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Methodologies for Assessment of Building's Energy Efficiency and Conservation: A Policy-Maker View

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Methodologies for assessment of building's energy efficiency and conservation: a policy-maker view

Dr. Aleksandra Novikova[*]

Abstract

Recent global peer-review reports have concluded on importance of buildings in tacking the energy security and climate change challenges. To integrate the buildings energy efficiency into the policy agenda, significant research efforts have been recently done. More specifically, the public domain provides a bulk of literature on the application of buildings-related efficiency technologies and behavioural patterns, barriers to penetration of these practices, policies to overcome these barriers. From the policy-making perspective it is useful to understand how far our understanding of building energy efficiency goes and the approaches and methodologies are behind such assessment.

This paper aims to address this issue; it describes the knowledge on building assessment, from the policy-maker standpoint. More specifically, the paper describes the key approaches to assess technological and non-technological potentials, then it reviews the metrics for setting political ambitions to explore these opportunities; further, it studies barriers to realisation of these ambitions and policies to overcome them. Finally, it reviews the approaches to policy impact evaluation and ways to diagnose the reasons for a particular level of policy performance. The paper concludes with an identification of gaps in knowledge which constrain successful realisation of the energy efficiency potential in buildings.

Keywords

Buildings, energy efficiency potential, greenhouse gas mitigation, policy assessment, energy policy impact evaluation, sectoral efficiency targets.

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1 INTRODUCTION

1.1 Buildings for energy and climate

In 2007, energy services delivered to the world's buildings – living, commercial, and public space – required 2 billion TOE fuels for direct combustion and 0.84 billion TOE in the form of electricity and heat (IEA 2010). These represent about 31%, 46%, and 51% of fuels, heat, and electricity available for global final energy consumption. Besides direct consumption for services, indirectly buildings are associated with energy input for building material manufacture and delivery, as well as energy consumption for transportation and other services inherited from the structure of the built environment. Industrial buildings, which require similar energy services to residential and commercial, such as lighting, thermal comfort, and others, are usually considered a part of the industrial sector although their inclusion in the overall buildings sector would be more relevant. Due to the significance of the buildings sector, the key world peer-review assessments, such as the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Barker *et al*. 2007), the Global Energy Assessment (Ürge-Vorsatz *et al*. 2011), Energy Technology Perspectives (IEA 2008) and others have recently agreed on buildings as a priority sector when considering energy security and climate mitigation challenges.

Buildings are a unique and interesting study from several perspectives. First, they are very heterogeneous: they are exploited by billions of users and influenced by multiple stakeholders, such as policymakers, constructors, building material manufacturers, equipment producers, the energy sector, and others. Second, there are diverse opportunities of a technological and non-technological nature to address energy services in a more efficient way. However, as many experts agree, in spite of these opportunities, globally, policy coverage of buildings is weaker than, for instance, that of the industry and the energy sector, and the efficiency potential is being realised at slower rates than is desirable.

1.1 Aims and objectives of the paper

The public domain provides the bulk of literature on the application of buildings-related efficiency technologies and behavioural patterns, barriers to penetration of these practices, policies to overcome these barriers, and associated benefits. From the research perspective, it is useful to understand the approaches and methodologies for buildings' energy efficiency assessment. This paper aims to address this issue; it describes the knowledge on building assessment, from the policy-maker standpoint. More specifically, after the introduction, the paper describes possibilities to explore resources for energy efficiency, then it reviews the metrics for setting political ambitions to explore these resources; further, it studies barriers to realisation of these ambitions and policies to overcome them. Finally, it reviews the approaches to policy impact evaluation and ways to diagnose the reasons for a particular level of policy performance. The paper concludes with an identification of gaps in knowledge which constrain successful realisation of the energy efficiency potential in buildings. The work relies on the author's expertise, recent energy and climate world reviews, methodological guides, and other literature available in the public domain.

2 ASSESSMENT OF THE POTENTIAL FOR ENERGY EFFICIENCY IN BUILDINGS

This paper starts by analysing opportunities to reduce energy consumption in buildings. These improvements can be made through the application of energy efficient technologies or through non-technological measures, like temperature choices.

2.1 Opportunities suggested by energy efficiency technologies

Since the first energy crisis in 1973, it has become clear that one of the key steps to security of energy supply is energy efficiency, on both the supply and demand sides (Meier *et al*. 1983; Lovins *et al*. 1989; Von Weizsäcker *et al*. 1997). In this regard, a wide range of literature has viewed (Koomey *et al*. 2010) technological energy efficiency[1] as a generous and relatively inexpensive resource of energy, which is, if delivered, often expressed in *negajoules* (Krause *et al*. 1995). Levine *et al*. (2007) concluded that buildings house a significant amount of energy efficiency potential, which can be realised using existing and mature energy efficiency technologies. Further, we discuss achievable energy performance of new constructions and existing buildings after their retrofit, methods of quantification of sectoral energy-efficiency potential, and the results of such calculations worldwide. The section concludes on the opportunities for further research in the field of estimating potential energy efficiency.

2.1.1 Highly efficient building retrofit and new constructions: best practice

The section reports summaries of best practice in retrofit of existing building and in new constructions. Best practice refers to combinations of existing mature technologies which allow the delivery of all energy services in buildings using a minimum amount of conventional energy.

Worldwide, there is a number of examples which suggests the possibility of buildings' not only consuming a small amount of energy but even becoming net energy suppliers. A few organisations track records of such best practices. These are the database collected by the WBCSD[2], the database of the Solar Heating & Cooling Programme - Task 28 and other initiatives of the IEA[3], a database of passive house projects supported by Passivhaus Institut, the Passivhaus Dienstleistung GmbH and the IG Passivhaus Deutschland, the database supported by IG Passivhaus Österreich, the High Performance Buildings Database supported by the US DOE[4], and others.

Based on the international database collected by Professor Danny Harvey of Toronto University, later widely referenced in the Buildings Chapter of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Levine *et al*. 2006) and the Buildings Chapter of the Global Energy Assessment (Ürge-Vorsatz *et al*. forthcoming), it was concluded that it is possible to reduce up to 75% of the primary energy requirement in buildings, through conventional retrofit; even deeper savings are possible if an integrated set of measures, including a solar retrofit, is applied. Such measures may be cost-effective. Clearly the possibility of achieving high energy savings cost-effectively through building retrofit depends on many factors. Analyses show that construction technology of the building shell and the state of the building components (often, but not necessarily, correlated with the age of the technology and components) are one of the key factors. Thus, Parker *et al*. (2000) concluded that the cost-effective energy savings are 25-30% for buildings constructed before the 1940s and about 12% for buildings built in the 1990s in Canada. Novikova (2008) found that the cost-effective CO_2 mitigation potential of the multi-residential brick buildings of Hungary constructed before the 1940s is 16% of their baseline emissions in 2025, whereas that of buildings constructed in 1960s-1980s, using industrialised technology, is 55%.

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1 Here and further we refer to energy efficiency in its classical terms, i.e. doing more with less. That is the opposite of doing less, doing worse or doing without energy (Rosenfeld 2005).

2 World Business Council for Sustainable Development

3 International Energy Agency

4 US Department of Energy

In contrast to existing buildings, where energy-efficiency measures are incremental improvements to existing structures, new buildings may be designed in a very efficient way, using the Integrated Design Approach (IDP). The IDP sees a building as a system which consists of interrelated components gaining synergies from one another advantage. Such buildings are therefore well-optimised, use utilities efficiently, and have a minimum negative impact on the environment (Busby Perkins + Will Stanec Consulting 2007a, 2007b). The IDP assumes a high level synergy of stakeholders involved into the building planning, design, and construction. In his review of building best practices, Harvey (2006) found that buildings constructed using the IDP design may cost less than conventional buildings, and costs of energy saved may go down as the amount of energy required goes up. Passivhaus Institut *et al*. (2010) reports tens of examples of new constructions in temperate climate with a heating requirement of 5-15 kWh/m^2-yr, versus a typical for new constructions 100 kWh/m^2-yr. (Novikova 2008).

In summary, the current state of technologies allows for new constructions and existing buildings consuming low amount of energy, compared to those of standard practice. The next section looks at methodologies for quantifying the energy-efficiency potential of the buildings sector as a whole, rather than focusing on its boundary cases for individual buildings.

2.1.2 Methodologies for quantifying the potential for energy efficiency

Classically, the literature classifies two major approaches to energy system assessment - *bottom-up (synthesis)* and *top-down (decomposition)*. For energy systems, the top-down models examine interactions between energy-related variables and macro-economic indicators. The output of top-down models is typically a change of macroeconomic indicators, such as gross domestic product (GDP) growth rates, GDP per capita, trade balance indicators, and others. Bottom-up modelling typically implies merging individual system elements into larger elements and subsystems. Thus, if applied to the energy system assessment, bottom-up models rely on analysis of individual technologies which are then merged into a sectoral picture.

The comprehensive overview of literature calculating the potential for carbon dioxide mitigation in buildings, which was mostly the result of technological efficiency measures, was conducted in Ürge-Vorsatz and Novikova (2008) for the Buildings Chapter of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Levine *et al*. 2007). Due to this reason, we do not repeat this task in this paper.

The majority of the studies covered in Levine *et al*. (2007) are bottom-up assessments. This is not surprising because, by definition, bottom-up models are more appropriate for technological assessments. Most bottom-up models may be simulated; some of them include an optimisation function; and some include top-down elements to a different degree. Application of a particular type of model is justified by its purpose, though recently it has become obvious that energy efficiency improvement analysis is the most useful if, besides identification of the magnitude of the potential, it also provides an estimate of associated costs. The number of top-down models examining buildings potential for energy efficiency is rather limited (the paper omits models which examine buildings as one among numerous energy-demand sectors[5]). Within the limit of time given to prepare the current review, it was possible to locate only a single paper (Newell and Pizer 2005), which constructed an econometric end-use and fuel-use model with which it was possible to formulate the marginal cost curve for carbon reduction (the definition is provided on the next page).

[5] WorldScan, MESSAGE-MACRO, E3MG, AIM/CGE, IMAGE, etc.

Analysis of literature shows that technological potential research is in either of the following categories:

- *Scenario models* which describe a storyline with a set of technological options implemented, versus a reference baseline; the potential is calculated as a difference between the reference baseline and the case with technologies applied
- Potential estimates which are often drawn in a form of *energy efficiency supply curves* which characterise the potential as a step-wise function of marginal costs per unit of energy saved, each step representing an efficiency measure
- *Optimisation models* which aim to find the optimal allocation of resources and other factors, for instance investments required or the technology penetration rate needed to allow sectoral energy consumption to meet a target at minimum costs

Even though using similar methodological approaches, model assumptions vary to a great extent even if applied to the same country. Table 1 illustrates this using two potential studies. At a closer look, it is clear that the cross-national comparison of their results is hardly possible. Thus, the studies may:

1. Be targeted at different results: the physical possibility for energy savings, the best combination of options in a particular schedule to reach the target, financial analysis of energy efficiency opportunities, and others.
2. Apply different sectoral delineations in terms of focusing on the whole building stock or on a section of it: residential/public/commercial and new/existing. The majority of studies focus only the residential sector for a few reasons: first, the residential sector is typically larger than the commercial sector in terms of energy consumption; second, it is more homogeneous in energy services and it is easier to analyse; and, third, for the same reasons, policy tools are better tailored to the residential sector than to commerce and the public sector.
3. Target different energy services. For developed countries located mainly on the north, research on space heating prevail, whereas for developing countries concentrated in the south, electrical services are better examined.
4. Cover only demand-side options or also include supply-side options such as renewable integration to buildings. Purely demand-side studies are more frequent than those focusing on both building demand and supply-side.
5. Use different baseline definitions, such as frozen-efficiency, business-as-usual, low efficiency, high efficiency, and other types.
6. Consider a different number of options. For instance, the ADB (1998c) looked only at three options for buildings in Thailand, whereas the California study (Rufo and Coito) examined about 150 options. It is clear that, due to the limited number of technological options considered by some studies, the real potential for that region/country is likely to be higher than reported.
7. Consider different type of options (for example not just efficiency only, but also fuel switch).
8. Look at different end years. Bottom-up studies usually look 20-30 years ahead, whereas the top-down approaches look to a long term period.
9. Use different potential definitions: technical, economic, market, programme.

10. Assume different economic input parameters, such as discount rates (varying from 0% to 100%), which may have a significant impact on the financial outcome.

Table 1. Examples of two national studies which quantify the potential for energy-efficiency improvement in the buildings sector

Country	**South Africa**	**UK**
Region	Developing	Developed: Europe
Reference	De Villiers and Matibe (2000)	Johnston *et al.* (2005)
Aim	Understanding of the magnitude, costs and benefits of CO_2 emissions reductions	Exploration of the technical feasibility of achieving the target stated
Model type	Bottom-up	Bottom-up
Model name	Excel spreadsheets	Advanced BREHOMES[6]
Type	Supply curve of the CO_2 mitigation potential	Target-oriented (60% CO_2 emissions reduction in 2050, relative to 1996)
Baseline, scenarios	- Frozen efficiency	- Business-as-usual - Demand-side (changes only in energy demand sectors) - Integrated (changes in both energy supply and demand-side)
Sectoral delineation	Demand-side only but options include small-scale renewables integrated into buildings	The outcome for the residential sector only is considered, but options target both demand and supply side
Energy services studied	Cooking, space heating, water heating, lighting, electrical home appliances	Space heating, water heating, lighting, cooking, electrical home services
Options considered	Efficient light practices; retrofits of humidification, ventilation and air-conditioning systems (HVAC); efficient stoves, cooking, heaters, new HVAC systems; thermally efficient envelope; shift from electricity to gas heaters; appliance standards & labelling; for hot water: improved insulation, heat pumps, efficient use; solar water heating.	Stringent European Union CO_2 emissions targets, shift in perception towards new appliances, best practices of energy-efficient housing, upgrading of the building envelope, changes in insulation of space and water heating, lights, appliances and cooking, changes in fuel mix, improvement in generation efficiency, fuel switch.
Commodity modelled	CO_2	Energy and CO_2
Financial considerations	The study looks at cost-effectiveness and return of initial investments	The study does not look at costs
Projection period	40 years (1990 – 2030)	54 years (1996 – 2050)
Approach, model	The study built a supply curve of CO_2 mitigation, assuming high penetration/share of the market of new efficiency equipment and improved technologies.	Technological options are modelled as retrofit options and those based on new standards. In the long term, a "notional" dwelling type and efficiencies of its energy end-use systems are modelled based on the present and expected building and system standards.

2.1.3 Identified potential in different geographical locations

Research on the potential for energy efficiency requires problem understanding, data, skills, time, and resources. For these reasons, the majority of comprehensive pieces of research are

6 The Building Research Establishment's Housing Model for Energy Studies

run for the developed world[7], and probably the most advanced are those for the US and for EU-15 countries. The US studies are conducted by national laboratories (Lawrence Berkeley National Laboratory, Argonne Laboratory, Pacific NorthWest National Laboratory) and private consultancies. In Western Europe, there are numerous research groups working on the subject, such as experts in the International Institute of Applied System Analysis (IIASA) in Austria, the Risoe Centre on Energy, Climate and Sustainable Development (URC) in Denmark - supported by the United Nations Environment Programme, University of Oxford in the UK, Ecofys Consultancy in several countries, and other entities. Research in developing and transition economies is commissioned/supported by international organisations such as UNEP (see series Economics for GHG Limitation) and the Asian Development Bank (Study of Least-Cost Greenhouse Abatement for Asia (ALGAS series)) and mostly look at all energy supply and demand sectors and do not separate buildings. Table 2 lists studies which are available in the public domain and which examine the energy efficiency potential in buildings by country group. This list was collected in a limited timeframe though the public domain and is not representative. Nevertheless, even with a limited review, it is possible to conclude that there is a shortage of research in developing countries, especially in the Northern Africa and Middle East and Asian countries and transition economies, especially in the Former Soviet Union.

