow energy demand, and on the influence of time horizon on energy efficiency. Similar to the Section 3, we identify variables and functions that determine the behaviour towards energy efficiency improvement.

4.1. Energy efficiency and rebound effects

In principle, end-use energy efficiency concerns the technical relationship between the maximum quantity of obtainable services (for instance, heating, lighting, cooling, mobility, etc.) and behavioural changes (for instance, people purchase an efficient technology that has to be used appropriately) and the quantity of end-use energy consumed. This relationship depends on all conversion processes, which transform end-use energy in services and on the boundary conditions of the processes and of the end-uses. In other words, similar to Eq. (3), end-use energy efficiency can be defined as

$$\sum_{i=1}^{n} Qe_i = \sum_{i=1}^{n} \beta_i Qs_i$$

where $\sum_{i=1}^{n} Qe_i$ is the total amount of end-use energy consumed from all services and $\sum_{i=1}^{n} \beta_i Qs_i$ the total quantity of energy services with all relevant conversion efficiencies.

Every improvement in energy efficiency is reflected in a decrease in the relative unit price of energy services (hence, in the price of energy services in relation to the prices of other goods), when investment costs for end-users can have a relatively short payback period (e.g. 5 years for energy saving technologies). For instance, mobility and cooling have been strongly influenced by the decrease in the relative price of end-use energy for unit of consumption (km and GJ). The economic literature refers to this reaction as the direct rebound effect, a similar concept of substitution effect in microeconomics (Ruzzenenti and Basosi, 2008; Binswanger, 2001; Greening et al., 2000; Haas and Biermayr, 2000; Milne and Boardman, 2000; Bentzen, 2004; Hertwich, 2003, Herring, 2004; Brannlund et al., 2007). The rebound effect could be explained from the following causal chain: an increase in energy efficiency tends to lower the marginal costs of using an energy service[4] (Quirion, 2004).

The rebound effect in quantifiable terms can be defined as the ratio of energy savings after the installation of the energy-efficient appliances/energy savings without the new energy-efficient devices. Greening et al. (2000) distinguished the rebound effect between the following:

- *Direct rebound effects*: The direct effects are the microeconomic price effects that consist of the substitution and income effect. The substitution effect refers to the increase of demand for the use of an energy service when its price decreases, as an effect of energy efficiency, given the same utility. The income effect occurs when the available income increases as a result of the reduced price of the energy service that leads to expenses towards *other* energy-consuming appliances or uses. (Hertwich, 2005). Gatersleben et al. (2002) and Steg (1999) found that income is one of the predictors of household energy use, indicating that indeed people tend to spend more money on energy as soon as they can afford it.
- *Secondary effects*: From the producer's side, increased energy efficiency measures can result in the reduction of the production costs, which in turn can lead to reduction of the price of the energy service and an increase in their total quantity supplied. In the following equilibrium, the market demand for this energy service will increase reducing, hence the expected effects from the policy-induced energy savings. However, this market procedure depends on other parameters, i.e. the decrease of the price of the energy service cannot be predetermined, since the price of the other factors of production might increase (Quirion, 2004).
- *Economy wide effects*: Market clearance adjustments (especially in fuel markets). These effects consist of the change of the market equilibrium in energy supply and demand relationships (and all the factors that they entail, i.e. consumer preferences) as a result of the shift of the determinants affecting one energy efficient good.
- *Transformational effects*: Changes in technology may also change the consumers' preferences and introduce new production techniques that transform the organization of production. These effects could result in a change in energy consumption from the consumers or producers.

Most studies cover in principle the substitution and income effects, since the other effects are difficult to isolate (Hertwich, 2005). Table 1 presents some indicative aggregate rebound effect results from several studies and Table 2, some results of disaggregated energy efficiency measures that could be taken into account for the effect of measures implemented due to energy efficiency policies.

