A Meta-Analysis of Bottom-Up Ex-Ante Energy Efficiency Policy Evaluation Studies

Luis Mundaca & Lena Neij

International Institute for Industrial Environmental Economics at Lund University, Sweden

ABSTRACT

Energy efficiency ex-ante policy evaluation is commonly, but not exclusively, concerned with the simulation and modelling of policy instruments and resulting technological change. Using the residential sector as case study, the paper provides a meta-analysis of models and modelling exercises and scrutinise their relevance for the field of energy efficiency policy evaluation. The methodology of study is based on: identification of modelling methodologies, selection of case studies, and cross-case analysis. We identify four types of ex-ante methodological modelling categories: simulation, optimisation, accounting and hybrid models. The analysis shows that modelling exercises have impact evaluation as their main research goal. Market and behavioural imperfections are often not explicitly captured and sometimes the use of implicit discount rates is identified to address this critical issue. Regarding modelled policy instruments, the majority of the cases focus on regulatory aspects (e.g. minimum performance standards, building codes). For the rest, evaluations focus on economically-driven policy instruments which are represented through technical factors and costs of measures. Informative policy instruments were identified as being much less modelled. Regarding modelling outcomes, studies are very context-specific so no generalisations can be made. The findings confirm some of the criticism and flaws related to bottom-up energy-economy modelling tools. At the same time, the study stresses that, albeit imperfectly, well-formulated energy modelling tools provide valuable frameworks for organising complex and extensive end-use data. Findings strongly suggest that there is no single-best method to evaluate (residential) energy efficiency policy instruments. Potential research areas to further advance energy-economy models are identified.

Introduction

The importance of energy efficiency policy in the context of sustainable development has re-gained political momentum (Goldemberg and Johansson, 2004; Metz et al., 2007). Recent years have seen highly volatile oil prices, increased awareness of the need for energy security, and growing energy-related environmental problems—including the threat of human-induced climate change. All these factors are contributing to a re-assessment of society’s energy use (Jochem et al., 2000; Metz et al., 2007). A growing body of evidence shows that increased energy efficiency can benefit both society and the environment (IAC, 2007; Jochem et al., 2000; Laponche et al., 1997).[1] Thus, ever-increasing attention has been given to public policy in providing more aggressive and effective policies to induce technological change and reduce energy demand sustainably.

In the above-mentioned context, policy evaluation research is commonly, though not exclusively, concerned with the bottom-up simulation and modelling of different energy efficiency policy instruments to induce technological change. The main function of bottom-up models is to describe and allow the examination of the current and future competition of technologies in detail; by showing different technology prospects and resulting economic and environmental impacts (Hourcade *et al*., 2006; Jaccard

---

[1] Efficiency improvements can reduce atmospheric pollution; lessen negative externalities resulting from energy production; boost industrial competitiveness; generate employment and business opportunities; improve the housing stock and the comfort level of occupants; enhance productivity; increase security of supply; and contribute to poverty alleviation.

et al., 1996).[2] In fact, bottom-up modelling tools have historically provided useful policy insights in aspects such as competition of demand-side energy technologies, end-use energy efficiency potentials, and fuel substitution and related atmospheric emissions; among others (e.g. Metz et al., 2007; Scheraga, 1994). In past decades, we have seen an increased use of bottom-up models to evaluate ex-ante the performance of energy efficiency policy instruments. The use of these models for energy efficiency policy evaluation has gained widespread recognition at all levels of policy-making. However, the growing complexities of energy systems, environmental problems and efficient-technology markets are driving and testing most conventional bottom-up modelling tools to their limits. There is also growing concern among policy makers and analysts regarding representation of consumers' technological preferences and policy aspects in energy-economy models (Laitner et al., 2003; Munson, 2004; Worrell et al. 2004). Furthermore, there is still limited detailed literature on the development and use of bottom-up energy models and corresponding assessments addressing energy demand and policy aspects to increase the energy efficiency in buildings (cf. Levine et al., 2007).

Using the residential sector as case study, the objective of this paper is to provide a critical review of bottom-up models and corresponding modelling exercises and scrutinise their relevance for the field of energy efficiency policy evaluation. The paper attempts to offer a comprehensive and updated examination and discussion of the conceptual and modelling aspects that are used to evaluate energy efficiency policy instruments targeting the residential sector. Numerous models were reviewed and modelling studies that focus on energy efficiency policy instruments for the household sector were analysed. To address the objective, the following questions were chosen:

- What bottom-up energy-economy modelling tools simulate household energy demand? Which ones were specifically built to analyse energy use and energy efficiency? What are the modelling methodologies embedded in these models?

- What is the main purpose of evaluation studies addressing energy efficiency in the household sector?

- What decision-making frameworks in the energy models determine technology choice?

- What are the modelling approaches for representing market barriers and energy efficiency policy instruments?

The research called for data to be collected from a variety of sources to approximate objectivity and reduce uncertainty. First, an extensive review was conducted of model documentation, peer-reviewed material, books and grey literature (project reports, workshop/seminar presentations). Interviews and personal communications with model developers and modellers played an important role during the research. This is because literature on certain aspects, such as model documentation and data implementation guidance was either limited or not readily accessible. Semi-structured interviews, based on a protocol, were carried out. The objective was to obtain key insights and background information about models and to discuss specific topics in detail. The interviews addressed aspects related to: (i) the model under analysis; (ii) technology-choice issues; and (iii) policy analysis.

For the analysis of modelling studies as such, more than 20 case studies were analysed in which the household sector was fully or partly addressed. The cases were randomly chosen based on a literature review which entailed the following selection criteria: i) availability and accessibility of data/information; ii) applicability to the household sector; iii) recent or updated information; iv) material that has undergone some kind of peer review process.

---

[2] On the other hand, the main function of top-down models is to examine the impacts of policy instruments in relation to employment, competitiveness and public finances (Hourcade *et al.*, 2006)

Conceptual Analytical Framework

This section aims to briefly provide a variety of conceptual considerations related to the aspects investigated. As in any research, we faced the challenge of making conceptual choices for framing our analysis. To begin with, in this paper the term *energy policy* as applied to the case of energy efficiency is employed here to refer to the sum of governmental actions and decisions addressing energy efficiency improvements and its present and future economic, environmental and social implications. Now the question is what are the measures or procedures that governments use to exercise their power through public policy. The answer lies in policy instruments (see more below).

Regarding *policy evaluation* as such, we understand that it is an applied area of the discipline of evaluation (Scriven, 1991). According to Dye (1976:95), policy evaluation is "the study of policy impacts". Dunn (1981) notes that evaluation is the activity of applied social science dealing with multiple methods of examination and arguments that support policy-making to solve public problems. With a retrospective focus, Vedung (1997:3) refers to evaluation as the "careful assessment of the merit, worth and value of the administration, output and outcome of environmental policies". Mickwitz (2003) takes Vedung's concept but also includes the ex-ante dimension of evaluation. Fischer (1995) points out that policy evaluation can focus on the expected effects (ex-ante evaluation) or on empirical results (ex-post evaluation) of policies. We use the term energy (efficiency) policy analysis to refer to the evaluation of energy policy, in particular policy instruments.