Table 2. Worldwide review of assessments energy efficiency[8] in buildings[9]

Developing countries	DEVELOPED COUNTRIES	TRANSITION ECONOMIES
Sub-Saharan Africa : South Africa (De Villiers and Matibe, 2000; De Villiers, 2000, Spalding-Fecher *et al*. 2002) ***Caribbean, Central and South America:*** Brazil (Almeida *et al*. 2001) ***Middle East*** ***Northern Africa*** ***Asia*** No buildings-specific research	***OECD Pacific***: Japan (Lopes *et al*. 2007) ***OECD North America:*** US (Koomey *et al*. 2001, Brown *et al*. 2000, Pizel and Newell 2005, Brown *et al*. 2008) California: (Itron 2006, Rufo and North 2006) ***European Union except CEE:*** EU-15 (Joosen and Blok 2001) UK (Johnston *et al*. 2005, Boardman *et al*. 2005) Greece (Gaglia *et al*. 2007; Mirasgedis *et al*. 2004) Denmark (Tommerup and Svendsen 2006) Switzerland (Siller *et al*. 2007) Norway (Satori *et al*. 2009) ***Developed Asian countries:*** No buildings-specific research	***CEE:*** Hungary, Slovakia, Slovenia, Estonia, Latvia, Lithuania, Poland, Czech Republic (Petersdorff *et al*. 2004), Hungary (Novikova 2008) ***FSU, except the Baltic States:*** No buildings-specific research

Further, we summarise the range of estimates of different potential types found in the literature, based on a review of 80 studies by Ürge-Vorsatz and Novikova (2008). This research focused on CO_2 mitigation potential, and the results for energy efficiency, though not the same, are similar. According to our best knowledge, there is no recent review of the

7 We could track only studies published in English language.
8 And related
9 The table focus only on buildings-specific studies and do not include studies which cover buildings as one of numerous sectors considered

worldwide potential for energy efficiency improvement. The estimates presented in Table 3 should be compared with caution, due to differences in approaches and assumptions, as discussed in the previous section. Table 3 concludes that the technical potential for CO_2 emissions reduction may reach 80% of the baseline in 2020 in the northern locations, which are developed, and transition economies. Because of the climate, these regions are heating-intensive and require retrofitting options. The available options, such as building component exchange or installation of better heating equipment are usually expensive to install ex-post. Due to this reason, a large part of the potential is not cost-effective. The technical potential in developing countries may reach 45% of the baseline emissions in 2020. Due to their southern location, options include efficient lighting, air-conditioning, and other electrical technologies. The difference in the potential estimates between developing and developed countries may also result from the fact that developed countries have better access to technologies and finance, and they may be interested in examining high-cost potential. By contrast, developing countries have access to the basic technologies and have rather limited finance; due to these reasons, their studies assess mostly high priority options.

2.1.4 Summary, insights, and opportunities for further research

As discussed in the section, there are numerous mature approaches and technologies which allow reduction of conventional energy consumption by up to 80% and 100%, as compared to the standard practice in existing buildings and new constructions respectively. Therefore, technologically there are no constraints to the transformation of the buildings sector and the challenge lies in acceleration of technological diffusion and cost reduction process. This is equally important for existing and new buildings: a large share of existing buildings will likely remain stand for 50 and more years, and their retrofit is important, whereas new construction adds an insignificant share to existing stock each year but would lock in inefficient energy consumption patterns in the long term. The latter conclusion calls attention to the growing importance of policy tools which may help increase diffusion rates.

The section also discussed different approaches to estimation of the potential for energy efficiency improvement in buildings. Even though some methodologies are similar, they still vary to a large extent and apply different assumptions which make it challenging to conduct cross-sectoral and cross-national comparisons, as well tracking historical sectoral performance if it was assessed using different methods. To allow the later analysis, universal guidelines and methodologies for potential studies are important. This statement does not diminish the role of individual modelling but calls for its convertibility to an informal format.

The section provided a geographical review of the potential studies. The key conclusion is that only developed regions are well-assessed (the US and the EU), whereas for the developing and transition countries, only a few, and mostly outdated, studies are available. Taking into account energy-security and climate challenges facing these countries, it is important to address this gap in knowledge.

All studies located for this paper took an end-of-pipe approach, considering only energy and emissions reduced at the point of energy demand, omitting the life-cycle approach of mitigation technology production and use. Finally, even though the overall idea of producing energy is to deliver services (warmth, entertainment, etc.) and therefore it is more logical to look at efficiency of energy services, the vast majority of research directly starts with the discussion of energy end-use technologies, omitting the opportunities of more efficient services, rather than technologies. Challenges and opportunities for research which relate to these particular assumptions are discussed in Section 8.

Table 3. CO_2 **emissions reduction potential for building stock in 2020**[10]

Economic region	Countries reviewed for the region	Potential as % of national baseline for buildings	Measures covering the largest potential	Measures providing the cheapest mitigation options
Developed countries	US, EU-15, Canada, Greece, Australia, Republic of Korea, United Kingdom, Germany, Japan	Technical[11]: 38%-79%[12] Economic (<US$ 0/tCO_2[13]): 22%-44%[14] Market[15]: 15%-37%	1. Shell retrofit, incl. insulation, esp. windows and walls; 2. Space heating systems; 3. Efficient lights, especially shift to compact fluorescent lamps (CFL) and efficient ballasts.	1. Appliances such as efficient TVs and peripherals (both on-mode and standby), refrigerators and freezers, ventilators and air-conditioners; 2. Water heating equipment; 3. Lighting best practices.
Economies in Transition	Hungary, Russia, Poland, Croatia, as a group: Latvia, Lithuania, Estonia, Slovakia, Slovenia, Hungary, Malta, Cyprus, Poland, and Czech Republic	Technical: 26%-72%[16] Economic (<US$ 0/tCO_2): 24%-37%[17] Market: 14%	1. Pre- and post-insulation and replacement of building components, esp. windows; 2. Efficient lighting, esp. shift to CFLs; 3. Efficient appliances, such as refrigerators and water heaters.	1. Efficient lighting and lighting controls; 2. Water and space heating control systems; 3. Retrofit and replacement of building components, esp. windows.
Developing countries	Myanmar, India, Indonesia, Argentina, Brazil, China, Ecuador, Thailand, Pakistan, South Africa	Technical: 18%-41% Economic (<US$ 0/tCO_2): 13%-38%[18] Market: 23%	1. Efficient lights, esp. shift to CFLs, light retrofit, and kerosene lamps; 2. Various types of improved cooking stoves, esp. biomass, followed by LPG and kerosene stoves; 3. Efficient appliances, such as air-conditioners and refrigerators.	1. Improved lights, esp. shift to CFLs, light retrofit, and efficient kerosene lamps; 2. Various types of improved cooking stoves, esp. biomass based, followed by kerosene stoves; 3. Efficient electric appliances, such as refrigerators and air-conditioners.

Source: the table is constructed based on analysis of about 80 country and regional assessments; the detailed methodology and the references are provided in Ürge-Vorsatz and Novikova (2008), they are not included in this paper due to space limitations.

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10 Except for EU-15, Greece, Canada, India, and Russia, for which the target year was 2010, and Hungary, Ecuador, and South Africa, for which the target was 2030.

11 The technical potential is defined as the amount by which it is possible to reduce CO_2 emissions by implementing already demonstrated technologies and practices without specific reference to costs although economic considerations might be applied (Halsnæs *et al*. 2007).

12 Both are extrapolated potential numbers from 2010 (21%-54%) to 2020 according to the formula: $\text{Potential}_{2020} = (1 - (1 - \text{Potential}_{2010})^{20/10}$.

13 The economic potential is a cost-effective potential for CO_2 mitigation when non-market social costs and benefits associated with mitigation options are considered with market costs and benefits using social discount rates instead of private ones at particular levels of carbon prices (Halsnæs *et al*. 2007). Since the majority of the studies reviewed did not take into account all social cost elements and the carbon price, the economic potential was assumed as the cost-effective potential at zero social cost and zero carbon price.

14 Both are extrapolated potential numbers (12% - 24%) from 2010 to 2020; if suggested above extrapolation formula is used.

15 The market potential is defined as the amount of CO_2 mitigation occurring under forecast market conditions including policies and measures based on private unit costs and discount rates (Halsnæs *et al*. 2007).

16 The last figure is the extrapolated one (47%) from 2010 to 2020, if the extrapolation formula is used.

17 The first figure is the extrapolated one (13%) from 2010 to 2020, if the extrapolation formula is used.

18 The last figure is the interpolated one (52) from 2030, if the suggested extrapolation formula is applied to derive the intermediate potential.

2.2 Quantification of non-technological energy savings potential

Schipper *et al*. (1989) and Schipper (1996) revealed a number of lifestyle[19] characteristics and behavioural patterns which evolve over time and ultimately result in a change of energy consumption patterns. According to conclusions in Levine *et al*. (2007), this link is very significant, along with technology use. Despite this fact, the potential for energy savings through changes in energy use patterns is poorly researched. This section aims to describe the state of knowledge in the field and identify the areas for further research[20].

2.2.1 Methodologies to quantify non-technological factors and selected case studies

Classical political economy specifies the ideal behaviour with a number of factors. These are perfect competition, perfect information, absence of externalities, divisibility into exchangeable units, excludability, zero transaction costs, zero entry barriers, economic rationality, and fair distribution of wealth and income (Harris and Carman 1983). Such conditions hardly exist and, therefore, even with the same technological setting, different non-technological factors define the level of energy consumption.

Non-technological drivers of an economic nature are usually studied through models learning price signals, which is out of the scope of this paper. The rest of the decision models are used to research and understand behaviour or design and evaluate the impact of interventions. Further, the latter two common approaches are discussed.

The first common approach is a comparison of energy consumption by groups of users characterised by different behavioural characteristics. Levine *et al*. (2007) provided a brief review of studies which use such an approach. These are, for instance, difference in dishwasher use in 21% of households in the UK versus 51% of households in Sweden (European Commission 2001); cold water use for clothes washing in China versus hot water for this purpose in Europe and the Americas (Biermayer and Lin 2004); difference in setting temperature levels and the longevity of lighting use worldwide (IEA 1997).

Another more common approach is to examine change in energy use due to an intervention. Such intervention could lead to a change in knowledge, motivation and attitude that impacts on energy consumption in experimental groups versus in a control group. Abrahamse *et al*. (2005) reviewed thirty-eight pieces of research which evaluated effectiveness of interventions to encourage households to reduce their energy consumption. There are different strategies used as interventions: commitments, goals, information, feedback, rewards and others. With such analysis, it is possible to understand the potential impact of interventions on behaviour, underlying behavioural factors, the longevity intervention effects, and the degree to which energy consumption reduction could be attributed to the interventions.

There are different models proposed by research groups to explore non-technological factors according to the approaches described. The key distinguished model types fall into four categories: conventional and behavioural economics, technology adoption theory and attitude-based decision making, social and environmental psychology, and sociology. Table 4 summarises the main assessment techniques used in the field, from an exceptional work of Wilson and Dowlatabadi (2007) which made an attempt to review the key methodological literature in the field and classify it. The authors highlighted significant differences in

[19] Lifestyle is a broad term often used to reflect differences in consumption patterns of groups with different social and economic characteristics. These are social identity, education, employment, family status, and others (Hertwich and Katzmayr 2004).

[20] The term of energy efficiency is not appropriate here because energy use pattern change is associated with using less, rather than using more efficiently.

models, and emphasised the challenge of making a bridge between the economic and social bases of behaviour.

Table 4. Comparison of disciplinary approach to decision making, in the contents of residential energy use

Main features	**Conventional economics**	**Behavioural economics**	**Technology diffusion**	**Social psychology**	**Sociology**
Decision model	Utility maximisation based on fixed and consistent preferences	Widely varying decision heuristics and context-dependent preferences	Attitude-based evaluation of technologies and the consequences of adoption	Interacting psychological and contextual variables	Sociotechnical construction of demand
Decision scale	Individual	Individual	Individual/social	Individual/social	Social
Main research methods	Quantitative (observed behaviour)	Quantitative (controlled experiments)	Quantitative and qualitative (surveys, interviews, observed behaviour)	Quantitative and qualitative (surveys, observed behaviour)	Qualitative (interviews, observation)
Main dependent variables	Preferences between decision outcomes	Preferences between decision outcomes	Rate of diffusion	Self-reports of behaviour and/or energy use	Observed or self-reported behaviour
Main independent variables	Costs and benefits of outcomes and their respective weightings	Aspects of the decision frame, context, and elicitation method, as well as outcomes	Adopter role in social networks, communication channels, technology attributes, and leadership of adopter	Values, attitudes, norms, sociodemographics, economic incentives, skills, capabilities, and resources	Social, cultural and technical determinants of energy demand embedded in routine behaviour
Empirical basis for energy use	Extensive	Very little	Some	Extensive	Some
Implications for interventions to reduce residential energy use	Provide information about benefits and incentives to improve cost-benefit ratio and improve cognitive capacity to assess net benefits/utility	Pay attention to framing and reference points for decisions, influence heuristic selection by emphasising associations or emotive attributes, control choice sets and default options	Segment target population, exploit communication channels through social networks and use change agents, identify stage of decision process in target groups and use appropriate change mechanisms, ensure desired technology or behaviour has key attributes	Influence attitudes only if external conditions are weak, use multiple interventions with due attention to interaction effects, identify and target barriers, design salient and personally relevant information, values provide a disposition for long-term change	Work toward long-term sociotechnical regime change, Exploit opportunities for transition, recognise the social role of routine or habitual behaviour, manage expectations
Timescales for interventions	Short term	Short term	Short to medium term	Short to medium term	Long term

Source: Wilson and Dowlatabadi (2007).

2.2.2 *Uncertainty of non-technological potential estimates*

The Fourth Assessment Report of the IPCC (Levine *et al*. 2007) and the follow-up complementary work (Ürge-Vorsatz *et al*. 2009) revealed a critical lack of robust, evidence-based studies on non-technological potential for energy conservation worldwide, especially in developing countries. Based on the available literature, Ürge-Vorsatz *et al*. (2009) concluded that the estimates of quantitative assessment of non-technological factors using comparison of user groups show a difference in energy consumption of from 10% to 100%. Abrahamse *et al*. (2005) concluded that a different magnitude of energy saving could be produced with different types of interventions, with no long-term effects guaranteed.

In general, the existing body of literature aims to assess the scale of energy consumption variation due to non-technological drivers, but not the costs associated with realising this potential. The overlap and interaction of technological and non-technological potential are not well understood; the methodologies to assess this linkage are missing. As Jelsma (2004) concluded, policy-makers prefer to fund technological assessments due to their transparency and straightforward approach. Nevertheless, Ürge-Vorsatz *et al*. (2009) made a hypothesis that the non-technological energy savings can be as high as the potential from technological improvement.