Greening and Greene (1998) present a review of 75 estimates of the rebound in the existing literature. These estimates stem from econometric analysis and direct measurements and are measured in terms of fuel efficiency of specific energy measure rather than energy consumption. The key findings are presented in Table 2.[5]

The inelastic short-term demand nature of energy use can increase the use of the energy service that raises the energy demanded; hence no actual savings are generated. A practical example can be with a user that exchanges his/her boiler for one with improved efficiency. As a result, the price of one unit of heat will decrease with respect to the price of the other goods. For the substitution effect and the income effect this could increase the demand for heating (and thus end-use energy), with a paradoxical result i.e. an increase in consumption caused by an improvement in efficiency (although a saturation point exists, which is depending on the energy service at stake). The rebound effect in quantifiable terms can be defined as the ratio of energy savings after the installation of the energy-efficient appliances to the autonomous energy savings without the new energy-efficient devices. In general, the relative decrease in end-use energy price also has an income effect: higher real spending capacity can push for higher consumption in several energy-consuming goods and services, which is frequently called as indirect rebound effect. Furthermore, when energy efficiency is encompassed in pervasive new technologies, in particular, in production processes, the rebound effect can became backfire effect, resulting in an increase of energy consumption due to efficiency (the so-called Khazzoom–Brookes effect). As a whole, substitution and income effects have been estimated in the range 10–30% of the estimated energy saving through energy efficiency improvement (UK Energy Research Center, 2007).

In Fig. 5, an improvement in energy efficiency is represented by a shift down and to the left of the technical function that links effort to energy bills. When energy efficiency improves, the effort being equal, one can obtain considerably greater results in terms of energy consumption. Trivially, one can imagine an end-user who produces an effort σ_1 to switch off lights in areas where light is not needed, thus obtaining a monetary reduction up to B_1 (in the point where the marginal cost of effort is equal to the

---

[4] Energy services could be defined as a commodity that is demanded, i.e. hot water, refrigeration, heat, etc. In order to produce this commodity energy is needed, alongside with other production factors, like capital, labor and management.

[5] All these rebound effect estimates assume a 10% increase in fuel-consumption efficiency.

Table 1
Empirical studies presenting aggregate rebound effects.

Study	Content	Results
Khazoom (1986)	Electricity-heated homes in Sacramento, CA	Long-run REf of 65%
Dubin et al. (1986)	Households participating in a program of improving the efficiency of home heating	REf between 8% and 13%
Dinan (1987)	Households whose dwellings were weatherized	REf small but statistically significant
Hirst (1987)	Evaluation of Residential Weatherization program throughout the Pacific NW, comparison of the behavior of participants with non-participants	REf between 5% and 25%
Bentzen (2004)	US manufacturing energy consumption	REf around 24%
Laitner (2000)	US	REf around 2–3%
Davis (2004)	Evidence from field trials of a front loading clothes washer for 104 households	REf around 5.6%
Schipper and Grubb (2000)	Reviewing of studies covering 80–90% of energy use in OECD countries	REf between 5% and 15%
Berkhout et al. (2000)	Studies estimating the effect of energy taxes in the Netherlands	REf between 0% and 15%
Haas and Biermayr (2000)	Space heating in Austria	REf between 20% and 30%
Sorrell et al. (2009)	Personal transport in Europe	REf around 10%
Schwarz and Taylor (1995)	Heating in households in US	REf between 1.4% and 3.4%
Douthitt (1986)	Heating in households in Canada	Long-run REf 35–60%
Haas et al. (1998)	Heating in households in Austria	REf around 15–48%
Guertin et al. (2003)	Heating in households in Canada	REf around 29–47%
Nesbakken (2001)	Heating households in Norway	REf around 21%
Klein (1987)	Heating households in US	REf between 25% and 29%
Dubin et al. (1986)	Space cooling in households in US	REf between 1% and 26%

Source: adapted from Binswanger (2001) and Sorrell et al. (2009).

Table 2
Overview of 75 studies on the rebound effect according to sectors and energy services.