According to Vedung (1998:21) "*policy instruments* are the set of techniques by which governmental authorities wield their power in attempting to ensure support and affect or prevent social change". Policy instruments are hereby understood to have the effect of guiding social considerations targeted by public policy, providing incentives or disincentives and information to subject parties (cf. Mont and Dalhammar, 2005). Howlett (1991) and Vedung (1998) discuss two approaches as far the classification of policy instruments is concerned: (i) the choice (or continuum) approach and (ii) the resource approach. The former is characterised as whether public authorities should intervene or not (i.e. intervention vs. non-intervention) and it acknowledges governmental inaction such that societal changes are left to market forces or civil society alone. The resource approach to classifying policy instruments seems much more appropriate to the research at hand, as it provides room for market-based mechanisms and excludes non-policy intervention. Based on Mont and Dalhammar (2005), Levine et al. (2007), van der Doelen (1998), and Vedung (1998), we classify energy efficiency policy instruments into three main categories (see beow).[3] We stress that the intention is not to discuss or clarify the distinction between different categories of policy instruments. We distance from the sometimes highly stylised debate about the taxonomy of policy instruments. We aim simply to stress what we see in practice: a portfolio of policy instruments.

Economic instruments provide financial incentives or disincentives that alter the economic conditions of subject target participants. In turn, the new economic conditions aim to trigger (or prevent) the change targeted by the instrument (e.g. higher environmental protection). Economic instruments in the field of energy efficiency include, for instance, taxes, tax credits, subsidies, tradable permit/certificate schemes, soft loans, rebate programmes and technology public procurement. They are often mandated by and/or implemented/supported through legal means.

Regulatory instruments refer to measures that involve the mandatory fulfilment of aspects by targeted participants. Through legislation, public authorities formulate laws that oblige various groups in society to attain certain targets or renounce to perform certain activities. Regulatory instruments applicable to the case of energy efficiency include, for instance, building codes, minimum energy performance standards (equipment, facilities, houses), mandatory energy audits and energy labelling of buildings. Legal penalties (e.g. in financial terms) may result in cases of non-compliance.

---

[3] Note that another resource-approach taxonomy of policy instruments comes from the environmental economics literature, in which the common typology of policy instruments differentiates between two types: (i) command-and-control and (ii) market-based instruments.

Informative instruments work through the provision of information or knowledge as crucial components in accomplishing or preventing social change. The rationale behind informative instruments is that market agents possess asymmetric information meaning they lack some of the knowledge necessary to reach the right decisions. For instance by means of persuasion or increased awareness, it is assumed that with the provision of the necessary information, people will act upon this and behave in a predictable manner. Informative instruments applicable to the case of energy efficiency include, for instance, communication campaigns, rating labelling of equipment, demonstration programmes, educational and advice centres and training programmes.

Policy evaluation can be focused on *outcomes* and/or *impacts*. In the reviewed literature, an 'outcome' is understood as the response to the policy instrument by subject participants (e.g. adoption of new technologies, development of new business plans, etc.). An 'impact' is understood to be the resulting changes generated by outcomes on society and the environment (e.g. energy consumption, health problems, etc.) (see e.g. EEA, 2001; Fischer, 1995; Hildén *et al*., 2002; Vreuls *et al.*, 2005). One has also bear in mind 'process evaluation' (i.e. addresses levers for improving policy implementation) and design evaluation (i.e. using theory-based approaches to improve policy design) (see e.g. Chen, 1990; Fischer, 1995; Rossi *et al*. 2004).

Finally, due to the fact that evaluation is also fundamentally normative in character, *evaluation criteria* (e.g. economic efficiency, cost-effectiveness, transaction costs) are advocated as a basis for normative judgements about any significant effect of public policy (see e.g Mickwitz, 2003; Bemelmans-Videc *et al.,* 1998).[4] In simple terms, the criteria are evaluative standards that are the framework upon which a policy choice is judged and eventually made (see e.g. Chen, 1990; Mickwitz, 2003; Rossi *et al.*, 2004). Note that evaluation criteria do not directly judge the policy instrument as such but the expected or actual outcomes and impacts (i.e. effects).[5]

Findings

Identified modelling methodologies and corresponding models

Following Heaps (2002), Hourcade et al. (2006), Jaccard et al. (1996) and Worrell et al. (2004), four methodological categories of bottom-up energy-economy models were identified: (i) simulation, (ii) optimisation, (iii) accounting and (iv) hybrid models. They are described as follows.

Simulation models provide a descriptive quantitative illustration of energy production and consumption based on exogenously determined scenarios. The methodological approach represents observed and expected microeconomic decision-making behaviour that is not limited to an optimal result. These models try to replicate end-user behaviour for technology choice considering different drivers (e.g. income, energy security, public policies and endogenous energy prices). Thus, and despite that economic data can be of high significance, drivers are often linked to other aspects of energy systems (e.g. CO2 constraints). Under this taxonomy we found, for instance, the following models: Residential End-Use Energy Planning System (REEPS); Mesures d'Utilisation Rationnelle de l'Energie (MURE); and the National Energy Modelling System - Residential Sector Demand Module (NEMS-RSDM).[6]

Optimisation models are prescriptive by definition. They attempt to find least-cost solutions of

---

[4] Whereas *economic efficiency* refers to the maximisation of the difference between total social benefits and costs (i.e. maximise net social benefits); *cost-effectiveness* focuses on whether an energy saving target can be achieved at the lowest possible cost (Tietenberg, 2006).

[5] As Bardach (2005) correctly points out, it is common in public policy to say that policy instrument A is better than B—providing a sort of binary appraisal for a 'yes' or 'no' judgement. However, this approach can sometimes create misleading conclusions, so it is suggested that the correct formulation should refer to 'policy instrument A being very likely to attain the (desired) effect X, which we (e.g. policy makers) judge to be best for the society, making A the preferred alternative (see Bardach, 2005).

[6] A detailed description of all reviewed models is given in Mundaca and Neij (2009).

technology choices for energy systems based on various policy and market constraints. Based on the rational model of consumer behaviour, the allocation of energy supplies to energy demands is based on minimum life cycle technology costs at given discount rates and determined by an optimisation approach (linear programming). Under this taxonomy we found, for instance, the following models: Market Allocation (MARKAL) model generator; PRIMES Energy System Model; and the Model of Energy Supply Strategy Alternatives and their General Environmental Impacts (MESSAGE).

Accounting models describe the physical flows of energy. They often use spreadsheets to arrange in tabular form the efficiency in a prescriptive (e.g. impacts from high-efficient technology adoption by end-users) or descriptive manner (e.g. portfolio of technologies resulting from one or various policy instruments). Instead of identifying the behaviour of market agents and resulting outcomes in an energy system, accounting models require modellers to determine and introduce outcomes beforehand (e.g. technology adoption rates). Under this taxonomy we found the following models: Long-Range Energy Alternatives Planning (LEAP); National Impact Analysis (NIA); Bottom-Up Energy Analysis System (BUENAS); Model for Analysis of Energy Demand (MAED); and the Policy Analysis Modelling System (PAMS).