2.2.3 *Opportunities for further research*

In summary, there is definite room for research in the area of non-technological potential for energy efficiency in the buildings sector. First, there is a critical lack of comprehensive universal methodologies applicable in a broad range of case studies. The research is conducted according to several disciplines with no bridge between the methods. Thus, the large body of literature is very fragmented and not comparable. Second, depending on many factors, such as timing, scope of action and design, research results vary even if applied to the same behavioural determent. Third, the relationship between technological potential and non-technological potential is not understood, and furthermore no methodologies exist to learn this link. The existing studies focus on the scale of the non-technological potential, but do not specify the costs of realising it. As Ürge-Vorsatz *et al*. (2009) suggest, if a relatively large set of literature on the impact assessment of interventions existed, mapping of the impact route of actions could lead to identifying the numerical value and the cost of non-technological potential. Finally, non-technological determinants should be better integrated in modelling and scenario analyses.

3 METRICS TO DEFINE AMBITIONS

Energy security and climate change challenges have forced governments to set ambitious efficiency and mitigation targets. Often the targets are specified for sectors which are the most important from this perspective. Depending on the country, sectoral targets are defined to a different degree of details - from a general sectoral number to a well-calculated and described action plan. Omitting decarbonisation of the grid providing electricity and heat, the buildings-related targets are set either for the whole stock or for its parts, usually separated into existing and new constructions. Since the author was unable to locate a review and implications of sectoral efficiency targets[21], the discussion below is based on a review of a few policy documents.

[21] We do not count the post-Kyoto sectoral approach, which is not very relevant here.

3.1 Sectoral targets as a part of national ambitions

The first type of efficiency ambitions for buildings is sectoral goals as a part of the overall national strategy for energy-efficiency improvement or climate change mitigation. The typical metric of doing so is to set a target in energy efficiency or GHG emissions reduction against a base year. Below, two examples are provided.

The first example is that of the European Union Energy and Climate Package (European Commission 2008), which sets the targets for greenhouse gas emissions reductions, energy efficiency improvement and renewable energy consumption. The Package sets a target of a 20% reduction in primary energy used, compared with levels expected through improved energy efficiency, especially in buildings. As regards the EU's GHG emissions, these should be reduced by 20%, from 1990 up to 2020. This target is divided between the sectors which are covered by the EU Emission Trading Scheme (EU ETS) and the rest of the sectors. For the non-ETS sectors, which include buildings, emissions of the EU member states may decrease by up to 20% or increase by up to 20% in 2020 as compared to 2005,## depending on the member states' gross domestic product per capita in 2005. Cumulatively, the EU non-ETS sector should decrease its GHG emissions by 12% in 2020, as compared to 2005.

The second example is the Energy Strategy of Russia to the period of 2030 (Government of the Russian Federation 2010). It lists the schedule of energy efficiency improvement in the buildings sector, as a part of overall national efforts. The Strategy requires buildings to improve their energy efficiency, as compared to the 2005 level, by minimums of 10%, 30% and 50% in 2015, 2020 and in 2030, respectively.

3.2 Targets for existing buildings stock and new constructions

Often policy-makers set ambitious targets for just a part of building stock. These requirements usually fall into those for existing buildings and for new constructions.

The lifetime of a building ranges from 50 years to several hundred; therefore, a substantial part of existing building stock is expected to stay for the long term. Staying that long, buildings undergo several refurbishments, with a major renovation every 30-40 years due to the lifetime expiration of windows, roofs, insulation materials, and other building components. If coupled with general refurbishment, building efficiency retrofit is cheaper (Petersdorff *et al*. 2004) and represents a win-win opportunity. Due to these reasons, policy-makers in many countries set ambitions and actions for existing buildings only. A frequent target is for a number of buildings to undergo efficient retrofits within a particular period of time. For instance, Energy Saving Association (2009) reported that the European Union was going to set a goal to retrofit 15 million buildings in the next decade. Regulating minimum performance of buildings undergoing refurbishment is also often referred to as a target but in fact it is a complex policy tool (see Section 4.24.2), as compared to policy ambitions, which are stipulated but usually not well specified.

The approaches to setting targets for new constructions are similar to those for existing buildings. Again omitting building codes, targets usually concern shares of highly efficient buildings within the sector of new constructions. Examples of such ambitions for EU member countries are provided in Table 5. Among the most ambitious targets is building only zero-carbon homes in the UK and Ireland from 2016 and 2013 respectively. Another ambitious target is in France: to have all new buildings comply with a "low-consumption" standard by 2012, and by 2020 to be energy positive, i.e. produce energy.

Table 5. Selected national targets for low-energy buildings

Country	Targets
Austria	Planned: social housing subsidies only for passive buildings as of 2015
Denmark	By 2020, all new buildings to use 75 % less energy than currently enshrined in code for new buildings. Interim steps: 50 % less by 2015 , 25 % less by 2010 (base year=2006)
Finland	30 – 40 % less by 2010; passive house standards by 2015
France	By 2012 all new buildings to be low-energy buildings (Effinergie standard), by 2020 new buildings to be energy-positive
Germany	By 2020 buildings should be operating without fossil fuel
Hungary	New buildings to be zero-emissions buildings by 2020, for large investments already in 2012
Ireland	60 % less by 2010, Net zero energy buildings by 2013
Netherlands	50 % reduction by 2015, 25 % reduction by 2010, both compared to current code plans to build energy-neutral by 2020
UK (England and Wales)	44 % better in 2013 (equivalent to Passivhauslevel) and zero carbon as of 2016
Sweden	Total energy use / heated square metre in dwellings and non residential buildings to decrease. The decrease should amount to 20% by 2020 and 50% by 2050, compared to corresponding use of energy in 1995.

Source: European Commission (2009).

4 BARRIERS TO PENETRATION OF ENERGY EFFICIENCY IN BUILDINGS, AND POLICY TOOLS TO OVERCOME THEM

4.1 Barriers to energy efficiency: typology and quantification

Many energy-efficiency and energy conservation opportunities in buildings are not taken up by markets despite their cost-effectiveness. As can be concluded from the previous chapters, this is due to various barriers, such as behavioural, technological, and market characteristics (de T'Serclaes 2007). Table 6 lists and classifies these barriers according to the system suggested in Carbon Trust (2005).

While there has been very extensive literature on classifying and explaining the barriers to energy efficiency in buildings, the scale and relative importance of these barriers are explained as gaps in knowledge. It is becoming increasingly clear that for private and governmental policy-making, along with information regarding the scale of technological and non-technological opportunities, there needs to be an understanding of the quantified importance of these barriers, of the monetised impact of some of them, and there needs to be an assessment of how much of this indirect cost can be prevented by policy.

The author identified fewer than twenty pieces of research that developed and used methodologies to quantify the effects of barriers (Krey 2005; UNFCCC 2002; Michaelowa and Lotzo 2005; Mundaca 2007; Sathaye and Murtishaw 2004; UNIDO 2003, de T'Serclaes 2007, Parker *et al*. 2006; Ueno *et al*. 2006; Dobson and Griffin 1992; Van Houwelingen and Van Raaij 1989; Hutton *et al*. 1986, Hausman 1979; Thompson 1997; Sanstadt *et al*. 1995; Kooreman and Steerneman 1998, CEA 1995, Hassett and Metcalf 1993, Meier and Eide 2007; Capros *et al*. 2001; OECD/IEA 2007 , McMakin *et al*. 2002). Among these studies, research in developed countries dominates. The studies most often focus on misplaced incentives, transaction costs, and the lack of real pricing. Such imperfections as political and legislative barriers, lack of financing, lack of information, lack of technologies or high technological risk, lack of enforcement, the taxation pattern, corruption, cultural traditions, and resistance to change are not covered extensively (if at all) by research. The methods used are heterogeneous and include surveys combined with statistical analysis, macro-economic models projecting the feedback (through assessment of energy-price elasticity), bottom-up simulation models, and authors' adjustments. There has been no one single study which quantified the overall aggregated effect of barriers on energy efficiency in buildings.

Table 6. Taxonomy of barriers that hinder the penetration of energy-efficient technologies/practices in the buildings sector

Barrier categories	**Definition**	**Examples**
Financial costs/benefits	Ratio of investment cost to value of energy savings	Higher up-front costs for more efficient equipment Lack of access to financing Energy subsidies Lack of internalisation of environmental, health, and other external costs
Hidden costs/benefits	Cost or risks (real or perceived) that are not captured directly in financial flows	Costs and risks due to potential incompatibilities, performance risks, transaction costs, etc. Poor power quality, particularly in some developing countries
Market failures	Market structures and constraints that prevent the consistent trade-off between specific energy-efficient investment and the energy saving benefits	Limitations of the typical building design process Fragmented market structure Landlord/tenant split and misplaced incentives Administrative and regulatory barriers (e.g. in the incorporation of distributed generation technologies) Imperfect information
Behavioural and organisational non-optimalities	Behavioural characteristics of individuals and organisational characteristics of companies that hinder energy-efficiency technologies and practices	Tendency to ignore small opportunities for energy conservation Organisational failures (e.g. internal split incentives) Non-payment and electricity theft Tradition, behaviour, lack of awareness, and lifestyle Corruption

Sources: IPCC 2007, Carbon Trust 2005.

4.2 Typology of policy tools used to promote energy efficiency in buildings

Policies and programmes have been designed and introduced worldwide to overcome the barriers to energy-efficiency penetration in buildings. While these policies and programmes vary, there have been several attempts to develop universal definitions and classifications for them. Based on a review of classifications available (Crossley *et al*. 1999, EFA 2002, Vine *et al*. 2003, Wuppertal Institute 2002, IEA 1997, Carbon Trust 2005, Köppel and Ürge-Vorsatz 2007), Table 7 arranges policies according to their typology and the stakeholders they impact upon. As Table 7 attests, the majority of policies are orientated on the final energy users in buildings, although there are also many tools to stimulate energy companies (mostly public utilities) to introduce efficiency measures in buildings, mostly households. Annex 1 provides definitions for policy tools listed in Table 7.

Table 7. Classification of buildings-related policy instruments, according to their primary target group

	Target groups\ Policy tools	Energy companies, incl. utilities	Energy service companies	Equipment/ appliance producers	Building architects, constructors	Public sector	Private sector	Households
Control and regulatory instruments	Appliance standards			√				
	Building codes				√			
	Public procurement regulations					√		
	Energy-efficiency obligations and quotas	√						
	Mandatory audits					√	√	√
	Utility demand-side management programmes	√						
	Mandatory labelling, certification programmes					√	√	√
Economic and market-based instruments	Energy performance contracting		√					
	Co-operative procurement						√	
	Energy-efficiency certificate schemes	√						
Fiscal instruments and incentives	Taxation					√	√	√
	Tax exemptions / reductions					√	√	√
	Public benefit charges	√						
	Capital subsidies, grants, subsidised loans					√	√	√
Support, information and voluntary action	Voluntary certification and labelling					√	√	√
	Voluntary and negotiated agreements	√		√	√			
	Public leadership programmes					√	√	√
	Awareness raising, education, information campaigns					√	√	√
	Detailed billing and disclosure programmes					√	√	√

Sources: amended from Köppel and Ürge-Vorsatz (2007).

4.3 The choice of policy tools and their mix as remedies for country-specific barriers

After a careful analysis of barriers to energy-efficiency penetration in buildings, a policy tool is selected to minimise the impact of those barriers. Table 8 reviews policy tools as remedies to different barriers. Each policy tool has its own advantages, conditions for success, and is associated with its individual operational cycle and financial characteristics. As Levine *et al*. (2007) concluded, the buildings sector is characterised by probably the highest and most numerous barriers, compared to other sectors. This is why there is no one single policy tool which is able to overcome all country-specific market imperfections. For this reason, policy tools are often implemented in a package, to take advantage of synergies.

Table 8. Barriers to energy efficiency, and policy instruments as remedies

Barrier categories	**Definition**	**Examples**	**Countries***	**Possible remedies***	**References**
Economic/ financial barriers	Ratio of investment cost to value of energy savings	Higher up-front costs for more efficient equipment Lack of access to financing Energy subsidies Lack of internalisation of environmental, health, and other external costs	Most countries Especially developing, but also developed countries	Fiscal and economic instruments, such as tax rebates, Kyoto Flexibility Mechanisms, subsidised loans, regulatory instruments. Or energy price increase, removal of energy price subsidies	Deringer *et al.* 2004 Carbon Trust 2005, IPCC 2007
Hidden costs/ benefits	Cost or risks (real or perceived) that are not captured directly in financial flows	Costs and risks due to potential incompatibilities, performance risks, transaction costs, etc. Poor power quality, particularly in some developing countries	All countries	Appliance standards, building codes (to overcome high transaction costs), EPC/ ESCOs, public leadership programmes	Carbon Trust 2005, IPCC 2007
Market failures	Market structures and constraints that prevent a consistent trade-off between specific energy efficiency investment and energy-saving benefits	Limitations of the typical building design process Fragmented market structure Landlord/tenant split and misplaced incentives Administrative and regulatory barriers (e.g. in the incorporation of distributed generation technologies) Imperfect information Unavailability of energy-efficiency equipment locally	All countries	Fiscal instruments and incentives Product standards Regulatory-normative Regulatory-informative Economic instruments Technology transfer, mechanisms	Carbon Trust 2005, IPCC 2007
Behavioural and organisational barriers	Behavioural characteristics of individuals and companies that hinder energy efficiency technologies and practices	Tendency to ignore small energy saving opportunities Organisational failures (e.g. internal split incentives) Non-payment and electricity theft Tradition, behaviour and lifestyle, Corruption Transition in energy expertise: Loss of traditional knowledge and non-suitability of Western techniques	Developed countries Developing countries	Support, information and voluntary action: Voluntary agreements Information and training programmes	Carbon Trust 2005, Deringer *et al.* 2004, IPCC 2007
Information barriers*	Lack of information provided on energy-saving potentials	Lack of awareness of consumers, building managers, construction companies, politicians	Especially develop-ping, but also deve-loped countries	Awareness-raising campaigns, Training of building professionals, regulatory-informative	Carbon Trust 2005, Yao *et al*. 2005, Evander *et al*. 2004

Barrier categories	Definition	Examples	Countries*	Possible remedies*	References
Political and structural barriers*	Structural characteristics of the political, economic, energy system which make energy-efficiency investment difficult	Process of drafting local legislation is slow Gaps between regions at different economic level Insufficient enforcement of standards Lack of detailed guidelines, tools and experts Lack of incentives for energy efficiency investments Lack of governance leadership/ interest Lack of equipment testing/ certification Inadequate energy service levels	Most developing (and some developed) countries	Enhance implementation of standards Incentive policy encouraging energy efficiency building design, Enhance international co-operation and technology transfer, Public leadership programmes	Yao *et al.* 2005 Deringer *et al.* 2004

Sources: Köppel and Ürge-Vorsatz (2007).

4.4 Opportunities for further research

While there is substantial body of theoretical literature describing barriers to efficiency penetration in buildings, this research mostly focuses on developed countries. The existing studies do not go beyond identification of these imperfections, whereas policy-makers would benefit from understanding the quantified importance of these barriers, their ranking, and cumulative effect. For existing studies, the methodologies vary to a large extent which makes it difficult to conduct cross-country comparison. In summary, barriers for energy efficiency in buildings are badly understood, and there is great large scope for further research.