Sector	Energy service	Rebound effect estimate (%)
Consumers		
	Space heating	10–30
	Space cooling	0–50
	Water heating	10–40
	Residential lighting	5–12
	Appliances “white goods”	0
Firms		
	Process uses (short-run)	0–20
	Lighting (short-run)	0–2
	Long-run aggregate impacts	
Economy wide effects		
	Change in total output growth	0.48

Source: (Greening et al., 2000).

marginal benefit in terms of monetary reduction of electricity bills). By installing fluorescent lights which are considerably more efficient, the same subject with the same effort σ_1 could obtain a reduction in bills to the level B_3. However, in the new conditions, it is better for an end-user to reduce the effort level to σ_2 (in the new point where the marginal cost of effort is equal to the marginal benefit in terms of the reduction in energy bills), thus obtaining an electricity bill equal to B_2 lower than the initial one, a fact that precisely recalls the rebound effect. The increase in efficiency therefore allows, in a certain way, a double dividend for the consumer: less effort in energy saving and, simultaneously, less money spent on energy bills. The trade-off between effort and energy bill saving, when an increase in efficiency is present at-work, will depend on the profile of the indifference curves: consumers who attribute a very high disutility to the effort will reduce it substantially, and vice versa, consumers with a marginal utility of income relatively high with respect to the effort, will choose to limit their bills further. Especially,. people with strong hedonic goals will be tempted to reduce their efforts to conserve energy (as this makes them feel good), while people with strong normative goals are more likely to keep on putting effort in energy conservation actions, because this is still the right thing to do. Even if the theory suggests relating the first category to high income and the second category to lower income end-users, intuitively the reality appears rather more complex.

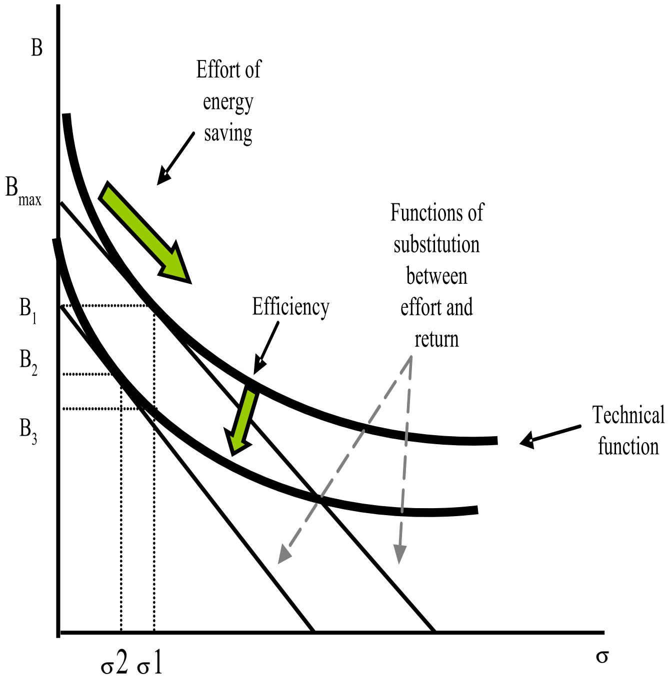

Fig. 5. Energy saving and energy efficiency.

4.2. Real and shadow energy demand

End-use energy demand is a function of the price of energy, given the technology used and end-user’s preferences. This relationship is explained in Eq. (6).