Table 1: General features of reviewed bottom-up energy-economy models

Energy-economy model	Methodological approach	Household technology representation	Technology-choice decision framework
BUENAS	Accounting, simulation	Explicit	User-defined
LEAP	Accounting, simulation	Explicit/stylistic	User-defined
MAED	Accounting	Explicit	Socio-economic and demographic factors
MARKAL	Optimisation, equilibrium	Explicit	Least-cost
MESSAGE	Optimisation, equilibrium	Stylistic	Least-cost
MURE	Simulation	Explicit	User-defined
NEMS	Simulation, optimization, equilibrium	Explicit	Least-cost
NIA	Accounting	Explicit	User-defined/shipment- model
PAMS	Accounting, simulation	Explicit	User-defined/shipment model
PRIMES	Optimisation, equilibrium	Explicit	Least-cost
REEPS	Simulation	Explicit	Ownership, efficiency, use & equipment size sub-models

Hybrid models basically merge different methodological components from the above-mentioned types of models.. Some of the reviewed models fall into this taxonomy. For instance, NEMS combines optimisation, simulation (for each demand sector) and accounting components that provide a general equilibrium system. Likewise, LEAP, PAMS and BUENAS combine elements of simulation and accounting models. In addition, some models (MARKAL, MESSAGE, NEMS and PRIMES) can also be integrated with top-down or general equilibrium models. That is, endogenous relationships between the economy and energy system take place instead. For instance in MESSAGE, price-driven energy demands are calculated with MESSAGE-MACRO, which is a macroeconomic top-down module that gives hybrid equilibrium features to the modelling (Messner and Schrattenholzer, 2000).

In summary, all identified models are driven by economic and engineering principles. All the reviewed models can be prescriptive or descriptive in nature. In terms of technology choice, most models use techno-economic data as main criteria. On the contrary, technology choice in accounting models is user-defined (i.e. exogenous).

Table 2: Reviewed modelling studies addressing energy efficiency policy evaluation

Energy-economy model	Policy instrument(s) analysed for the household sector	Geographical focus	Reference(s)
BUENAS	Minimum energy efficiency performance standards and labelling endorsement for appliances, lighting, and HVAC equipment	Global	McNeil *et al.* (2008, 2009)
LEAP	DSM and IRP programmes (e.g. labelling, audits, technology transfer, financial incentives) targeting household appliances	Ecuador	Morales and Sauer (2001)
LEAP	Subsidy removal (on kerosene); subsidies on biogas, solar water heater and solar cooker; energy labelling and performance standards for household appliances	India	Kadian *et al.* (2007)
LEAP	Minimum performance standards and labelling on household appliances, building codes, energy management training and awareness raising campaigns	China	Yanbing and Qingpeng (2005)
MAED	A variety of policy instruments are assumed, such as performance standards and labelling for appliances and support for micro renewable energy technologies)	Syria	Hainoun *et al.*, 2006
MARKAL	Per capita energy consumption cap and CO_2 emission targets	Switzerland	Schulz *et al.* (2008)
MARKAL	EU-wide Tradable ‘White Certificate’ scheme	EU-15 + Iceland, Norway and Switzerland	Mundaca (2008)
MARKAL	CO_2 emission reduction targets	UK	Kannan and Strachan (2009)
MARKAL	DSM measures, including different energy labelling classes for cloth washing, drying machines, refrigerators, freezers and dish washers (including A to E consumption classes)	Croatia	Božić (2007)
MURE	Building codes, minimum performance standards and product labelling for heating equipment and household appliances	Germany	Eichhammer (2000)
MURE	Building codes, minimum performance standards and product labelling for heating equipment and household appliances	Italy	Faberi and Enei (2000)
MURE	Building codes, minimum performance standards and product labelling for heating equipment and household appliances	UK	Fenna (2000)
NEMS	Tax credits foe efficient technologies (e.g. electric heat pumps and air conditioners)	USA	Richey (1998), Kommey (2000)
NEMS	Tax credits for building upgrades, installation of new equipment and appliances; minimum performance standards (e.g. furnaces, furnace fans, torchiere lamps, ceiling fan light kits) and building codes	USA	EIA (2005)
NIA	Minimum energy efficiency performance standards for residential furnaces and boilers	USA	DOE-EERE (2007)
NIA	Minimum energy efficiency performance standards for clothes washers	USA	DOE-EERE, 2000
PAMS	Minimum energy efficiency performance standards for refrigerators	Central America	McNeil *et al.* (2006)
PAMS	Labelling endorsement programme for colour TVs	India	Iyer, 2007
PAMS	Minimum energy efficiency performance standards for refrigerators	Ghana	Van Buskirk *et al.*, 2007
REEPS	Minimum efficiency standards based on the 90-75 American Association of Heating, Refrigeration, and Air Conditioning Engineers (ASHARE) voluntary thermal designs	USA	Cowing and McFadden (1984)
REEPS	No policy instruments as such are explicitly modelled. Instead, the modelling exercise analyses current and projected future energy use by end-use and fuel for the US residential sector. Exogenous inputs for baseline development include minimum efficiency performance standards.	USA	Koomey *et al.* (1995)

Evaluation focus of modelling studies

Different case studies (21 in total) were used to analyse how the reviewed models have been used to evaluate policy instruments for energy efficiency in the household sector (see Table 2).[7]

First, we found that the research goal of modelling studies is to demonstrate the use of a given modelling tool to forecast or simulate energy efficiency technologies, such as the MURE and PAMS models. For instance the studies carried out by Eichhammer (2000), Fenna (2000) and McNeil et al. (2006) are quite explicit in this regard. Within the context of cross-model evaluation as such, we found the study carried out by Cowing and McFadden (1984). This focuses on a detailed comparative evaluation between the REEPS model and the Oak Ridge National Laboratory model.[8]

Secondly, most of the reviewed case studies have policy 'impact' evaluation as their research goal. Research goals in relation to impact policy evaluation range from the quantification of GHG emission reductions as a result of increased energy efficiency, to the study of CO_2 emission reductions and resulting economic implications, including the description of future energy use and energy efficiency potential by end-use. For instance, the study carried out by Kadian et al. (2007) with the LEAP model analyses the energy use and quantifies associated emission from the household sector in Delhi, India. Likewise, Morales and Sauer (2001) focus on GHG mitigation for the household sector in Ecuador also using the LEAP model. The modelling exercise carried out by Schulz et al. (2008), with MARKAL, assesses intermediate steps and corresponding implications for achieving the 2000 Watts society in Switzerland.

Thirdly, and building upon impact evaluation, the majority of the case studies focus on the explicit evaluation purpose to assess one or more energy efficiency policy instruments and related policy scenarios. For instance, the modelling work done by Yanbing and Qingpeng (2005) with LEAP focuses on the impacts related to the implementation of different policy instruments targeting the Chinese building sector. Using MARKAL, the research goal of Bozic (2007) is to evaluate the impacts of DSM measures and labelling programme for a group of islands in Croatia. All the reviewed modelling exercises carried out with NEMS also entail the explicit research goal to analyse a variety of policy instruments in the building sector, such as taxes, performance standards and building codes. Likewise, the reviewed modelling exercises using NIA concentrate explicitly on the research goal to evaluate minimum performance standards. Using PAMS, van Burskirk et al. (2007) focus also on standards and Iyer (2007) on labelling endorsement programmes.