5 DIAGNOSIS OF POLICY PERFORMANCE

Thousands of buildings-related policies have been designed and introduced worldwide, to realise energy-efficiency potential after the first energy crisis in the 1970s. Since then, the focus has been on the choice of the most efficient policy tools and their appropriate design in country-specific conditions. Individual policy evaluation helps us recognise the resource of energy efficiency, and see that it is more attractive than exploring the resource of conventional energy.

There is a wide range of literature on evaluation buildings-related policies worldwide. Even though in the vast majority, it is fragmented and its accuracy is questionable (Ellis 2009), the present section attempts to structure the existing knowledge. First, the section looks at methods for understanding the structure and trends of energy consumption in buildings, then it reviews the literature which assesses the outcome of policy tools applied worldwide, and finally it concludes on the ways to diagnose the reasons for a particular level of policy performance. The section relies on analysis of methodological guidelines which are relevant for the buildings sector and meta-studies which cover, among other policies, buildings related policies.

5.1 Performance of buildings transformation

Even though the potential for energy efficiency in buildings is very significant (see Section 2.1), the rates of realisation are far below than those desired. In the EU, with probably one of the most advanced buildings-related policies, the average energy-efficiency progress rate was

0.8%/yr. during the last decade (Figure 1). Furthermore, some experts argue that the rebound effect[22] and the economy-wide effect[23] may erode most of energy savings produced (Geller and Atalli 2005). Therefore, persistent and comprehensive policies are very important for delivering existing potential, and delivering it better.

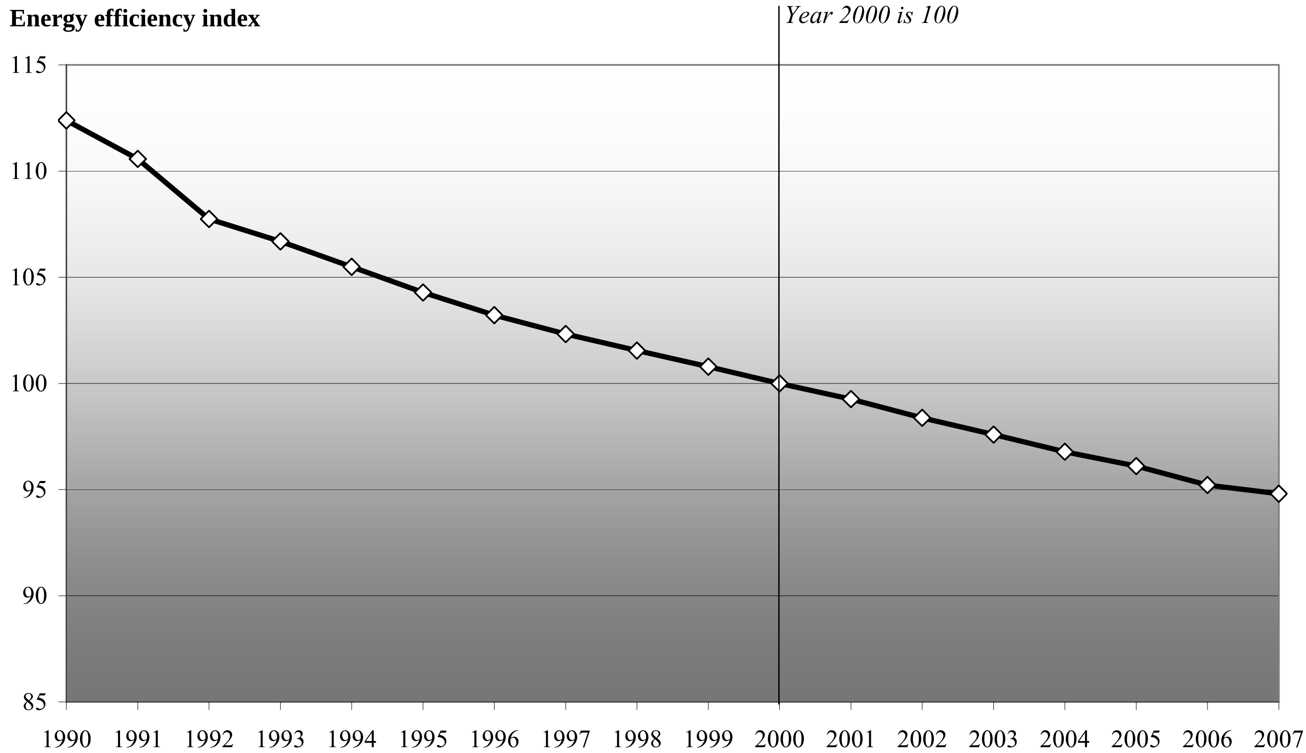

Figure 1. Energy efficiency index of the EU-27 households in 1990 - 2007

Source: ODYSSEE database 2010.

Note: The energy efficiency index (ODEX) is the end-use weighted average of household efficiency progress. End uses accounted for are space and water heating, cooking, and five large electrical appliances. The index is corrected to behavioural impacts including the rebound effect.

The first step, however, to evidence-based – and therefore likely effective policy-making – is to understand the current picture of energy consumption in buildings. Figure 2 presents the methodologies which can be used to understand the structure and implications of buildings' energy consumption. However, as projects of even the most advanced countries[24] signal that the structure and trends of buildings' energy demand, factors underlying that, and the implications for designing policies, are poorly understood. This is because it takes significant

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22 Increase in demand for energy services due to energy cost reductions associated with energy-efficiency improvement.

23 Increase in energy consumption due to the economic growth associated with cheaper input energy.

24 Conclusions from the REMODECE (Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe) and EL-TERTIARY (Monitoring Electricity Consumption in Tertiary Sector) projects which were run under the Intelligent Energy Europe Programme.

and expensive efforts to collect and process detailed energy statistics for so many heterogeneous stakeholders – households, various commerce units, and administrations. There are only a few robust and systematic assessment worldwide, and all are for developed countries. Their examples are:

- US: Residential Energy Consumption Survey (RECS)[25], Commercial Energy Consumption Survey (CBECS)[26]
- Canada: Survey of Household Energy Use (SHEU)[27], Commercial and Institutional Building Energy Use Survey (CIBEUS)[28]
- Germany: Residential Energy Consumption Survey[29], Energy consumption of the tertiary sector (trade, commerce and services)[30]

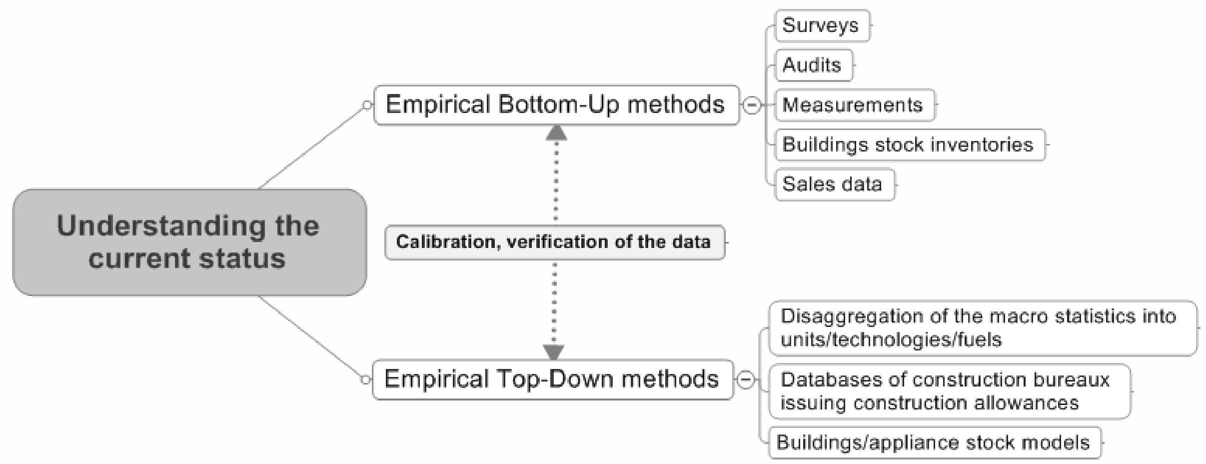

Figure 2. Methodologies for understanding the current status of energy consumption in buildings

5.2 Methodologies for measuring policy outcome

Assessments of policy tools targeted at efficiency improvement in buildings may help to understand the actual savings of energy, actual programme spending and its effectiveness, impact on buildings and equipment performance, policy weaknesses, and opportunities for policy improvement. Khan *et al*. (2007) found that, out of the whole body of literature in the field, the largest part studies the final effects of policies. These are:

- Target achievement or effectiveness of the policy tool, i.e. the extent to which the policy tool delivered the target set
- Net impact of the policy tool, i.e. the extent to which a policy instrument made a difference compared to the situation without it
- Cost-efficiency, i.e. the relationship between the net impact and spending required to achieve this impact

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25 http://www.eia.doe.gov/emeu/recs/
26 http://www.eia.doe.gov/emeu/cbecs/
27 http://www.oee.nrcan.gc.ca/corporate/statistics/neud/dpa/data_e/sheu07/tables.cfm?attr=0
28 http://www.oee.nrcan.gc.ca/corporate/statistics/neud/dpa/data_e/cibeus_description.cfm?attr=0
29 http://www.bmwi.de/English/Navigation/Service/publications.html
30 http://www.bmwi.de/English/Navigation/Service/publications.html

Relative to the time, policy impact assessment can be ex-ante and ex-post. Ex-ante assessment is a forecast made before the implementation of a policy instrument whereas ex-post assessment evaluates policy instruments after or during their implementation. Like the evaluation of the potential for energy-efficiency improvement, assessment of policy impacts may be conducted using both approaches – bottom-up and top-down (For more details, see Section 5.2.1.4.).

Technically, the approaches of ex-ante and ex-post evaluations are similar, but for ex-ante simulations, instead of using the data from measurements, surveys, and statistics, assumptions on expected values must be made. The rough approach of ex-ante assessment would be to estimate the potential for energy efficiency and then evaluate, based on expert judgment, the share of this potential to be captured with the policy tools planned. Ideally, besides information on the scope of potential available and existing barriers to its penetration, ex-ante simulations should be based on knowledge gained from previous ex-post monitoring and evaluation (Khan *et al*. 2007).

As experts assert (Köppel and Ürge-Vorsatz 2007; Farrell 2009), within a large body of literature on the topic, there have been only a few examples of robust ex-ante and ex-post evaluations. Like assessments discussed in previous chapters, the methodologies vary to a large extent, making it difficult to compare performance amongst policy tools and performance in different countries. Further, the key methodological papers and meta-studies are discussed.

5.2.1 Key methodological papers

This section summarises the key methodological papers on policy impact evaluation. The review is structured in chronological order, to allow development of a theme. These key papers are listed in Table 9.

Table 9. Key studies which contain extensive methodological research on policy impact evaluation

Title	Implementing organisations	Reference
Greenhouse Gas Mitigation Assessment: A Guidebook	Lawrence Berkeley National Laboratory	Sathaye and Meyers 1995
Evaluating Energy Efficiency Policy & Demand-Side Management Programmes – Evaluation Guidebook	IEA Demand Side Management Programme	IEA DSM 2005a
Model Energy Efficiency ProgrammeImpact Evaluation Guide	US Environmental Protection Agency	US EPA 2007a,b
Evaluation and Monitoring for the EU Directive on Energy End-Use Efficiency and Energy Services (EMEEES project)	Consortium of 21 partners led by Wuppertal Institute	Thomas 2009

5.2.1.1 A GHG mitigation assessment guidebook of the LBNL

Sathaye and Meyers (1995) were probably among the first to develop guidelines for assessment of mitigation technological potential and policy evaluation, with a special focus on developing countries and transition economies. The guidelines explained both bottom-up and top-down modelling components. The guidelines covered non-energy sectors, energy supply and demand sectors, including residential and commercial buildings. Particular for the buildings sector, the guidelines suggest assuming that policies and programmes capture a fraction of the savings potential. Mechanically, it could be illustrated as a supply curve of energy efficiency shrunk to the degree at which the potential can be realised and moved up due to policy costs (Figure 3). Such an approach provides an ex-ante estimate of policy outcome in the year the supply curve is built for. The guidelines do not detail the procedures of adjusting the supply curve of energy efficiency to the impacts of policies, but provides some references to further develop this idea.

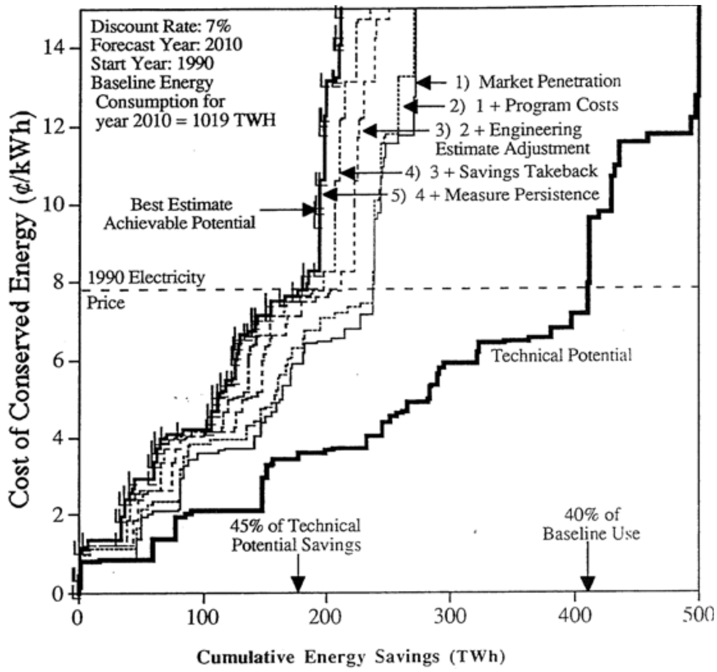


Figure 3. Illustration of achievable conservation potential in US residential electricity use in 2010

Source: Brown 1993.