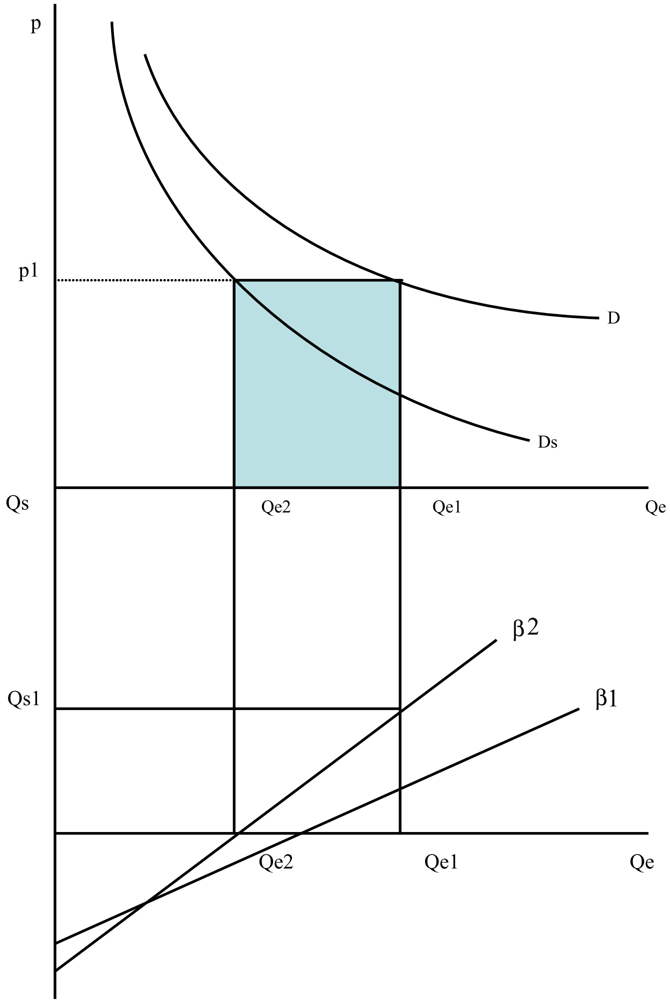

Fig. 6. Real and shadow energy demand and energy efficiency.

$$De = f(Pe) \tag{6}$$

where De is the end-use energy demand.

Consumers are interested in energy services (Q_s) that end-use energy can supply (heating, lighting, cooling, mobility, other); these services are connected to the quantity of end-use energy by a previously introduced technical parameter (Eq. (1)).

Fig. 6 outlines the relationship between end-use energy demand, the energy services and the shadow end-use energy demand, throughout the effects of improvement in efficiency. Given the demand curve D and the price p_1, the quantity Q_{e1} of requested final energy is related to the quantity Q_{s1} of energy services obtained, according to the technical function with parameter β_1. With an improvement in efficiency, represented by the rotation of the technical function in an anti-clockwise direction (β_2), the same quantity Q_{s1} of energy services can be obtained with a smaller quantity Q_{e2} of final energy, which constitutes the "shadow" end-use energy demand of the consumer. The curve of the shadow demand (D^s) is built, with respect to the curve of real demand (D), following the correspondence between every possible energy price and the quantity of final energy strictly necessary (Q_{e2}), with an improvement in efficiency in order to obtain the desired level of energy services.

The shaded area represents the monetary savings in the energy bill potentially associable to the improvement in energy efficiency. These savings are, with respect to the social energy efficiency value, the private economic benefit that Energy Service Companies (ESCO's) can use and can plan their commercial strategies upon. Alternatively, policy schemes that address financing options for such actions could be set in place, which could enable investments of more expensive energy saving projects and overcome financial and other market barriers faced by end-users.

4.3. *Energy efficiency and time*

Differently from the case of ES, in the choices of new equipment that generates end-use energy efficiency the time factor plays an important role. The temporal distribution of costs and benefits is considerably different, with strong initial investments and multiannual return flows. The discount rate used in the evaluation of investments in EE affects the actual value of the shaded area in Fig. 6.

5. Energy saving and energy efficiency as value reservoirs

Both energy efficiency and energy saving in the end-uses can be considered as potential reservoirs of resources extractable through actions and investments. The economic value contained in these pools can be subdivided in two components:

1. Private economic value
2. Public economic value

The first component represents the reward for actions and investments in energy efficiency. The economic analysis should, in addition to quantifying the deposits of this value, identify the reasons that lead to a greater or lesser exploitation in different markets, geographical, and regulation conditions. With efficient and well-functioning markets, these deposits should be attractive to companies that identify, quantify, and exploit them, bringing energy savings and energy efficiency to optimal levels from the point of view of utility and private profits. The second component concerns externalities and public goods associated with end-use energy consumption, such as air pollution, security of supply, and the continuity of service. Combined energy efficiency and environmental policies, if properly fine-tuned with minimum or no overlaps, can address both issues simultaneously, where with the same actions (energy saving) private economic value can be increased and adverse environmental effects minimized. Such could be the hypothetical case, for instance, of quota schemes on the purchase of clean energy, with a parallel benefit on the decrease of energy demand.