In summary, when analysing the research goals of the case studies, our findings are consistent with the fact that the limited number of energy efficiency policy evaluation studies has traditionally targeted the narrow, albeit challenging area of impacts, in terms of energy savings, emission reductions and energy savings costs (cf. Boonekamp, 2005; Harmelink et al., 2007; SCR et al., 2001; Swisher et al., 1997).

Treatment of market barriers

Market imperfections are not explicitly addressed in the reviewed modelling exercises. We find that, to some extent, they are incorporated through high discount rates (see more below). One can assume that market imperfections are at least partly taken into account in the historical techno-economic data used for setting the baseline (e.g. low or limited market share of efficient-technologies). This is because, for instance, the work done with the NEMS model considers that "the reference case projections are business-as-usual trend forecasts, given known technology, technological and demographic trends, and current laws and regulations" (EIA, 2005:9). The modelling work done with MURE considers that a given scenario "represents the continuation of current autonomous trends with no additional support in

---

[7] Note that for the case of PRIMES, no modelling study addressing energy efficiency policy in the household sector was found.

[8] The latter is not addressed under our study.

terms of legislation, grants or information campaigns". The work done by Kadian et al. (2007:6200) assumes in the business-as-usual scenario that "historical trends will continue". However, no details are often given regarding those specific and existing market imperfections or how previous market imperfections have been already reduced or overcome due to the existing portfolio of policy instruments. A more explicit attempt is made by Morales and Sauer (2001), in which several market barriers are mentioned. These include lack of information and high initial cost of technologies. However, no further details are given and the study states that "no substantial changes will result from specific measures or introduction of energy conservation programs" (Morales and Sauer, 2001:51-52).

Market imperfections are sometimes also represented through an assumed high (implicit) discount rate. This approach departs from the fact that there is extensive literature showing that consumers use high implicit discount rates (100% or 200% and even much higher), hindering the adoption of efficient technologies (see Gately, 1980; Hausman, 1979; Howarth and Sanstad, 1995; Jaffe and Stavins, 1994a, 1994b; Lutzenhiser, 1992; Metcalf, 1994; Ruderman et al., 1987; Train, 1985).[9] Consequently, high implicit discount rates cause greater financial hurdles to be set for efficient technologies than for conventional ones. Once policy instruments are modelled, high discount rates are then lowered to reflect 'real' or 'social' rate levels to mimic household preferences for energy-efficient technologies in positive response to policy instruments; such as information campaigns and certification programmes. However, this modelling approach has been criticised because of numerous limitations to infer inefficient behaviour from such high implicit discount rates. These include omitted transaction costs that householders are likely to bear; miscalculation in equipment costs and/or energy savings; and need for compensation for risk (see e.g. Huntington, 1994; Jaffe and Stavins, 1994a, Sutherland, 1991). Furthermore, it is argued that household investments in energy-efficient appliances might correctly use high discount rates because these investments are illiquid (e.g. retrofits) and, for example, in the case of home insulation have long payback periods (Andersson and Newell, 2002; Sutherland, 1991).

On the other hand, the use of high implicit discount rates to represent market imperfections should be compared to the modelling approach of using 'real' or 'normal' discount rates – as also identified in some modelling exercises. The reviewed cases indicate that the real or private discount rates applied are in the range of 3-20%. For instance, the PRIMES model uses a discount rate of 17.5% for the household sector and the NIA tool uses discount rates of 3 and 7 percent to assess minimum energy efficiency performance standards.[10] Once the future costs of capital, operation and maintenance, fuel consumption, abatement control equipment, etc. are calculated and translated into present values using real discount rates, many energy-efficient technologies emerge as profitable and attainable under different policy scenarios. However, this modelling approach has been also criticised because of the critical assumptions of 'well-defined consumer preferences' and 'unbounded rationality'.[11] Consequently, the use of 'real' discount rates generates (over) optimistic but unrealistic penetration rates for efficient technologies (Bataille et al., 2006; Jaffe and Stavins, 1994a).

In summary, findings strongly suggest that the explicit or implicit assumption that market imperfections are considered in historical data is part of the evaluation challenge itself. Even though high implicit discount rates and related causes have been the most common mentioned evidence for the non-adoption of efficient technologies (Huntington, 1994), the debate regarding the use of appropriate discount rates in modelling exercises continues. More research is needed on discount rates to mimic consumer behaviour and market imperfections.

---

[9] Implicit discount rates are often estimated by comparing future savings in operating costs with initial capital or purchase costs (see e.g. Hausman 1979; Train 1985; Huntington, 1994).

[10] To assess the costs and benefits of performance standards, PAMS uses real discount rates for the determination of cost-benefit and social discount rates for the evaluation of national impacts. Both rates are user-defined; however, consumer discount rates are parameterized by PAMS according to the Human Development Index. In addition, the default national discount rate is set at 10 percent.

[11] Note that discount rates are not used in BUENAS as there is no financial and economic analysis.

Modelled policy instruments

In terms of identified policy instruments being evaluated, the majority of the cases focus, either implicitly or explicitly, on minimum performance standards and building codes (see Table 2). One explanation for this lies in the fact that some of the reviewed models were specifically developed for such purpose (e.g. PAMS, NIA, BUENAS). In the analysed modelling studies, they capture most of the research interest. A possible explanation is the relatively simple modelling approach needed to do so. The way the modellers mimic these policy instruments is mainly through modification of efficiency ratios, technology market availability and penetration rates. For instance in the REEPs model, efficiency standards can be modelled by restricting the 'legal' and 'market' availability of given technologies (through exogenous inputs for 1990-2030). In relation to market penetration rates, we found cases in which a 'shipment model' is used to endogenously forecast estimates of sales and market share by product class in the presence or absence of policy instruments (NIA and PAMS models). Technology shipments are forecasted usually as a function of capital costs and are driven by fuel costs and projected housing stock.

Next to performance standards and building codes, the majority of the policy instruments being modelled are economically-driven in nature. This seems to be consistent with the historical development of energy efficiency policy in general, where we have witnessed a substantial use of economic instruments, such as rebates, subsidies, taxes and soft loans (Vreuls et al., 2005). Taxes and subsidies dominate the area of economic policy instruments being modelled. In general, the identified modelling approach for these economic instruments involves the effects on capital and operating costs and the resulting adoption rates. For instance in the NEMS and MARKAL models, rebates can be modified at the equipment investment level. Given the economic-engineering orientation of the reviewed models, this seems to be the simplest modelling approach.

An exception can be found in Richey (1998), in which a tax rebate is assessed using a more elaborated modelling approach. The consumer response to a tax rebate and resulting shipments is divided into two components: (i) the 'announcement effect', which represents the consumer response to the tax rebate, independent of the rebate level; and (ii) the 'direct price effect', which represents the consumer response to the rebate level as such. In addition to the 'announcement' and 'direct price' effects, the approach includes a 'progress ratio' (or so-called 'increased production experience effect') that is used to forecast decreases in future capital costs relative to currently installed costs data due to increased production experience.