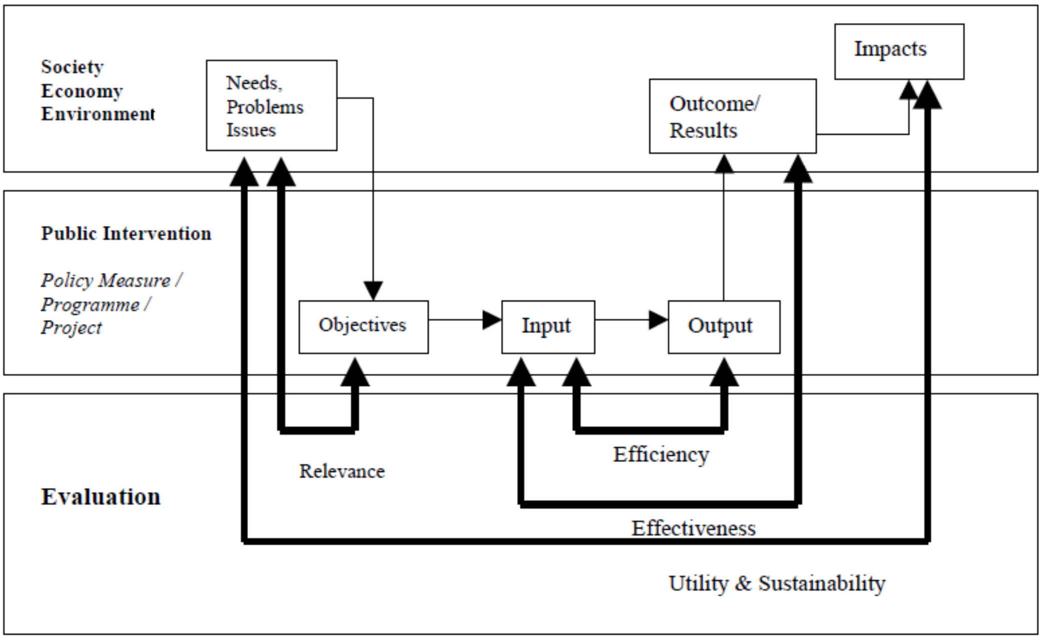
5.2.1.2 The IEA DSM guidebook

The IEA Demand Side Management Programme issued its Guidebook (IEA DSM 2005a) to assist with evaluation of regulatory, informative, economic policy tools and voluntary agreements which affect energy-using sectors. The guidebook aims to help set up realistic expectations with regard to policy evaluation, identify appropriate analytical methods, specify data needed and their sources, and set the schedule depending on the phase of the policy cycle. The guidebook focused only on policy outcomes such as changes in awareness level, changes in attitude to adoption of energy–efficiency technologies, changes in availability and prices of efficiency equipment, changes in the market share of technologies, and other impacts which finally result in energy savings at the point of energy demand.

It was suggested that that policy evaluation should focus on seven steps listed below, and also illustrated in Figure 4. Each of these steps were extensively defined and described in the Guidebook. The steps are:

1. Policy measure theory, which is used for developing and implementing a measure.
2. The choice and specification of indicators showing the success of a measure.
3. The baselines for the selected indicators.
4. Assessment of outputs and outcomes of the policy measure.

5. Assessment of energy savings and emissions reductions, and other relevant impacts of the policy measure.
6. Calculation of cost, cost-efficiency and cost-effectiveness.
7. The choice of level of evaluation efforts: comprehensive, targeted, or review.



Evaluation Questions

- *Relevance*: To what extent are the objectives justified in relation to needs?
- *Effectiveness*: To what extents have the expected objectives been achieved?
- *Efficiency*: Have the objectives been achieved at lowest cost?
- *Utility & Sustainability*: Do the expected or unexpected effects contribute to a net increase in social welfare and sustainability?

Figure 4. Design of policy evaluation suggested by the IEA DSM Guidebook (IEA DSM 2005a)

The IEA DSM Guidebook also described how to evaluate three typical types of policy packages. For this, the approach was modified in the next steps: learning combination theory, making the right choice of indicators and baselines, running the impact assessment in the simplest form, understanding critical elements for each measure. The policy packages in focus were:

- Regulation, information and economic incentives
- Voluntary agreements, information, and economic instruments
- Market transformation: economic incentives (technology procurement), information and voluntary agreements

In summary, the IEA DSM Guidebook represents a very comprehensive source of methodologies for policy impact evaluation. It details to a significant degree the assessment procedures for key policy tools applied on the demand side, as well as their packages. The 2nd Volume of the Guidebook contains case studies for developed countries (see Section 5.2.2.3), but the procedures are universal and replicable in any world region.

5.2.1.3 US EPA Guides on programme impact evaluation

The US EPA (2007a) issued the Guide for Energy Efficiency Programme Impact Evaluation. The Guide is for evaluation of programmes – a group of projects with similar characteristics – not a policy tools although it could be applied to the latter as well. The Guide focused on three key impacts: estimates of gross energy savings, estimates of net energy savings (attributed to only this programme), and estimates of co-benefits, such as reduced air pollution. The process of programme impact evaluation, as recommended by the US EPA, (2007a) is presented below in Figure 5.

Another guide of the US EPA covers understanding cost-effectiveness of energy efficiency programmes (US EPA 2007b). This Guide suggests using five cost-effectiveness tests: the participant cost test, the utility/programme administrator cost test, the ratepayer impact measure test, the total resource cost test, and the societal cost test. The choice of the test should be justified by the research aim, though the participant cost test is used the most often.

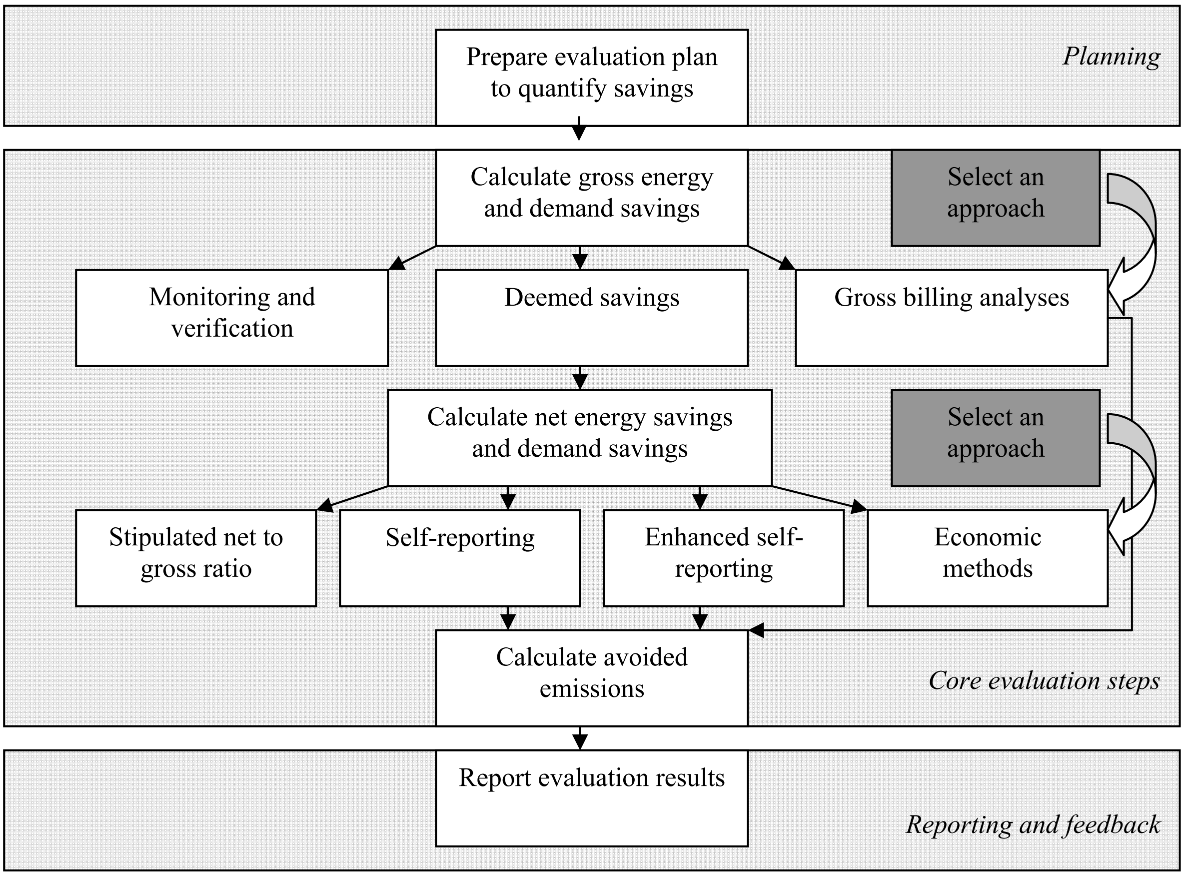


Figure 5. The process of programme impact evaluation

Source: US EPA (2007a).

The EPA Guides represent a straightforward and transparent framework for programme evaluation. It provides key definitions, describes standard evaluation planning, standard assessment approaches, suggests key equations, and lists main supporting literature. It does not focus on a particular sector or a programme type. Designed for programme evaluation, it is a useful but not sufficient source for assessment of policy tools.

5.2.1.4 The EMEEES project

One challenge for conducting high quality policy impact evaluations with their follow-up comparison has been recognised by many experts (Levine *et al*. 2007). To address this challenge within the EU, recently the Intelligent Energy Europe Programme supported a 21-party project called "Evaluation and Monitoring for the EU Directive on Energy End-Use Efficiency and Energy Services (EMEEES)". The project reviewed and classified evaluation methodologies for energy-efficiency policies, developed criteria for the choice of the most appropriate evaluation methodology for a particular policy tool, and attempted to suggest the methodologies for evaluation of policy packages. The project results were tailored to the purpose of the EU Directive mentioned; nevertheless, its theoretical results are also important for global knowledge.

First, the project made an attempt to find the universal definitions for policy evaluation methods, separating top-down and bottom-up methods. Thus, the project identified and described direct measurement, energy bill analysis, sales data analysis, population surveys, engineering estimates, deemed estimates, and stock modelling among bottom-up methods, while monitoring of diffusion indicators, monitoring of sectoral energy consumption indicators, and econometric modelling are among top-down methods. The project described how it is possible for bottom-up policy evaluations to allow correction of the double-counting (interdependent measures), multiplier effect (spill-over effect), free-rider effect, and direct rebound effect. For the top-down policy evaluation the project defined how to allow for adjustment to the structural effects, economic rebound effect, impact of earlier policy, effects of changes in world market energy prices, and other autonomous savings (Eichhammer *et al*. 2008).

Further, Vreuls *et al*. (2009) developed the methodology for bottom-up data collection, monitoring and calculation methods, while Thomas and Höfele (2009) identified the default values for bottom-up case studies which were then tested for 20 case studies. Lapillone *et al*. (2009) developed top-down methods for the evaluation of the energy savings, mostly based on the ODYSSEE[31] project data and Lapillone and Desbrosses (2009) applied the methodology developed for 14 top-down case studies. Boonekamp and Thomas (2009) suggested a combined bottom-up and top-down approach to match the results of both methods as much as possible.

The project searched for the best method for evaluation of energy-efficiency measures, based on typical data available in the EU. The criteria considered in choosing the method were data availability and reliability, simplicity of approach, effective and sufficient evaluation of impacts, and others (Eichhammer *et al*. 2008). Annex 2 and Annex 3 summarise the conclusions of this piece of work for the residential and tertiary sectors. The most common method for policy impact evaluation in the residential sector is deemed savings, i.e. estimations based on the assessment of unitary energy savings, multiplied by the number of units used in all instruments and for all uses (Nilsson *et al*. 2008). In some cases, it is complemented by stock modelling.

The project concluded on the impact evaluation of policy packages (Eichhammer *et al*. 2008). Based on literature review, it was found that top-down methods are the most powerful for this purpose. The project developed a separate stepwise procedure, which helps to eliminate overlaps between the policy impacts, which relies on both top-down and bottom-up elements.

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[31] ODYSSEE cover EU-27 + Norway and Croatia

In summary, the methodologies and the supporting documentation developed within the EMEEES project represent the strong base for policy impact evaluation in the countries of the EU. It helps manoeuvre and overcome the challenges of energy-efficiency assessments such as lack of data, setting up the input assumptions, and others. It suggests the solution for making the bridge between the results of bottom-up and top-down policy impact evaluation. The project recommendations are, however, very EU-specific nevertheless also useful for other world regions.

5.2.2 Key meta-studies

As mentioned before, the literature on policy impact evaluation in buildings relies on different methodologies, is often of poor quality, and is very fragmented. The present section reviews the main meta-assessments in the field and summarises their key results. These studies are listed in Table 10.

Table 10. Key meta-analyses on policy impact evaluation, which include the buildings sector

Title	Implementing organisations	Key reference	Coverage
Economics of Greenhouse Gas Limitation	UNEP Risoe Centre on Energy, Climate and Sustainable Development UNEPRISOE in collaboration with Lawrence Berkeley National Laboratory	Halsnaen *et al*. 1999	Argentina, Ecuador, Estonia, Hungary, Indonesia, Mauritius, Senegal, Vietnam Southern African Development Community (SADC), the Andean Group
Asia Least-Cost Greenhouse Gas Abatement Strategy (ALGAS)	Asian Development Bank, United Nations Development Programme (UNDP), and the Global Environment Facility	ALGAS 1999a–k	Pakistan, Republic of Korea, Thailand, Myanmar, China, Philippines, Bangladesh, India, Indonesia, Mongolia, Vietnam
Evaluating Energy Efficiency Policy Measures & DSM Programmes Volume II Country Reports and Case Examples used for the Evaluation Guidebook	IEA Demand Side Management Programme	IEA DSM 2005b	Regulation tools: Belgium, Canada, Denmark, Korea Information: Belgium, Canada, Denmark, France, Korea, Sweden Economic: Italy, Canada, Netherlands Voluntary agreements: Canada, Korea, Netherlands, Sweden Policy packages: Sweden, Belgium
MURE[32] database	Co-ordinated by the Institute of Studies for the Integration of Systems (Italy) and the Fraunhofer Institute for Systems and Innovation Research ISI (Germany)	MURE online	Countries of the EU + Norway, Croatia
Energy Efficiency: A Worldwide review. Indicators, Policies, Evaluation	World Energy Council	WEC 2004	Labelling and standards: Brazil, China, Japan, Thailand, UK, US Energy audits: Australia, Finland, Korea, Thailand, US Economic and fiscal incentives: China, Japan, Thailand, Philippines, Brazil, US, UK, Greece Building codes (new buildings): Australia, California, China, European Union, Germany, Hong Kong, Japan, Poland, Slovakia, Thailand

32 MURE (Mesures d'Utilisation Rationnelle

Title	Implementing organisations	Key reference	Coverage
Assessment of policy instruments for reducing greenhouse gas emissions from buildings	Center for Climate Change and Sustainable Energy Policy at Central European University	Köppel and Ürge-Vorsatz 2007	Worldwide
Evaluation and Monitoring for the EU Directive on Energy End-Use Efficiency and Energy Services (EMEEES project) EMEEES project	Consortium of 21 partners led by Wuppertal Institute	Thomas 2009	Energy efficiency commitment: UK FEMP: US Building EE: US EPS Building Code: Netherlands Building regulation: Italy Elsarefonden: Denmark Appliance labelling: Netherlands Energy + Europe: EU KfW programme: Germany Helles NRW : Germany Technology procurement : Sweden

5.2.2.1 ALGAS series and Economics of GHG Limitation

Starting in chronological order, two meta-studies with an extensive methodological component were developed for transition and developing economies. These are, first, the Asia Least-Cost Greenhouse Gas Abatement Strategy by the Asian Development Bank, United Nations Development Programme (UNDP), and the Global Environment Facility (ALGAS, 1999a–k), and the second, the Economics of Greenhouse Gas Limitation by the United Nations Environment Programme (UNEP) Collaborating Centre of Energy and Environment (CEEEZ 1999; CEEST 1999; EECG *et al*. 1999; FEDEMA 1999; Halsnaen *et al*. 1999a,b; Hydrometorological Service of Vietnam 1999; IDEE-FB 1999a,b; MENP 1999; Ministry of Environment, Republic of Estonia and Stockholm Environment Institute Tallinn Centre 1999; BPPT and PPLH-IPB 1999; Szlavik *et al*. 1999). Both series were guided by the same aims and similar research principles but applied different modelling approaches. The buildings sector was not studied separately in the majority of cases, but related options were included in overall national strategy. The studies aimed to identify technological opportunities for GHG emissions reductions and policy strategies which might help realise this potential. The studies applied bottom-up and top-down ex-ante modelling. Even though now outdated, the ALGAS and UNEP series have been so far the largest sets of studies run for transition and developing countries.