It is necessary to highlight the fact that the relationship between energy policies and externalities, in particular environmental externalities, can have distorted effects. For instance, the rebound effect signals that a policy based on the dissemination of energy efficiency could bring, in the medium to long-term, an increase in consumption and therefore emissions, with opposite effects to those desired in any environmental strategy.

Paradoxically, in order to avoid that the private gains derived from energy efficiency are shifted towards increased consumption (of energy or other goods, with a consequent elimination of the environmental potential of energy efficiency), the necessity to move the gains of end-users, with some form of public policy, towards investments in natural capital should be addressed (Wackernagel and Rees, 1997). Only in these conditions the public environmental value of energy efficiency could be completely exploited. Naturally, the proposed correction requires us to address the problem of the energy efficiency incentive with private subjects that would see their return reduced from an energy taxation policy or an increase in energy price, financing new investments.

Broadly speaking, it seems that every policy on end-use energy efficiency should be coupled with policies aimed at raising the cost of energy through Pigouvian taxes or tradable rights markets, which could compensate the rebound effect setting final prices nearer to the social cost of economic choices. Another strategy for energy efficiency policy is moralization, which implies convincing people that they should protect collective environmental qualities (despite it may also involve some individual costs), and that their contribution will be socially helpful.

6. Conclusions and outlook

Microeconomic analysis of private behaviour in relation to end-use energy demand and consumption gives rational foundations to the outline and implementation of public energy efficiency policy instruments. The present analysis suggests a theoretical framework in which private choices in energy conservation and energy efficiency are explained in terms of private preferences and costs: in this cadre they produce controversial effects, mainly for rebound phenomena. Still, the economic rationality in energy use and energy conservation is often debated and depends on various parameters.

Initially, we differentiated between the concepts of energy efficiency and energy conservation, often used in parallel in literature. Energy savings addresses the reduction of final energy use, while energy efficiency concerns the technical ratio between the quantity of primary energy consumed and the maximum quantity of energy services obtainable. Policies can address each one or both aspects simultaneously.

Departing from the microeconomic theory, we aim at understanding drivers for promoting energy saving beyond energy prices. To this end, we integrated some theories well established in environmental psychology in order to identify parameters that affect end-users behaviour for both energy efficiency and energy savings. From a rationalist information deficit model, for instance, we can extract that a parameterized energy use depends on awareness, trust, and commitment, moral obligation, cultural norms, routine practices, and habits, social networks and fashion. Some of these issues, like awareness and social behaviour, can be tackled with respective information diffusion policies, which target at these specific-market barriers. Other parameters explaining the energy users' behaviour are found in the theory of planned behaviour i.e. people make planned, rational decisions and behavioural choices are motivated by self-interest, hassle, time and social approval and the theory value-belief-norm theory (i.e. general values of people determine environmentally oriented behaviour). To this end, policies that impose a cost (e.g. in the form of taxation) on individual energy behaviour do not lead to common action. Therefore, internalizing the common benefit by proper information in individual decisions concerning energy use can indeed lead to energy savings in the long-run. Alternative policies that can target at a certain extent this social dilemma could involve a form of market trading, where negotiations in the form of price arrangement for energy saving take place, as for instance in case of White Certificates or other market-based mechanisms.