Informative policy instruments were identified as being much less modelled compared to economic ones. In some reviewed cases, non-economic/regulatory instruments, such as awareness raising campaigns and labelling endorsement programmes are addressed (see Kadian et al., 2007; Hainoun et al., 2006; Yanbing and Qingpeng, 2005). However, a lack of explicit modelling methodological details prevents any analysis and judgement in this regard. In other cases, the modelling approach is simplified to the extent that technology adoption targets driven by these policy instruments are based on expert knowledge (see e.g. McNeil et al., 2008).

When it comes to the determinants used to model the identified policy instruments, the majority of the reviewed case studies address policy instruments through technical factors and costs of measures for energy efficiency improvements. The so-called 'policy handles' in REEPS include a variety of economic and engineering factors, among them energy prices; functional forms and coefficients for choice equations; pre-failure replacement/conversion decision algorithms; restrictions on legal or market availability of specific technologies; and modification of the purchase price and efficiencies of specific technologies. Similarly, the reviewed modelling exercises with MARKAL reveal the usage of technical and economic parameters, such as efficiency ratios, O&M costs, emission factors, energy prices, capital costs, discount rates, and technology market shares (more details below). Higher efficiency ratios compared to the baseline are commonly used across the reviewed case studies as another user-defined parameter to model policy-driven efficient technologies. Yanbing and Qingpeg (2005) used high efficiency ratios for HVAC systems (relative to the base case scenario) in LEAP as key technical variable to model efficiency improvements in the Chinese building sector. Similarly, all the case studies related to MURE use lower energy consumption values to demonstrate the use of the model to assert the impact of numerous policy-driven technologies. For instance, for more efficient policy-driven space heating, the following parameters were modified: (i) average u-value of new buildings; (ii) average u-value of walls; and (iii) average u-value of windows (see Eichhammer, 2000; Faberi and Enei, 2000; Fena, 2000).

In summary, the majority of the cases studies focus on regulatory policy instruments, such as minimum performance standards and building codes. For the rest, evaluations focus on economically-driven policy instruments; which are represented through technical factors and costs of measures for energy efficiency improvements. The dominance of economic and engineering determinants for technology choice gives little or no room for the representation of informative policy instruments.

Estimated energy saving potentials

When it comes to modelling outcomes in relation to energy saving potentials, we focused on those studies in which policy scenarios are explicitly compared to a baseline case (see Figure 1). Other cases (e.g. single-technology specific improvements due standards; gained savings per technology with no comparison to baseline) were omitted.

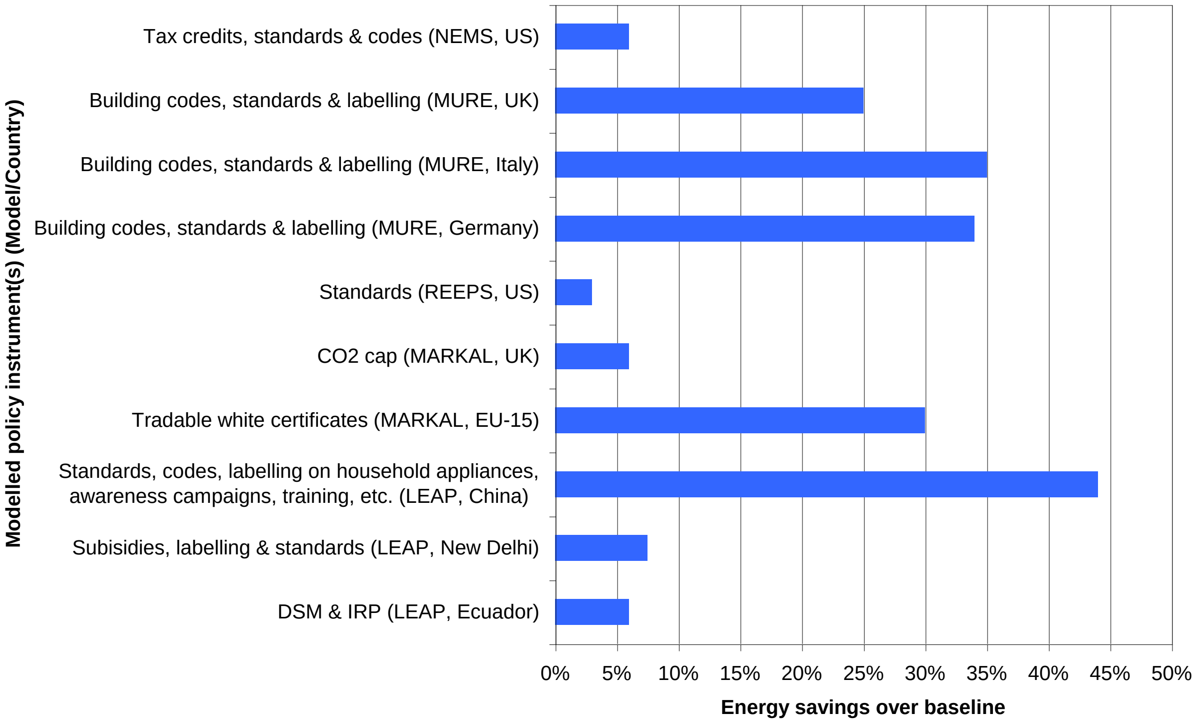

Figure 1: Estimated energy saving potentials over base case scenarios

Figure 1 shows estimated energy saving potentials (upper bounds) for 10 (out of 21) of the reviewed case studies that use different bottom-up models applied to different geographical scopes. However, studies are very context-specific so no generalisations can be made. For instance, factors explaining differences are the time horizon under analysis, the end-use coverage of the model, the type of technology and corresponding efficiency ratios under examination; among others. Regardless of the geographical areas and modelled policy instruments, potentials vary largely. This can be largely explained due to different sets of assumptions, modelling methodologies, technological databases, research frameworks, which make resulting modelling outcomes very case- and context-specific. Furthermore, sometimes figures refer to the combined energy saving potential between the commercial and residential sector (i.e. building sector) – like the work done for EU-15 with MARKAL and China with LEAP. Therefore, a cross-case analysis is difficult to perform and figures must thus be taken with due caution.

One can observe that most of the studies estimate potentials based on the assessment of a mix of policy instruments, in particular building codes combined with minimum performance standards. In certain cases (e.g. modelling studies for China and Ecuador) it is not possible to ascertain the contributions made by each policy instrument and high uncertainty about de-linking estimated potentials remain.

Discussion

The *limited number of determinants driving technology choice* in the reviewed models confirms the long-standing criticism of bottom-up modelling tools. Whereas household decisions addressing energy-efficient technologies are far more complex and depend on multiple parameters, the reviewed case studies confirm the dominance of economic drivers assumed to be affecting those decisions. Undoubtedly, the number of determinants affecting household's choices regarding efficient technologies is extensive (Moukhametshina, 2008). For instance, a combination of factors, including design, comfort, brand, functionality, reliability and environmental awareness is likely to influence consumers' decisions regarding energy-efficient equipment.[12] Those determinants can be relevant to different types of technologies (Lutzenhiser, 1993; Stern, 1986; Uitdenbogerd, 2007). It can be safely argued that a great variety of determinants that frame and drive consumer's energy-related decisions regarding technology choices is needed to further enhance modelling tools for energy use scenarios and support energy efficiency policy evaluation. The key question now is to what extent a better representation of empirically estimated determinants of choice is actually feasible in energy modelling. Which determinants are more workable than others in improving such tools?