5.2.2.2 MURE database

The European database MURE[33] tracks and provide qualitative evaluation of the impact of completed and ongoing policies in the residential buildings and commercial sectors in the EU, Norway and Croatia. The database defines the scale of the impact in terms of “high”, “medium” and “low”, although the system for assigning these grades is not clear. For example, see Table 11 below.

33 URL: http://www.isis-it.com/mure

Table 11. Impact of planned, ongoing and completed mandatory standards for buildings

Countries	AU	BE	DK	FI	FR	DE	EL	IE	IT	LU	NL	PT	ES	SE	UK
Energy Performance Standards			M L L	U H	H H H H H	H	M L H	H H H H	M L L	U U	H H H	H	H H H H		H H
Minimum thermal insulation standards	H	H H	M			H H H	L		L	H H		H H	H H H H H H H H H H	M	H H
Countries	EU	BG	CY	CZ	EE	HU	LT	LV	MT	PL	RO	SK	SI	CR	NO
Energy Performance Standards	H H	M	H		H H			M	M L		H M	H H	H H	U U U	M M
Minimum thermal insulation standards	U U L	H	H	U U	H	M	U U U	M		H	H	H H	H H	H	M M H

Note: Impact is defined as **L** = Low, **M** = Medium, **H** = High, **U** = Unknown

Source: MURE database online, 2010.

5.2.2.3 IEA DSM case studies based on its Guidebook

Section 5.2.1.2 described the first Volume of the IEA Demand-Side Management Programme Guidebook (IEA DSM 2005a), on the methods suggested for impact evaluation of policy tools and their packages. The second volume of the Guidebook (IEA DSM 2005b) provided evaluation for 20 policies in selected countries, based on methodology developed (see Table 12 for details). The choice of examples was defined by the wish to present an important and interesting aspect of policy evaluation theory, and did not depend on data quality. The Guidebook tracked both ex-ante and ex-post evaluations and methods applied to conduct those evaluations. It did not compare the impacts of policy tools but described the degree to which these impacts investigated.

Table 12. Overview of elements of policy impact - assessment conducted for case studies in the IEA DSM Guidebook

	Case Country	**Theory**	**Indic ators**	**Base-lines**	**Output and outcome**	**Energy savings & emissions**	**Costs**	**Level of evaluatio n efforts**
Policy Type: Regulation								
Building codes	Belgium	+ (law)	-	-	+	-	-	B/C
Energy Efficiency Regulations for Residential Equipment	Canada	+ (law)	+	+/-	+	+	+	B
Energy management scheme for large buildings	Denmark	+ (law)	+	+	+	+	+	B
Minimum energy performance standards	South Korea	+ (law)	-	-	+	+	-	C
Energy Performance Standard (EPS) for houses	Netherlan ds	+ (law)	-	+	+	+	+	A/B

	Case Country	Theory	Indic ators	Base-lines	Output and outcome	Energy savings & emissions	Costs	Level of evaluation efforts
Policy Type: Information								
Local energy-efficiency information centres	Belgium	-	-	-	-	-/+	-	C
Energy guide for houses	Canada	-	+	+/-	+/-	+	-	B
Energy labelling of small buildings + (law)	Denmark	+ (law)	-	+/-	+	+	+	B
Free-of-charge electricity audit	Denmark	+	+	+/-	+	-	+	A
Project 'Red-Hot' (element of stand-by campaign)	Denmark	+	+	-	+	-	+-	A
The 'A' campaign 1999	Denmark	+	+/-	+/-	+	+	+	B/C
Promotional campaign for efficient ventilation	Denmark	+	+	+	+	+	+	A
Information campaign (2001)	France	-	-	-	+	-	+	B
Local energy information centres (Espaces Info Energie, EIE)	France	+	+/-	-	+	+	+	A/B
Audits ("Aides a la decision")	France	+/-	+	+/-	+	+	+	B
Energy audits in industry	South Korea	+/-	-	+/-	+	+	+	C
Energy audits in buildings	South Korea	+/-	-	+/-	+	+	-	C
Energy Efficiency Rating Labelling	South Korea	+	-	+/-	+	+	-	A
Information centres in local region	Sweden	+	-	-	+	+	-	A/B
Information and education programme 1998-2002	Sweden	-	+	+/-	+/-	+	-	B
Policy type: Economic								
Criteria adopted for the evaluation of primary energy savings in end-uses / EE Certificates	Italy	-	+	+	-	+	+/-	C
Rebate programme for highly efficient electric inverters	South Korea	-	-	-	+	+	-	C
Financial incentives for DSM	South Korea	+	-	-	+	+	+	C
Energy premium scheme households	Netherlands	+	-	+/-	+	+	+	A/B
Energy Investment Reduction (EIA and EINP)	Netherlands	+	-	+/-	+	+	+	C

	Case Country	Theory	Indicators	Base-lines	Output and outcome	Energy savings & emissions	Costs	Level of evaluation efforts
Policy Type: Voluntary Agreements								
Canadian Industry Program for Energy Conservation (CIPEC)	Canada	+/-	+	+	+/-	+/-	-	A/B
Voluntary Agreements	South Korea	+/-	-	+/-	+	+	-	C
Voluntary Agreements on Industrial energy Conservation 1990 – 2000	Netherlands	+	+/-	+/-	+	+	+	A/B
Eco-energy	Sweden	+/-	+	+	+/-	+/-	-	A/B
Policy Type: Combination of policy measures								
Rebate programme for household appliances	Belgium	+	+/-	+/-	+	+	+	A/B
STEM programmes	Sweden	+	+	+/-	+	+/-	+/-	A/B

Note: + = Attention, +/- = Some attention, - = (Almost) no attention. A: comprehensive evaluation, B: targeted evaluation, C: review evaluation

Source: IEA DSM (2005b).

5.2.2.4 A worldwide review of the World Energy Council

The World Energy Council (WEC 2001, 2004) conducted a review of energy efficiency policies in selected countries worldwide. The review conducted a survey through a questionnaire sent to the WEC and ADEME networks. The survey focused on five policy tools in detail. For this, country experts prepared reports of 10-20 pages on national experiences with these policy tools, which were later harmonised and unified. Detailed reports were prepared for efficiency standards and labelling of household electrical appliances, new financing schemes (e.g. guarantee funds, innovative funds), and voluntary/negotiated agreements with large energy consumers or equipment manufacturers. The report concluded that: regulations are the most popular tool in the domestic sector; buildings codes have been extended to existing buildings; the coverage of labelling schemes and standards has grown; tax incentives prevail over direct subsidies; audits have often become mandatory; energy service companies are becoming popular, etc. The report identified building codes and labelling as the most effective policy tools; market instrument were also identified as policies playing a significant role in the policy mix. The research represents a broad overview of policy characteristics and results conducted in a common framework; conclusions made in the review are based on qualitative assessment and expert judgements after the investigation of information gathered.

5.2.2.5 Global meta-analyses for the IPCC, the GEA, and the UNEP

Over the last five years, the research group at Central European University has been running research on comparison of buildings policy performance for different countries and regions. The estimates are detailed in Köppel and Ürge-Vorsatz (2007) and are also summarised in world peer-review assessments Levine *et al*. (2007) and Ürge-Vorsatz *et al*. (2007). The research relied on published literature, databases (such as the MURE database), expert interviews, personal contacts, and research requests to locations with particularly weak research experience (developing countries). Ex-post evaluations were preferred to ex-ante assessments, if both were available. The following criteria were applied to policy evaluation:

- Effectiveness – i.e. the degree to which the policy instrument achieves its goal – was assessed based on expert judgment, as High, Medium, or Low
- Cost-effectiveness of CO_2 reduction, in terms of US$/t$CO_2$ evaluated in a quantitative[34] and a qualitative way, based on expert judgement, as High, Medium, and Low
- Barriers, remediates, advantages, success factors – explaining the reasons for the success or failure of policy instruments – is rather qualitative

Table 13 summarises results for all buildings policy tools which were evaluated in the research. The research represents the most comprehensive meta-analysis of policy tools related to buildings energy-efficiency worldwide.

Table 13. The impact and effectiveness of selected policy instruments, aimed at mitigating GHG emissions in the buildings sector through use of best practices

Policy instrument	**Emissions Reduction Effective-ness[a]**	**Cost-effective-ness[b]**	**Special conditions for success, major strengths and limitations, co-benefits**
Appliance standards	High	High	Factors for success: periodic update of standards, independent control, information, communication and education.
Building codes	High	Medium	No incentive to improve beyond target. Only effective if enforced.
Public leadership programmes, inc. procurement regulations	High	High/ Medium	Can be used effectively to demonstrate new technologies and practices. Mandatory programmes have higher potential than voluntary ones. Factor for success: ambitious energy efficiency labelling and testing.
Energy efficiency obligations and quotas	High	High	Continuous improvements necessary: new EE measures, short-term incentives to transform markets, etc.
Demand-side management programmes	High	High	Tend to be more cost-effective for commercial sector than for residences.
Energy performance contracting/ESCO support[c]	High	Medium	Strength: no need for public spending or market intervention, co-benefit of improved competitiveness.
Energy efficiency certificate schemes	Medium	Medium	No long-term experience. Transaction costs can be high. Institutional structures needed. Profound interactions with existing policies. Benefits for employment.
Kyoto Protocol flexible mechanisms[d]	Low	Low	So far limited number of CDM & JI projects in buildings.
Taxation (on CO_2 or fuels)	Low	Low	Effect depends on price elasticity. Revenues can be earmarked for further efficiency. More effective when combined with other tools.

[34] The costs included the investment (capital and implementation) costs of policies, as well as the direct economic benefits yielding from energy savings. The high cost-effectiveness was assigned if the costs of GHG reduction were negative or benefit-cost ratio was more than 1. The medium cost-effectiveness was associated with the costs of GHG reduction were in the range of US$0-25/t$CO_2$eq. or the benefit-cost ratio was in the range of 0.8-1. The low cost-effectiveness meant the costs of GHG reduction higher than US$25/t$CO_2$eq. and the cost-benefit ratio below 0.8.

Policy instrument	Emissions Reduction Effective-ness[a]	Cost-effective-ness[b]	Special conditions for success, major strengths and limitations, co-benefits
Tax exemptions/ reductions	High	High	If properly structured, stimulate introduction of highly efficient equipment and new buildings.
Capital subsidies, grants, subsidised loans	High	Low	Positive for low-income households, risk of free-riders, may induce pioneering investments.
Labelling and certification programmes	Medium/High	High	Mandatory programmes more effective than voluntary ones. Effectiveness can be boosted by combination with other instruments and regular updates.
Voluntary and negotiated agreements	Medium / High	Medium	Can be effective when regulations are difficult to enforce. Effective if combined with financial incentives, and threat of regulation.
Education and information programmes	Low / Medium	High	More applicable in residential sector than commercial. Success condition: best applied in combination with other measures.
Mandatory audit and energy management requirement	High, but variable	Medium	Most effective if combined with other measures such as financial incentives.
Detailed billing and disclosure programmes	Medium	Medium	Success conditions: combination with other measures and periodic evaluation.

Notes:
[a] *includes ease of implementation; feasibility and simplicity of enforcement; applicability in many locations; and other factors contributing to overall magnitude of realised savings*
[b] *Cost-effectiveness is related to specific societal cost per carbon emissions avoided.*
[c] *Energy service companies*
[d] *Joint Implementation, Clean Development Mechanism, International Emissions Trading (includes the Green Investment Scheme)*

Source: Barker *et al*. (2007).

5.2.2.6 Case studies of the EMEEES project

Section 5.2.1.4 described the work on the description and harmonisation of methodologies for policy impact evaluation within the framework of the EMEEES project. The methodologies developed were applied to thirty-four case studies, eleven of which were for the residential and tertiary sectors (Table 14). The conclusion from the table is that the buildings sector is more convenient to study with various bottom-up methods, and that among them, deemed estimates – unitary energy savings multiplied by the number of units – are the most popular. Deemed estimates are often mixed with information from previous ex-post evaluations. Among top-down methods, equipment consumption and its penetration rates is the most used method. The majority of listed bottom-up studies allowed the correction of double counting, the multiplier effect, the free-rider effect, and the direct rebound effect. For evaluation of the research comprehensiveness, please see Section 5.2.1.4.

Table 14. Evaluation methods used for case studies in the EMEEES project

Energy efficiency measure	**Country**	**Main type of measure**	**Bottom-Up**						**Top-Down**		
			Direct measurement	Bills and sales data analysis	Enhanced engineering estimates	Mixed deemed and ex-post estimate	Deemed estimate	Bottom-up modelling	Equipment diffusion/ specific consumption	End-use sector consumption indicators	Econometric modelling
Energy efficiency commitment	UK	R/F				X	X	X	X		
Federal energy management programme	US	R		X	X		X	X		X	
Building energy efficiency	US	F			X		X	X			
EPS Building Code	Netherlands	R	X				X	X			
Building regulation	Italy	R			X	X	X				
Elsarefonden	Denmark	F		X		X	X				
Appliance labeling	Netherlands	I/F		X				X	X		
Energy + Europe	EU	I				X	X		X		
KfW programme	Germany	F				X	X	X			
Helles NRW	Germany	F/I					X				
Technology procurement	Sweden	I/F						X	X		

Note: R – regulatory, F – financial, I – informative.

Source: Thomas (2009).

5.3 Methodologies used for policy process evaluation

As mentioned before, the majority of studies focus on evaluation of policy impacts, such as energy savings and policy cost-effectiveness, whereas the whole policy implementation process, its weaknesses and advantages, are often neglected. This section focuses on research about process evaluation, i.e. a design process of policy tools, their implementation and enforcement.

Experts agree that even a brilliantly designed policy tool may lose its value if inadequately enforced. Such an example is discussed, for instance, in Köppel and Ürge-Vorsatz (2007) for building codes. The study cited the UK and Dutch cases, where new building compliance with building codes is only 40% (Deringer *et al*. 2004) and 20% respectively (Klinckenberg and Sunikka 2006). In developing countries, the situation is often more dramatic. Deringer *et al* (2004) note that building codes there exist only on paper, due to insufficient implementation and enforcement, corruption and other problems. The authors cited a study which showed 70% compliance of new buildings to the standard, compared to real compliance of about 30%. Policy tools in developing countries are often supported by donor agencies and when the project finished - usually after the design and introduction phase – the policy tool is not well implemented.