Moving a step further, we expressed with the private utility theory the relationship between the effort of energy savings and the results in terms of monetary savings in energy bills, or in other words, the opportunity cost of investing in energy saving and enjoying more comfort from energy consumption. Our main finding there, by incorporating the goal-framing theory is that people not only consider comfort and costs of energy savings, but also moral aspects such as environmental quality and future generations. Questionnaire study data has revealed that although higher income groups can consume more energy and theoretically can afford to invest more in energy efficiency, there is a direct association between intention to conserve energy and psychological factors, whereas socio-demographic characteristics do hardly come into play. To this end, higher levels of perceived behavioural control and positive attitudes towards energy conservation can drive towards greater energy savings. Behavioural control and attitude change can also be triggered by policies of self-monitoring, such as introduction of smart metering in the market.

A third aspect we explored is the rebound effect, which is a typical income effect and originates from the increased energy efficiency that allows a double dividend for the end-user: less effort in energy saving and, simultaneously, less money spent on energy bills and more space for increased energy use in the future. The trade-off between effort and energy bill saving, when an increase in efficiency is present at-work, will depend on the overall perception towards energy saving: consumers who attribute a very high disutility to the effort will reduce it sensitively, and vice versa, consumers with a marginal utility of income relatively high with respect to the effort, will choose to limit their bills further. Energy policy on efficiency should be integrated with financial or market-based policies, which can minimize the rebound effect by setting private costs of using energy closer to the social costs, hence reducing the externalities.

Finally, we consider that this analysis can provide a useful insight for policymakers when designing policies for energy efficiency improvement, since departing from the normative aspects of end-users rational behaviour, more parameters have to be taken into account that generate a differentiated behaviour. More specifically, some key policy lessons summarized from this study are: (a) policies can be 'smart' targeting at both use and investments, (b) taxing individuals is not enough for long-run energy saving, as information campaigns and market instruments are necessary to induce collective behaviour, (c) policies stressing the moral obligation to conserve energy can increase their acceptability, (d) financial compensation for savings must take place in the short-run in order to enable end-users to monitor their daily energy use, (e) behavioural change can be triggered in the medium-run by self-monitoring policies, which can modify the end usage, and (f) enabling financing options through policy schemes can overcome substantial market barriers of consumers towards energy efficiency investments.

Acknowledgement

This paper was reviewed and presented in the International Energy Workshop (2008) of the International Energy Agency.

References

Abrahamse, W., 2007. Energy Conservation through behavioral change: Examining the effectiveness of a tailor-made approach, Master thesis, University of Groningen, the Netherlands. Download at: 〈http://dissertations.ub.rug.nl/faculties/ppsw/2007/w.abrahamse/〉.

Ajzen, I., 1985. From intentions to actions: a theory of planned behavior. In: Kuhl, J., Beckmann, J. (Eds.), Action Control: From Cognition to Behavior. Springer, Berlin, pp. 11–39.

Ajzen, I., Fishbein, M., 1980. Understanding Attitudes and Predicting Social Behavior. Prentice Hall, Englewood Cliffs, NJ.

Alcott, B., 2008. The sufficiency strategy: would rich-world frugality lower environmental impact? Ecological Economics 64 (4), 770–786.

Bentzen, J., 2004. Estimating the rebound effect in US manufacturing energy consumption. Energy Economics 26 (1), 123–134.

Berkhout, P.H.G., Muskens, J.C., Velthuijsen, J.W., 2000. Defining the rebound effect. Energy Policy 28 (6–7), 425–432.

Bertoldi, P., Rezessy, S., Oikonomou, V., Boza-Kiss, B., 2009. Feed-in tariff for energy saving: thinking of the design. European Council for Energy Efficient Economy (ECEEE) Summer Study Proceedings, France.

Binswanger, M., 2001. Technological progress and sustainable development: what about the rebound effect? Ecological Economics 36, 119–132.

Bor, Y.J., 2008. Consistent multi-level energy efficiency indicators and their policy implications. Energy Economics 30 (5), 2401–2419.

Brandon, G., Lewis, A., 1999. Reducing household energy consumption: a qualitative and quantitative field study. Journal of Environmental Psychology 19, 75–85.

Brannlund, R., Ghalwash, T., Nordstrom, J., 2007. Increased energy efficiency and the rebound effect: effects on consumption and emissions. Energy Economics 29 (1), 1–17.