The *model of rational choice* (i.e. unbounded rationality, clear preferences) seems to dominate much of the conventional energy-economy modelling tools (see also Greening and Bernow, 2004). As revealed by the cases studies, most conventional bottom-up models usually assume perfect information and individuals with well-defined preferences that make decisions to maximise them. Consequently, they can be criticised for offering an unrealistic portrait of investment decision-making processes (Hourcade et al., 2006). From our review of case studies, one can argue that the modelling and evaluation of policy instruments addressing consumer behaviour through informative policy instruments remains a challenge for the modelling community. The dominance of economic and engineering determinants for technology choice embedded in the reviewed models gives little room for the representation of these specific policy instruments.

The traditional but narrow *single-criterion evaluation approach based on cost-effectiveness* seems to dominate the evaluation studies. In contrast, empirical research suggests that the cost-effectiveness criterion is inappropriate to comprehensively addressing the attributes of energy (efficiency) policy instruments and the institutional and market conditions in which they work (Greening and Bernow, 2004; Gupta *et al.*, 2007). Besides the specific integration of co-benefits into evaluation studies (i.e. attempt to comprehensively approach economic efficiency), the use of other evaluation criteria is further justified when policy instruments explicitly address multiple policy objectives (e.g. social, environmental, economical and technical). In public policy, we very often see that one policy objective can be maximised only at the expense of other(s). Thus, a multi-criteria evaluation framework can help to better comprehend the complexity of the instruments' effects and to identify inevitable trade-offs. Results from broad evaluation studies can provide an extensive foundation for balanced discussions and may contribute to improved communication among stakeholders.

---

[12] For an extensive and recent literature review see Moukhametshina, (2008).

Finally, *policy instruments do no function in isolation*, so findings stress that it is necessary to better analyse the interaction among policy instruments when they are modelled as a whole. This is critical in order to identify synergies and avoid overlaps. It is also relevant to consider how the 'additionality' of measures implemented under a given policy instrument can be ensured if a mix of policy instruments exists. In turn, another challenge involves de-linking the effects (impacts and outcomes) of different energy efficiency policy instruments. It is recognised that disentangling the contributions made by different policy instruments is a complex and challenging task for the evaluator (see e.g. Chen, 1990; Rossi et al., 2004). Neglecting the interdependence of policy instruments can lead to biased evaluation results. The development of credible baselines, causal-loop relationships and specific (impact and outcome) indicators can support the evaluation in distinguishing the specific contributions made by each policy instrument.[13]

Conclusions

It is concluded that the limited number of residential ex-ante energy efficiency policy evaluation studies has traditionally targeted the narrow, albeit challenging, area of impact evaluation of mostly regulatory and economic policy instruments. The findings confirm some of the criticism and flaws related to bottom-up energy modelling tools. The modelling approaches depart from the critical assumption that we can mimic policy instruments using techno-economic criteria as the primary driver for decision making and corresponding household technology choice. However, the study stresses that, albeit imperfectly, well-formulated energy modelling tools provide valuable frameworks for organising complex and extensive end-use data. In addition, some of the modelling tools reviewed in our study were never designed to analyse energy efficiency policy instruments in particular (e.g. LEAP, MARKAL, PRIMES). Therefore, it is not surprising that they may be inadequate to the energy efficiency community.

At the risk of oversimplifying, the findings stress the need to continuously scrutinize the capability of the modelling tools in relation to the appropriate policy evaluation questions. Our study shows that many aspects related to energy efficiency policy are testing models to their models. In the light of the research findings, we identify different research areas that could potentially further advance the appropriateness of bottom-up models from a multidisciplinary energy policy evaluation perspective:

- When it comes to modelling approaches, efforts could be devoted to develop explicit methodologies to model and represent energy efficiency policy instruments; need to better translate modelling outcomes into policy language; complement modelling studies with other qualitative and quantitative methods of research for policy design and instrument choice and; complement modelling outcomes with an agent-based model.

- Regarding techno-economic and environmental issues, one could explore the integration of co-benefits of increased energy efficiency; introduction of transaction costs; synergies among modelling tools to further improve cost-revenue specifications; accounting for and use experience curves of efficient technologies.

- In terms of behavioural aspects, findings suggest the improvement of microeconomic decision-making frameworks and a larger representation of determinants for technology choice; further analysis of the usefulness of using discount rates to mimic consumer behaviour and market imperfections and; focus on outcome evaluation.

- As far policy considerations are concerned, further research could address a better representation of the portfolio of policy instruments; development of alternative and credible counterfactual

---

[13] See Neij and Åstrand (2006) for examples of outcome indicators applicable to new energy efficient technologies.

situations; support from multi-criteria evaluation studies and; accounting of administrative costs. Note that by no means we argue that these suggested research areas can improve models by default. On the contrary, as in any rigorous research work, to ascertain their usefulness, these research areas need to be further developed, implemented and duly evaluated and scrutinized.

The findings also stress the need and significance of ex-post policy evaluation. Empirical evaluation can feedback not only the design and functioning of policy instruments, but also provide critical information to improve modelling tools (e.g. in relation to achievable impact, transaction costs and market imperfections). It can also provide useful lessons about positive (or negative) feedback mechanisms among instruments (e.g. synergies among building codes and performance standards).

Even if we use sophisticated modelling tools, there are inherent complex challenges to overcome and that demand new foundations for future advancements and support from other research methods and disciplines. Our analysis strongly suggests that there is no single best method to evaluate (residential) energy efficiency policy instruments. A portfolio of research methods (e.g. surveys, agent-based modelling, cost-benefit analysis, intervention theory, Delphi method, interviews, statistical analysis, hybrid models) can allow us to better understand the broad effects, attributes and complexities of energy efficiency policy instruments. Whereas a comprehensive policy evaluation can sometimes be a complex, challenging and resource-intensive process, it is a doable exercise that provides a continuous learning process.

References

Anderson, S. T. & Newell. R., G. (2002). *Information programs for technology adoption: The case of energy-efficiency audits. Discussion paper 02-58. Resources for the Future.* Retrieved May 2007, from www.rff.org/Documents/RFF-DP-02-58.pdf

Bataille, C., Jaccard, M., Nyboer, J. & Rivers, N. (2006). Towards general equilibrium in a technology-rich model with empirically estimated behavioral parameters. *The Energy Journal*, 93-112.

Bemelmans-Videc, M., Rist, R., & Vedung, E. (Eds.) (1998). *Carrots, sticks and sermons*. New Brunswick NJ: Transaction Publishers.

Boonekamp, P. (2005). *Improved methods to evaluate realised energy savings.* Utrecht University, Utrecht.

Bozic, H. (2007, 21-23 May). *Optimization of energy consumption and energy efficiency measures with MARKAL Model.* Paper presented at the International Conference on Clean Electrical Power - ICCEP '07, Capri, Italy.

Chen, H. T. (1990). *Theory-driven evaluations*. Newbury Park CA: Sage Publications.

Cowing, T. G. & McFadden, D. L. (1984). *Microeconomic modeling and policy analysis. Studies in residential energy demand*. Orlando, FL: Academic Press.