Despite the importance of the policy process evaluation, literature review on policy process evaluation in the field of energy efficiency appeared very scarce and fragmented. The key research in the public domain has been the project entitled Active Implementation of the European Directive on Energy Efficiency (AID-EE), supported by the Intelligent Energy Europe Programme. The authors (Khan *et al*. 2007) suggested a "theory-based policy evaluation" which examines the whole policy process. This method is translated into six steps (below). It is assumed that the policy process (Figure 6) is further improved according to conclusions of the analysis. The six steps are:

1. Make an initial characterisation of the policy instrument
2. Draw up a policy theory
3. Translate the policy theory into concrete indicators and identify success and failure factors
4. Draw up a flow-chart of the policy theory
5. Collect information to verify and adjust the policy theory
6. Collect additional information and analyse all aspects of the policy theory (including target achievement, net impact and cost effectiveness)

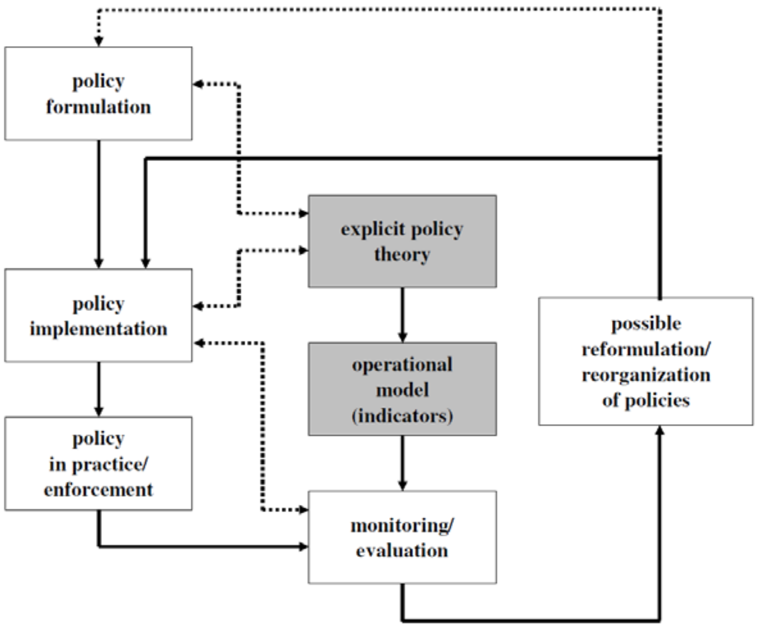

Figure 6. Policy cycle

Source: Khan *et al*. (2007).

The project applied the traditional ex-post policy impact evaluation, as well as evaluation based on the method developed, to twenty case studies across Europe (Table 15). The conclusions of the traditional assessment are summarised below:

1. Quantitative objectives and time frame of policy tools are often lacking.

2. Policies often have multiple objectives, the impact of some of which cannot be separated.
3. Impacts of separate policy instruments are difficult to separate and they are often assessed as a package.
4. Quantified targets usually exist for regulatory and voluntary agreements, whereas no such targets exist for informative instruments.
5. Most policy tools benefit from interrelation, but research on the synergy effects of policy packages is lacking.
6. Cost-effectiveness data is usually limited and of limited reliability.

In addition to the traditional analysis, the report conducted assessed policy tools against the theory-based method developed. The key lessons learnt are as follows:

1. The policy process evaluation helps us understand success and failure factors of policy instruments, when combining quantitative assessment with qualitative factoral analysis.
2. While for most instruments monitoring information has been regularly collected, its quality and reliability is low, especially as concerns quantitative information.
3. Lack of time and resources for data collection is common.
4. Even though the instrument is tailored to overcome a specific barrier in a given country, its success very much depends on the design of the instrument and the way it is implemented, rather than on its nature.
5. It appeared that policy-makers had only a vague idea about the work of policy instruments, which results in a phenomenon that ex-post assessments had to make a reconstruction, which might result in misinterpretation.
6. The effects of the cause-effect relationship are not always clear when applying policy instruments: for example, a policy tool may have several effects or a delayed effect.
7. Finally, among identified success and failure factors, it is difficult to determine the most important.

Table 15. Case studies of the AID-EE studies

Policy instrument	Country	Sectoral coverage	Evaluation indicators	Period followed
Building code	NL	Households, services	Target achievement; total net impact, annual savings as baseline share, its uncertainty; total governmental costs, annual costs, cost-effectiveness (€/GJ final energy saved); characteristics of success	1996-2004
Buildings energy regulation	IT	Households	Characteristics of success.	2003-2005
Top runner approach	JP	Households, services	Target achievement, characteristics of success.	1999-2005
Energy-Efficiency Commitment	UK	Households	Target achievement; total net impact, annual savings as baseline share, its uncertainty; total governmental costs, annual costs, cost-effectiveness (€/GJ final energy saved), characteristics of success.	2002-2005

Policy instrument	Country	Sectoral coverage	Evaluation indicators	Period followed
Obligation to have an energy manager	ITA	Services	Total governmental costs, annual costs; characteristics of success.	1999-2003
Mandatory targets for electricity grid companies	BE	Households, Services	Total net impact, annual savings as baseline share, its uncertainty; total governmental costs, annual costs, cost-effectiveness (€/GJ final energy saved); characteristics of success.	2003-2004
Audit programme	FI	Services	Target achievement; total net impact, annual savings as baseline share, its uncertainty; total governmental costs, annual costs, cost-effectiveness (€/GJ final energy saved); characteristics of success.	1992-2004
Public leadership program	US	Public	Target achievement; annual savings as baseline share, uncertainty; total governmental costs, annual costs, cost-effectiveness (€/GJ final energy saved); characteristics of success.	1985-2004
Energy efficiency procurements	SE	Services	Target achievement; total governmental costs, annual costs; characteristics of success.	2001-2005
Advice service	DE	Services	total governmental costs, annual costs; characteristics of success.	1996-2003
Local energy advisors	SE	Households, Services	Total net impact, annual savings as baseline share, its uncertainty; total governmental costs, annual costs; characteristics of success.	1998-2004
Appliances labelling	NL	Households	Target achievement; total net impact, annual savings as baseline share, its uncertainty; total governmental costs, annual costs, cost-effectiveness (€/GJ final energy saved); characteristics of success.	1995-2004
Soft loans for buildings	DE	Households	Target achievement; total net impact, annual savings as baseline share, its uncertainty; total governmental costs, annual costs, cost-effectiveness (€/GJ final energy saved); characteristics of success.	1996-2004
Energy investment deduction scheme	NL	Services	Total governmental costs, annual costs, cost-effectiveness (€/GJ final energy saved); characteristics of success.	1997-2004

Source: Khan *et al*. (2007).

In summary, the project has formulated well the problem and has suggested the method for policy process evaluation. The method is however is not exhaustive, can be further developed, and states itself the number of questions which should be resolved.

5.4 Opportunities for further research

The chapter discussed various methods for a diagnosis of the current situation, methods for impact evaluation of energy-efficiency policies in buildings, and methods for process evaluation of these policies. This section summarises the results of this review and suggests opportunities for further research.

First, the review revealed that, even in the most advanced countries, the structure of buildings' energy consumption and the underlying factors are poorly understood. This is especially true of developing and transition economies, where data collection for such analysis is not demanded by policy-makers, and thus is not conducted. For this reason, more efforts are needed to raise information awareness among policy makers, on the necessity to collect and analyse the data on the energy-demand side.

Second, the chapter identified a range of questions about policy impact evaluation for further research. The chapter showed that there have been a number of methodologies and case studies of policy impact evaluation produced worldwide. However, as experts report, many of these evaluations are of poor quality and rather fragmented. The methodological assumptions vary to a large degree, which makes evaluations difficult to compare. In addition, policy tools are usually combined to benefit from their synergy effect, but evaluation of such packages is technically challenging and therefore rare. With regard to geographical coverage of the research, the vast majority is on EU member states and the US. Developing countries and transition economies suffer from an extreme lack of recent comprehensive policy evaluations. The review showed the importance of developing a universal guidebook for policy impact evaluation, which would be applicable to a broad range of countries depending on data availability. The guidebook, if properly used, would guarantee the robustness, reliability, and comparability of policy impact evaluations. Transparent and high-quality information about the effectiveness and cost-effectiveness of policy tools in some countries would stimulate adoption of these policies in other countries. Further, a guidebook on data collection for policy impact evaluation should be issued, to assist governments and implementing agencies with information about the need for such research. Further, more country studies of both ex- and follow-up ante- studies – especially in developing countries and transition economies – are needed, for effective evidence-based policy-making. A good idea is also to create a pool of buildings policy evaluation studies, similar to the MURE database (which covers energy-efficiency policies in the EU only) or the CLASP database (covers only the standards and labelling programme worldwide) but with a wide policy and geographical coverage.

Third, the chapter cited to the extensive research on policy process examination. It provided evidence that policy results depend not only on design of a policy, but also on its implementation and enforcement. However, based on the literature available, it was concluded that the cycle of energy-efficiency policies in buildings is hardly studied. Even though associated with numerous challenges, policy process research is of vital importance for policies, to enable them to deliver their promises. Therefore, there is an acute need for research frameworks and methodologies which would promote understanding of the reasons for policy failures, depending on country-specific conditions. Once the methodology is developed, its urgent implementation is needed, to allow for the correction of policy processes as soon as possible, for the best policy effects.

6 CROSS-CUTTING ISSUES

As chapters on the potential, barriers, and policies concluded, the research greatly varies in terms of methodologies and specific assumptions applied. This chapter briefly discusses the methodological issues which are relevant for all these topics.

6.1 Modelling period

The majority of studies investigates the potential for energy efficiency in buildings for the short- and medium- term future, i.e. up to 20 - 30 years ahead, and monitors policy implementation for up to 10 years. This is because of the challenge ofg making assumptions about factors such as emerging technologies, and their technical and cost characteristics, for a longer period. It is argued that the potential for energy efficiency relative to the baseline does not change significantly over time. Taking into account this assumption, the policy impact should remain significant, if updated regularly.

6.2 Baseline and potential definition

There are different types of baselines considered by the literature. These are most often frozen efficiency, low efficiency/low carbon, business-as-usual (BAU) and other baselines. A frozen efficiency baseline implies that no energy-efficiency improvement and no reduction of specific energy consumption occur. A low efficiency/low carbon baseline typically assumes some (low) penetration level of energy efficiency/low carbon technologies. A BAU baseline assumes that no new energy efficiency and low carbon policies are implemented, additionally to those which have been already realised, and that energy and carbon intensities change because of market forces.

Similarly, there is a variation in definition of the energy efficiency potential used. As a consequence of the second law of thermodynamics, there is a minimal energy required to provide a service. The thermodynamic (theoretical) potential is rather uncertain and relies on the development of new technologies (Halsnaes *et al*. 2007); also, this potential can be reduced through redefinition of the tasks when the understanding of a service changes. Depending on the technical, economic and social feasibility of technological options and market barriers hindering their application, the efficiency/mitigation potential estimates are often further classified as technical, economic, or market potentials, depending on the assumptions used for their derivation. Rufo (2003) concluded that, typically, technical potential options are those available with application of the current technologies. Among them, one can pick out economic potential options which are also often referred to as cost-effective, i.e. those options associated with net negative costs (benefits from energy saved are higher than costs incurred). Market potential options are economic potential options, narrowed by the current market conditions without implementation of new policies, reforms or measures. Policy potential is referred to as the market potential which it is possible to realise with the policy tool in question. The relationship between different types of baselines and potentials is presented in Figure 7.

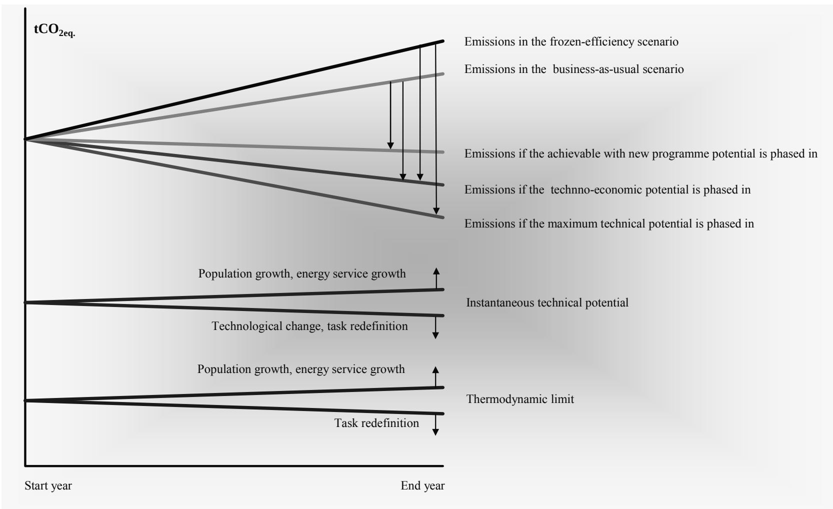

Figure 7 Alternative definitions of baselines and efficiency potentials

Source: adapted from Koomey et al. (1996).

6.3 Technology development modelling

One of the biggest challenges of energy-efficiency modelling into the future is envisioning technological development. Below, the experience of international research groups in considering technological development in their studies, is summarised:

- First, it is possible to consider mainly known (old and revolutionary) technologies and assume that their characteristics improve over time. The technologies are replaced at least once during the project period.
- Second, some literature suggests modelling technology development by merging econometric and bottom-up technological modelling (see the LIEF model by Ross and Hwang (1992)). The approach implies modelling through changes in real energy intensity due to technical change and energy-price effects, rather than modelling of specific technologies or end-uses.
- Third, the future-specific technologies themselves are not modelled but their extra energy savings and costs, for a given carbon/energy price increase based on, for instance, investment into R&D (see IAG (2002) as an example).

6.4 Penetration/uptake of technologies

Studies have applied several approaches to modelling penetration/saturation rates of technologies. As examples below show, penetration of technologies can be assumed exogenously (in most cases), estimated based on direct cost characteristics (e.g. internal rate of return of technology). In the first case, the saturation rates are obtained based on interviews and a literature review. In the second case, models assume that the technology options can compete and penetrate the market based on their relative economics (capital and operation and maintenance costs) within each energy end-use. For example, the IAG (2002) built up functions of future technological uptake depending on the level of the rate of return; in turn, the potential of technologies is a function of technological update because of attractiveness of this technology for investments.

6.5 Costs of technologies

Most often, the future costs of technologies are assumed based on market reviews and interviews. A very popular method of calculating the future costs of technologies is to apply learning curve analysis (Berglund and Söderholm 2006). The approach is based on the assumption that it is possible to measure the empirical relationship between the cumulative experience of a given technology and related cost reduction, i.e. a technology becomes cheap through its increased application and learning-by-doing. Typically, studies measure the effect of such learning-by-doing through the progress ratio, which indicate the cost change (in %) for a given technology resulting from each doubling of capacity (or production). The most commonly employed learning curve is dependent on cumulative capacity only (single factor supply-curve). Several other studies have attempted to incorporate R&D investments as additional drivers of innovation and account it in the learning-by-doing effect (two-factor learning curves). Besides this approach, when the technological costs decline over time as the penetration of technology increases, it is possible to incorporate technology learning linked to investment cost, whereby additional investment results in additional learning, which results in additional investment and so on (de Feber 2003; Gielen *et al*. 2004). However, this approach is used less often.