Burgess, J., Harrisson, C., Filius, P., 1998. Environmental communication and the cultural politics of environmental citizenship. Environment and Planning A 30 (1), 1445–1460.

Clinch, J.P., Healy, J.D., University College Dublin Department of Environmental Studies, 2000. Cost-benefit analysis of domestic energy efficiency. Dublin, University College Dublin Department of Environmental Studies.

Davis, L.W., 2004. The Rebound Effect for Energy Efficient Residential Durable Goods. University of Wisconsin, Madison.

De Groot, J., Steg, L., 2008. Value orientations to explain beliefs related to environmental significant behavior: how to measure egoistic, altruistic, and biospheric value orientations. Environment and Behavior 40 (3), 330–354.

Dinan, T.M., 1987. An Analysis of The Impact of The Residential Retrofit on Indoor Temperature Choice. Oak Ridge National Laboratory.

Douthitt, R.A., 1986. The demand for residential space and water heating fuel by energy conserving households. The Journal of Consumer Affairs 20 (2), 231–248.

Dubin, J.A., Miedema, A.K., Chandran, R.V., 1986. Price effects of energy-efficient technologies a study of residential demand for heating and cooling. Rand Journal of Economics 17 (3), 310–325.

Gardner, G.T., Stern, P.C., 2002. Environmental Problems and Human Behavior, 2nd ed. Pearson, Boston, MA.

Gatersleben, B., Steg, L., Vlek, C., 2002. Measurement and determinants of environmentally significant consumer behavior. Environment and Behavior 34 (3), 335–362.

Greening, L.A., Greene, D.L., 1998. Energy use, technical efficiency, and the rebound effect: a review of the literature. Oak Ridge National Laboratory, Center for transportation analysis.

Greening, L.A., Greene, D.L., Difiglio, C., 2000. Energy efficiency and consumption – the rebound effect – a survey. Energy Policy 28 (6–7), 389–401.

Guertin, C., Kumbhakar, S., Duraiappah, A., 2003. Determining demand for energy services: investigating income-driven behaviours. International Institute for Sustainable Development.

Haas, R., Auer, H., Biermayr, P., 1998. The impact of consumer behavior on residential energy demand for space heating. Energy and Buildings 27 (2), 195–205.

Haas, R., Biermayr, P., 2000. The rebound effect for space heating Empirical evidence from Austria. Energy Policy 28 (6–7), 403–410.

Herring, H., 2004. Energy efficiency—a critical view. Energy 31 (1), 10–20.

Hertwich, E., 2003. Consumption and the rebound effect: the consideration of information and communication technologies. In: Proceedings of the SETA-C–ISIE Case Study Symposium, Lausanne.

Hertwich, E.G., 2005. Consumption and the rebound effect: an industrial ecology perspective. Journal of Industrial Ecology 9 (1–2), 85–98.

Hirst, E., 1987. Changes in indoor after retrofit based on electricity billing and weather data. Energy Systems Policy 10, 99–110.

Howarth, R., Andersson, B., 1993. Market barriers to energy efficiency. Energy Economics 15 (4), 262–272.

Howarth, R., Haddad, B.M., Paton, B., 2000. The economics of energy efficiency: insights from voluntary participation programs. Energy Policy 28 (6–7), 477–486.

IEA, 1997. Indicators of Energy Use and Efficiency: Understanding the Link between Energy and Human Activity. OECD/IEA, Paris.

Jaffe, A.B., Stavins, R.N., 1994. The energy-efficiency gap. What does it mean? Energy Policy 22 (10), 804–810.

Jackson, T., 2007. Sustainable consumption. In: Atkinson, Giles, Dietz, Simon, Neumayer, Eric (Eds.), Handbook Sustainable Development. Edward Elgar, Cheltenham, pp. 254–268.

Khazoom, D.J., 1986. An Econometric Model Integrating Conservation in the Estimation of The Residential Demand for Electricity. JAI Press, Greenwich.