DOE-EERE (Department of Energy - Energy Efficiency and Renewable Energy). (2000). *Final technical rule support document: Energy efficiency program for consumer products - Clothes washers*: U.S. Department of Energy, Ernest Orlando Lawrence Berkeley National Laboratory & Arthur D. Little Inc.

DOE-EERE (Department of Energy - Energy Efficiency and Renewable Energy). (2007). *Technical support document: Energy efficiency program for consumer products: Energy conservation standards for residential furnaces and boilers*: U.S. Department of Energy, Ernest Orlando Lawrence Berkeley National Laboratory & Navigant Consulting Inc.

Dunn, W. N. (1981). *Public policy analysis*. Englewood Cliffs: Prentice-Hall.

Dye, T. R. (1976). *Policy analysis: What governments do, why they do it, and what difference it makes*. Alabama: The University of Alabama Press.

EEA (European Environment Agency). (2001). *Reporting on environmental measures: Are we being effective?* : European Environment Agency.

EIA. (2005). *Assessment of Selected Energy Efficiency Policies*: Energy Information Administration, U.S. Department of Energy. Washington D.C.

Eichhammer, W. (2000). *Best available technologies in housing - German case study*. Retrieved January 2009, from http://www.mure2.com/doc/Hh_d.pdf

Ellerman, D. A., Joskow, P. L., Schmalensee, R., Montero, J. P. & Bailey, E. M. (2000). *Markets for clean air - The US Acid Rain program*. Cambridge UK and New York: Cambridge University Press.

Faberi, S. & Enei, R. (2000). *Best available technologies in housing - Italian case study*. Retrieved January 2009, from http://www.mure2.com/doc/Hh_i.pdf

Fenna, G. (2000). *Best available technologies in housing - Case study UK*. Retrieved January 2009, from http://www.mure2.com/doc/Hh_uk.pdf

Fischer, F. (1995). *Evaluating public policy*. Belmont CA: Wadsworth Group.

Gately, D. (1980). Individual discount rates and the purchase and utilization of energy-using durables: Comment. *Bell Journal of Economics, 11*(1), 373-375.

Goldemberg, J., & Johansson, T. B. (Eds.) (2004). *World energy assessment - Overview 2004 update*. New York: UNDP.

Greening, L. & Bernow, S. (2004). Design of coordinated energy and environmental policies: Use of multi-criteria decision-making. *Energy Policy, 32*(6), 721-735.

Gupta, S., Tirpak, D., Burger, N., Gupta, J., Höhne, N., Ivanova-Boncheva, A., et al. (2007). Policies, instruments and co-operative arrangements. In B. Metz, O. Davidson, P. Bosch, R. Dave & L. Meyer (Eds.), *Climate Change 2007: Mitigation. Contribution of Working III to the Fourth Assessment Report to the Intergovernmental Panel on Climate Change.* (pp. 745-807). New York: Cambridge University Press.

Hainoun, A., Seif-Eldin, M. K. & Almoustafa, S. (2006). Analysis of the Syrian long-term energy and electricity demand projection using the end-use methodology. *Energy Policy, 34*(14), 1958-1970.

Harmelink, M., Harmsen, R. & Nilsson, L. (2007, June 4-9). *From theory-based policy evaluation to SMART policy design: Lessons learned from 20 ex-post evaluations of energy efficiency*. Paper presented at the European Council for an Energy Efficiency Economy (ECEEE) - Summer Study: Saving energy- Just do it!, La Colle sur Loup, France.

Hausman, J. A. (1979). Individual discount rates and the purchase and utilization of energy-using durables. *Bell Journal of Economics, 10*(1), 33-55.

Heaps, C. (2002). *Integrated Energy-Environment Modeling and LEAP*. Retrieved November 2007, from http://unfccc.int/resource/cd_roms/na1/mitigation/Module_5/Module_5_1/b_tools/LEAP/Training_Materials/LEAP_Slides.ppt.

Hildén, M., *et al.* (2002). *Evaluation of environmental policy instruments: A case study of the Finnish pulp and paper and chemical industries*: Boreal Environment Research.

Hourcade, J. C., Jaccard, M., Bataille, C. & Ghersi, F. (2006). Hybrid modeling: New answers to old challenges - Introduction to the Special Issue of The Energy Journal. *The Energy Journal*, 1-11.

Howarth, R. B. & Sanstad, A. H. (1995). Discount rates and energy efficiency. *Contemporary Economic Policy, 13*(3), 101-109.

Howlett, M. (1991). Policy instruments, policy styles and policy implementation: National approaches to theories of instrument choice. *Policy Studies Journal,* 19(2): 1-21.

Huntington, H. G. (1994). Been top down so long it looks like bottom up to me. *Energy Policy, 22*(10), 833-840.

IAC (InterAcademy Council). (2007). *Lighting the way. Toward a sustainable energy future.* Amsterdam: InterAcademy Council.

Iyer, M. (2007). *Techno-economic analysis for labeling color televisions in India*. Retrieved January 2009, from http://ies.lbl.gov/drupal.files/ies.lbl.gov.sandbox/CTV%20Labeling%20Analysis%20Report%20Feb%202008%20-%20Final.pdf

Jaccard, M., Bailie, A. & Nyboer, J. (1996). CO2 emission reduction costs in the residential sector: Behavioral parameters in a bottom-up simulation model. *The Energy Journal, 17*(4), 107-135.

Jaffe, A. B. & Stavins, R. N. (1994a). The energy-efficient gap: What does it mean? *Energy Policy, 22*(10), 804-810.

Jaffe, A. B. & Stavins, R. N. (1994b). The energy paradox and the diffusion of conservation technology. *Resource and Energy Economics, 16*(2), 91-122.

Jochem, E., *et al.* (2000). Energy end-use efficiency. In UNDP (United Nations Development Programme), UNDESA (United Nations Department of Economics and Social Affairs), & WEC (World Energy Council) (Eds.) *World energy assessment - Energy and the challenge of sustainability* (pp. 173-217). New York: UNDP.

Kadian, R., Dahiya, R. P. & Garg, H. P. (2007). Energy-related emissions and mitigation opportunities from the household sector in Delhi. *Energy Policy, 35*(12), 6195.

Kannan, R. & Strachan, N. (2009). Modelling the UK residential energy sector under long-term decarbonisation scenarios: Comparison between energy systems and sectoral modelling approaches. *Applied Energy, 86*(4), 416-428.

Koomey, J. (2000). *Avoiding 'The Big Mistake' in forecasting technology adoption*. Retrieved January 2008, from http://enduse.lbl.gov/info/LBNL-45383.pdf

Koomey, J., Brown, R. E., Richey, R., Johnson, F. X., Sanstad, A. & Shown, L. (1995). *Residential sector end-use forecasting with EPRI-REEPS 2.1: Sumary input, assumptions and results*. Retrieved January 2009, from http://enduse.lbl.gov/info/LBNL-34044.pdf

Laitner, J. A., DeCanio, S. J., Koomey, J. G. & Sanstad, A. H. (2003). Room for improvement: increasing the value of energy modeling for policy analysis. *Utilities Policy, 11*(2), 87-94.

Laponche, B., Jamet, B., Colombier, M., & Attali, S. (1997). *Energy efficiency for a sustainable development*. Paris: International Conseil Énergie.

Levine, M., *et al.* (2007). Residential and commercial buildings. In Metz, B., *et al.* (Eds.) *Climate Change 2007: Mitigation. Contribution of Working III to the Fourth Assessment Report to the Intergovernmental Panel on Climate Change.* (pp. 387-446). Cambridge UK and New York: Cambridge University Press.

Levine, M., Ürge-Vorsatz, D., Blok, K., Geng, L., Harvey, D., Lang, S., et al. (2007). Residential and commercial buildings. In B. Metz, O. Davidson, P. Bosch, R. Dave & L. Meyer (Eds.), *Climate Change 2007: Mitigation. Contribution of Working III to the Fourth Assessment Report to the Intergovernmental Panel on Climate Change.* (pp. 387-446). Cambridge UK and New York: Cambridge University Press.

Lutzenhiser, L. (1992). A cultural model of household energy consumption. *Energy, 17*(1), 47-60.

McNeil, M., de la Rue du Can, S. & McMahon, J. (2009, 1-6 June). *Enduse global emissions mitigation scenarios (EGEMS): A new generation of energy efficiency policy planning models.* Paper presented at the European Council for an Energy Efficiency Economy (ECEEE) - Summer Study: Reducing energy demand sustainably, La Colle sur Loup, France.

McNeil, M., Letschert, V. & de la Rue du Can, S. (2008). *Global potential of energy efficiency standards and labeling programs*. Retrieved March 2009, from http://www.clasponline.org/files/S&LGlobalPotential-Nov2008.pdf

McNeil, M., Van Buskirk, R. & Letschert, V. (2006). *The value of standards and labelling: An international cost-benefit analysis tool for standards & labelling programs with results for Central American Countries*. Retrieved March 2009, from http://www.clasponline.org/files/4260_paper_McNeil_final.pdf

Messner, S. & Schrattenholzer, L. (2000). MESSAGE-MACRO: linking an energy supply model with a macroeconomic module and solving it iteratively. *Energy, 25*(3), 267-282.

Metcalf, G. (1994). Economics and rational conservation policy. *Energy Policy, 22*(10), 819-825.

Metz, B., Davidson, O., Bosch, P., Dave, R., & Meyer, L. (Eds.) (2007). *Climate Change 2007: Mitigation. Contribution of Working III to the Fourth Assessment Report to the Intergovernmental Panel on Climate Change.* New York: Cambridge University Press.

Mickwitz, P. (2003). A Framework for Evaluating Environmental Policy Instruments: Context and Key Concepts. *Evaluation,* 9(4): 415-436.

Mont, O., & Dalhammar, C. (2005). Sustainable consumption: At the cross-road of environmental and consumer policies. *International Journal of Sustainable Development,* 8(4): 258-279.

Morales, A. C. & Sauer, I. L. (2001). Mitigation of greenhouse gas emissions originating from energy consumption by the residential sector in Ecuador. *Energy for Sustainable Development: The Journal of the International Energy Initiative, 5*(3), 47-59.

Moukhametshina, E. (2008). *Choice determinants for the (non) adoption of energy efficiency technologies in households - A literature review*. Lund: International Institute for Industrial Environmental Economics, Lund University.

Mundaca, L. (2008). Markets for energy efficiency: Exploring the implications of an EU-wide 'Tradable White Certificate' scheme. *Energy Economics, 30*(6), 3016.

Mundaca, L. & Neij, L. (2009). *Energy models and energy efficiency policy evaluation for households: An analysis of modelling tools and analytical approaches* Lund: International Institute for Industrial Environmental Economics, Lund University.

Munson, R. (2004). Improving prediction of energy futures. *Issues in Science and Technology* (Spring 2004), 26-29.

Richey, C. (1998). *Methodology for tax rebate analysis*. Retrieved December 2008, from http://enduse.lbl.gov/SharedData/taxmethod.rtf

Rossi, P., Lipsey, M., & Freeman, H. (2004). *Evaluation - A systematic approach*. (Seventh ed.). Thousand Oaks CA: Sage Publications.

Ruderman, H., Levine, M. D. & McMahon, J. E. (1987). The behaviour of the market for energy efficiency in residential appliances including heating and cooling equipment. *The Energy Journal, 8*(1), 101-124.

Scheraga, J. (1994). Energy and the environment. Something new under the sun? *Energy Policy, 22*(10), 798-803.

Schulz, T., Kypreos, S., Barreto, L. & Wokaun, A. (2008). Intermediate steps towards the 2000 W society in Switzerland: An energy-economic scenario analysis. *Energy Policy, 36*(4), 1303.

SCR, Novem, Motiva, Norsk, Centre for energy conservation, ELKRAFT System, et al. (2001). *A European ex-post evaluation guidebook for DSM and EE service programmes*: SCR International A/S Denmark.

Scriven, M. (1991). *Evaluation thesaurus*. (Fourth ed.). London: Sage Publications.

Stern, P. C. (1986). Blind spots in policy analysis: What economics doesn't say about energy use. *Journal of Policy Analysis and Management, 5*(2), 200-227.

Sutherland, R. (1991). Market barriers to energy-efficiency investments. *The Energy Journal, 12*(3), 15-34.

Swisher, J. N., Jannuzzi, G. & Redlinger, R. Y. (1997). *Integrated resource planning*. Roskilde: UNEP Collaborating Centre on Energy and Environment - Risoe National Laboratory.

Tietenberg, T. (2006). *Emissions trading. Principles and practice* (Second ed.). Washington DC: RFF Press.

Train, K. (1985). Discount rates in consumers' energy related decisions: A review of the literature. *Energy*, *10*(12), 1243-1253.

Uitdenbogerd, D. (2007). *Energy and households. The acceptance of energy reduction options in relation to performance and organisation of household activities.*, Wageningen University., Wageningen.

van Buskirk, R., Hagan Essel, B., Ahenkorah, A. O. & McNeil, M. (2007). Refrigerator efficiency in Ghana: Tailoring an appliance market transformation program design for Africa. *Energy Policy, 35*(4), 2401.

van der Doelen, F. C. J. (1998). The "give-and-take" packaging of policy instruments: Optimising legitimacy and effectiveness. In Bemelmans-Videc, M., Rist, R., & Vedung, E. (Eds.) *Carrots, sticks and sermons* (pp. 129-149). New Brunswick NJ: Transaction Publishers.

Vedung, E. (1997). *Public policy and program evaluation*. New Brunswick NJ: Transaction Publishers.

Vedung, E. (1998). Policy instruments: Typologies and theories. In Bemelmans-Videc, M., Rist, R., & Vedung, E. (Eds.) *Carrots, sticks and sermons* (pp. 21-58). New Brunswick NJ: Transaction Publishers.

Vreuls, H., *et al.* (2005). *Evaluating energy efficiency policy measures & DSM programmes*: International Energy Agency - DSM & SenterNovem.

Worrell, E., Ramesohl, S. & Boyd, G. (2004). Advances in energy forecasting models based on engineering economics. *Annual Review of Environment and Resources, 29*(1), 345-381.

Yanbing, K. & Qingpeng, W. (2005). Analysis of the impacts of building energy efficiency policies and technical improvements on China's future energy demand. *International Journal of Global Energy Issues, 24*(3-4), 280-299.