Klein, Y.L., 1987. Residential energy conservation choices of poor households during a period of rising energy prices. Resources and Energy 9 (4), 363–378.

Laitner, J.A., 2000. Energy efficiency: rebounding to a sound analytical perspective. Energy Policy 28 (6–7), 471–475.

Lindenberg, S., Steg, L., 2007. Normative, gain and hedonic goal frames guiding environmental behavior. Journal of Social Issues 65 (1), 117–137.

Milne, G., Boardman, B., 2000. Making cold homes warmer: the effect of energy efficiency improvements in low-income homes. A report to the energy action grants agency charitable trust. Energy Policy 28 (6–7), 411–424.

Mintel International Group Ltd, 1997. Energy Efficiency and the Consumer. Mintel International Group, London.

Nesbakken, R., 2001. Energy consumption for space heating: a discrete-continuous approach. Scandinavian Journal of Economics 103 (1), 165–184.

Owens, S., Driffill, L., 2008. How to change attitudes and behaviours in the context of energy. Energy Policy 36 (12), 4412–4418.

Poortinga, W., Steg, L., Vlek, C., Wiersma, G., 2003. Household preferences for energy saving measures: a conjoint analysis. Journal of Economic Psychology (24), 49–64.

Poortinga, W., Steg, L., Vlek, C., 2004. Values, environmental concern and environmental behavior: a study into household energy use. Environment and Behavior 36, 70–93.

Quirion, P., 2004. Les certificats blancs face aux autres instruments de politique publique pour les economies d'energie : bilan de literature economiques et priorites de recherche. Institut Francais de l'Energie.

Ruzzenenti, F., Basosi, R., 2008. The role of the power/efficiency misconception in the rebound effect's size debate: does efficiency actually lead to a power enhancement? Energy Policy 36 (9), 3626–3632.

Sanstad, A., Howarth, R., 1994. Consumer Rationality and Energy efficiency. ACEEE Summer Study on Energy Efficiency in Buildings.

Schipper, L., Grubb, M., 2000. On the rebound? Feedback between energy intensities and energy uses in IEA countries. Energy Policy 28, 367–388.

Schwarz, P.M., Taylor, T.N., 1995. Cold hands, warm hearth: climate, net take back, and household comfort. Energy Journal 16 (1), 41–54.

Sorrell, S., 2004. The Economics of Energy Efficiency: Barriers to Cost-Effective Investment. Edward Elgar, Cheltenham.

Sorrell, S., Dimitropoulos, J., Sommerville, M., 2009. Empirical estimates of the direct rebound effect: a review. Energy Policy 37, 1356–1371.

Steg, L., 1999. Verspilde energie? Wat doen en laten Nederlanders voor het milieu (Wasted energy? What the Dutch do and don't do to protect the environment). Den Haag: VUGA/Social and Cultural Planning Office of the Netherlands. (English summary available on: 〈http://www.scp.nl/boeken/cahiers/cah156/uk/samenvatting.htm〉).

Steg, L., 2008. Promoting household energy conservation. Energy Policy 36, 4449–4453.

Steg, L., Dreijerink, L., Abrahamse, W., 2005. Factors influencing the acceptability of energy policies: testing VBN theory. Journal of Environmental Psychology 25 (4), 415–425.

Stern, P.C., 2000. Toward a coherent theory of environmentally significant behaviour. Journal of Social Issues 56, 407–424.

Tietenberg, T., 2000. Environmental and Natural Resource Economics, Colby College.

UK Energy Research Center, 2007. The Rebound Effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency, Download at: 〈www.ukerc.ac.uk/Downloads/PDF/07/0710ReboundEffect/0710ReboundEffectReport.pdf〉.

Varian, H.R., 2003. Intermediate Microeconomics, A Modern Approach. Norton & Company, New York.

Wackernagel, M., Rees, W., 1997. Perceptual and structural barriers to investing in natural capital: economics from an ecological footprint perspective. Ecological Economics 20 (1), 3–24.