6.6 Discount rates

The cost effectiveness of mitigation options is very sensitive to the discount rate chosen for the analysis. Studies often use consumer discount rates that are based on expected rates of return of competing investments. Sometimes, somewhat lower discount rates are used to identify the economic potential from a social perspective. Sathaye and Meyers (1995) propose not discounting costs and benefits of GHG emissions at all, because not discounting them assumes the future economic damage which is caused by a GHG increase at the real rate. This is probably true, because this effect is likely to increase dramatically, and is largely unknown. Another approach is setting the discount rate as high as 100%, based on observed consumer behaviour (often referred to as 'hurdle' rates) and considering all possible costs associated with the implementation of mitigation measures discounting direct investment, operation, and maintenance costs (Rufo 2003). At the same time, even small changes in the discount rate can affect the costs of future technology options and their financial indicators. For instance, AIM (2004) used 5%, as well as 33%, to highlight high investment risk for energy-efficiency equipment in the residential sector. The result of the reduction potential for the 5% discount rate was 255Mt higher than for the second one (at the negative mitigation cost).

6.7 Summary

This chapter provided examples of assumptions of energy efficiency assessments which have a large impact on the assessment results, and which vary from study to study. The review showed that each assumption itself represents a significant issue for research, and different research groups approach these issues from different angles. From the point of view of comparability of results of studies, it is convenient to have these assumptions simulated in such a way as to make studies comparable if needed. This conclusion is in line with summaries of other chapters, which call for a unification of energy efficiency assessment methodologies.

7 CONCLUSION

This paper examined the state of knowledge of energy-efficiency assessment in buildings. It reviewed the key methodologies for evaluation of the technological and non-technological potentials for energy savings, barriers to potential realisation, and policies which help overcome these barriers. These key approaches and methodologies are summarized in Figure 8. Further, the key conclusions of the paper are summarised.

There are numerous existing mature technologies which are able to reduce conventional energy consumption in existing and new buildings by 80% and 100% respectively, which is illustrated by existing practices. Such investments in energy efficiency may be cost-effective. Therefore, technologically, there are no constraints to the transformation of the buildings sector; the challenge is, rather, to accelerate technological diffusion to the market worldwide. Furthermore, the research available attributes 10-100% of energy consumption difference in population groups to non-technological factors, such as lifestyle and culture.

There have been different approaches developed worldwide to calculate the technological potential for energy efficiency improvement and to understand possible savings due to change in energy consumption patterns. Even though some methodologies are similar, they vary to a large extent and apply different assumptions, which make it challenging to conduct cross-sectoral and cross-national comparisons, as well as tracking the historical sectoral performance. The relationship between technological potential and non-technological potential is not well understood and, furthermore, no methodologies exist to evaluate such a link. For these reasons, universal guidelines are important for the development of methodologies for technological and non-technological potential evaluation worldwide.

In general, technological potential is better researched than non-technological opportunities. Existing studies on non-technological potential focus on its scale, but do not specify the costs of realising it. It was suggested that if a relatively large set of literature on the impact assessment of interventions existed, mapping of the impact route of actions could lead to identifying the numerical value and cost of non-technological potential.

Further, the existing literature emphasises the importance of understanding the barriers to energy-efficiency penetration in the buildings sector, but the existing research does not go beyond identification of these imperfections. At the same time, policy-makers would benefit from understanding the quantified importance of these barriers, their ranking, and cumulative effect. For existing studies, the methodologies vary to a large extent, which makes it difficult to conduct cross-country comparison. Barriers for energy efficiency in buildings represent a large area for further research.

This paper also discussed approaches and methodologies to policy evaluation. A distinction was made between energy-efficiency policy impact evaluation and examination of the policy process. Above all, it was revealed that the structure of buildings-sector energy consumption and the underlying factors are poorly understood. Therefore, more efforts are needed to raise information awareness about the necessity to collect and analyse data on the energy-demand side among policy makers. This would allow for greater understanding of the priorities and trends to promote.

The paper reviewed the key literature on policy impact evaluation, including methodological guidelines and large meta-studies. The review found the knowledge to be very fragmented, and dominated by single policy impact research, whereas in reality, policy is more often implemented as a policy package. The review revealed that the methodological assumptions vary to a large degree, which makes evaluations difficult to compare. This is why – as with the research on potentials – the review showed the importance of developing a universal guidebook for policy impact evaluation, which would be applicable to a broad range of countries depending on data availability. The guidebook, if properly used, would guarantee the robustness, reliability, and comparability of policy impact evaluations. It was advised that a pool of buildings policy evaluation studies, with a wide policy and geographical coverage, should be designed.

The paper provided evidence that policy results depend not only on design of the policy but also on its implementation and enforcement. However, only an insignificant share of the literature focuses on policy cycle analysis in the field of buildings energy efficiency. Given this lack of knowledge, the paper highlighted the need for research frameworks and methodologies which would better our understanding of the reasons for policy failures, depending on country-specific conditions.

All subjects of research in this paper are better studied in developed countries, whereas developing and transition countries benefit from only a few and mostly outdated studies. Taking into account energy security and climate challenges facing these countries, it is important to expand research activities to these under-researched geographical areas.

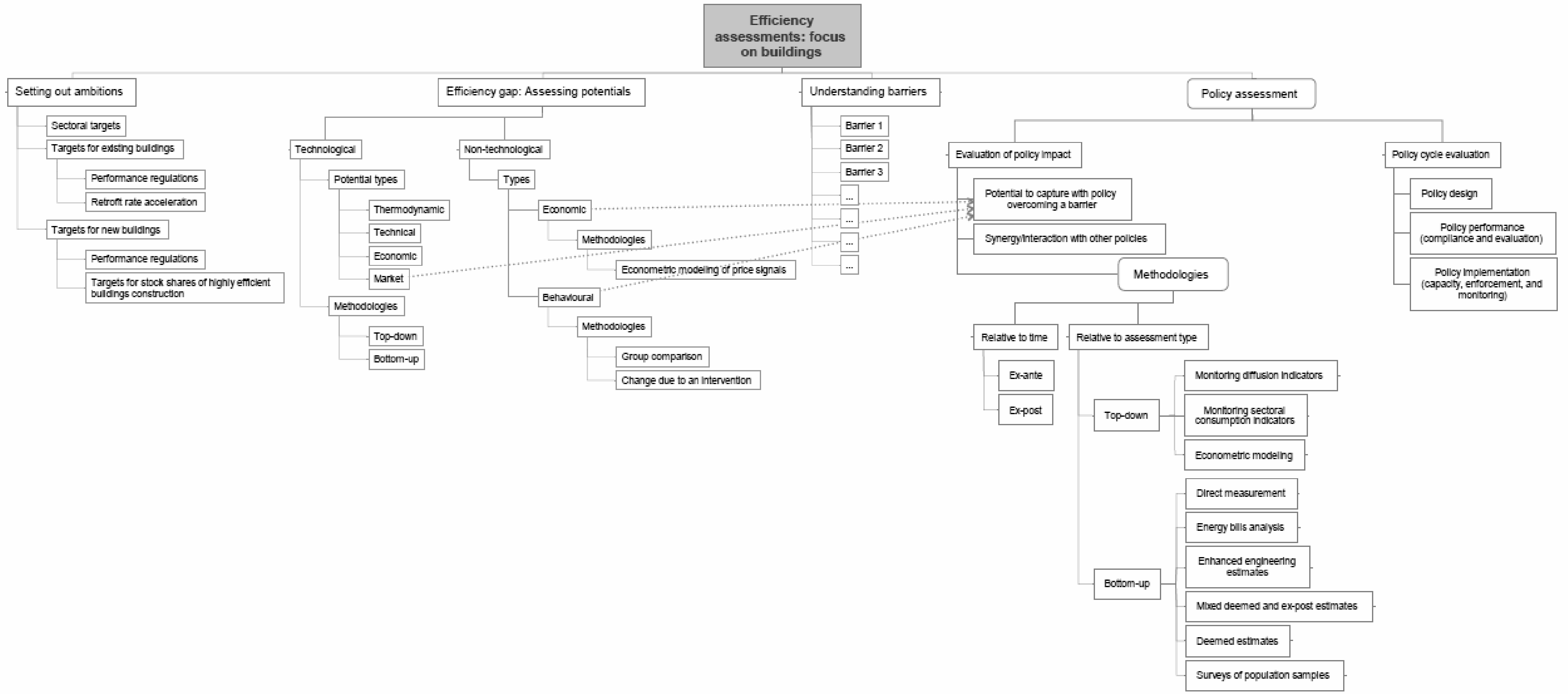

Figure 8. Architecture of energy efficiency assessment in buildings

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9 Annexes

Annex 1. Policy instruments chosen for the study and their definitions

Policy instrument	Definition
Appliance standards	Define a minimum energy efficiency level for a particular product class, such as refrigerators, to be fulfilled by the producer (Birner and Martinot 2002)
Building codes	Minimum standards which address the energy use of an entire building or building systems, such as heating or air conditioning (Birner and Martinot 2002)
Procurement regulations	Provisions for energy efficiency in the public procurement process.
Energy efficiency obligations and quotas (EEOs)	Requirement, for example, for electricity and gas suppliers to achieve targets for the promotion of improvements in energy efficiency for instance in households (Lees 2006)
Mandatory labelling programmes	Mandatory provision of information to end users about the energy-using performance of products, such as electrical appliances and equipment, and even buildings (Crossley *et al*. 2000)
Mandatory audit programmes	Mandatory audit and energy management in commercial, industrial or private building, sometimes subsidised by government
Utility demand-side management (DSM) programmes	Planning, implementing, and monitoring activities of energy-efficiency programmes among/by utilities
Energy performance contracting (EPC)/ ESCO support	A contractor, typically an Energy Service Company (ESCO), guarantees certain energy savings for a location over a specified period; implements the appropriate energy efficiency improvements, and is paid from the actual energy cost reductions achieved through the energy savings (EFA 2002)
Co-operative procurement	Private-sector buyers who procure large quantities of energy-using appliances and equipment work together to define their requirements, invite proposals from manufacturers and suppliers, evaluate the results, and actually buy the products, all in order to achieve a certain efficiency improvement in products equal or even superior to world best practice (Crossley *et al*. 2000)
Energy efficiency certificate schemes	Similar to energy efficiency obligations, but certificates for energy savings can be traded (often referred to as “white certificates”)
Kyoto flexibility mechanisms	Joint Implementation (JI) and Clean Development Mechanisms (CDM)
Taxation (on CO_2 or household fuels)	Imposed by government. The effect is to increase the final price that end-users pay for each unit of energy purchased from their supplier, although the tax may be levied at any point in the supply chain (Crossley *et al*. 2000)
Tax exemptions/ reductions	Reduction of VAT or income tax when energy-efficient products are purchased or investments made, provides signals promoting investment in EE to end-use customers
Public benefit charges	Raising funds from the operation of the electricity or energy market, which can be directed into DSM/ energy-efficiency activities (Crossley *et al*. 2000)
Capital subsidies, grants, subsidised loans	Financial support for the purchase of energy-efficient appliances or buildings
Voluntary certification and labelling	Provision of information to end-users about the energy-using performance of products, such as electrical appliances and equipment, and even buildings. Voluntary for producer (Crossley *et al*. 2000)
Voluntary and negotiated agreements	Involve a formal quantified agreement between a responsible government body and a business or organisation, which states that the latter will carry out specified actions to increase the efficiency of its energy use (Crossley *et al.* 2000)
Public leadership programmes	Energy-efficiency programmes in public administrations, demonstration projects to show private sector which savings and technologies are possible
Awareness raising, education, information campaigns	Policy instruments designed by government agencies with the intention of changing individual behaviour, attitudes, values, or knowledge (Weiss & Tschirhart 1994)
Detailed billing and disclosure programmes	Display detailed information related to the energy consumption to the user, either on the bill and/ or directly on appliance or meter

Source: Köppel and Ürge-Vorsatz 2007

Annex 2. Evaluation methodology matrix for the residential sector

			Bottom-Up With monitoring of the number of units/participants							Top-Down		
								BU/TD	BU/TD			
			Direct measurement	Billing analysis	Enhanced engineering estimates	Mixed demed and ex-post estimate	Deemed estimate unit savings	Stock modelling based on stock, market statistics, surveys	Monitoring of equipment diffusion/ specific consumption	Monitoring of specific consumption for whole sectors / end uses	Econometric modelling (e.g., I/O analysis with price elasticities)	Integrated bottom-up and top-down methods
			1	2	3	4	5	6	7	8	9	10
		Legislative/Normative										
		Mandatory Standards for Buildings										
1	Building shell/Heating systems	Energy Performance Standards	L	H	M			H	M	H		
2	Building shell	Minimum thermal insulation standards			M			H	M	H		
		Regulation for Heating Systems and hot water systems										
3	Heating systems/hot water	Minimum efficiency standards for boilers					H	H		H		
4	Heating systems/hot water	Compulsory replacement of old boilers above a certain age					H	H		H		
5	Heating systems/hot water	Thermostatic zone control					H		H	H		
6	Heating systems/hot water	Control systems for heating (Regulation)					H		H	H		
7	Heating systems/hot water	Mandatory heating pipe insulation					H		H	H		
8	Heating systems/hot water	Periodic mandatory inspection of boilers	H				H			H		
9	Heating systems/hot water/ventilation	Periodic mandatory inspection of Heating/Ventilation/AC Equipment (HVAC)	H				H			H		
10	Heating systems/hot water	Mandatory use of solar thermal energy in buildings			H		H	H	M			
		Other Regulation in the Field of Buildings										
11	Behaviour/Heating system/hot water	Individual billing (multi-family houses)		H			M		M	H		
12	Behaviour/Heating system	Maximum indoor temperature limit(s)/limitation heating period	M				H			H		
		Mandatory Standards for Electrical Appliances										
13	Electrical appliances	Minimum efficiency standards for electrical appliances					H	H	H	H		
14	Lighting	Mandatory measures for efficient lighting							H	H		
		Legislative/Informative										
15	Heating systems/hot water	Mandatory labelling of heating equipment							H	H		
16	Electrical appliances/lighting	Mandatory energy labelling of electrical appliances	H					H	H	H		H
17	Building shell/Heating systems	Mandatory energy efficiency certificates for existing buildings			H		H	H	H	H		
18	Building shell/Heating systems	Mandatory energy efficiency certificates for new buildings			H			H	H	H		
19	Building shell/Heating systems	Mandatory audits in large residential buildings	H	H	H			H		H		
20	Building shell/Heating systems	Mandatory audits in small residential buildings		H	M		H	H		H		
		Financial										
		Grants / Subsidies										
21	Building shell/Heating systems	For investments in new buildings exceeding building regulations			H			H	H	H		
22	Building shell/Heating systems	For investments in energy-efficient building renovation	M	H	H	H	H	H		H		
23	Heating systems/hot water	For the purchase of more efficient boilers				H	H		H	H		
24	Electrical appliances/lighting	For the purchase of highly efficient electrical appliances	M			H	H		H	H		
25	All	For other energy efficiency investments				H	H		H	H		
26	Building shell/Heating systems	For investment in renewables				H	H		H			
27	Building shell/Heating systems	For CHP investments			H	H	H		H	H		
28	Building shell/Heating systems	For energy audits			H	H	H			H		

			Bottom-Up With monitoring of the number of units/participants					BU/TD	BU/TD	Top-Down		
			Direct measurement	Billing analysis	Enhanced engineering estimates	Mixed demed and ex-post estimate	Deemed estimate unit savings	Stock modelling based on stock, market statistics, surveys	Monitoring of equipment diffusion/ specific consumption	Monitoring of specific consumption for whole sectors / end uses	Econometric modelling (e.g., I/O analysis with price elasticities)	Integrated bottom-up and top-down methods
			1	2	3	4	5	6	7	8	9	10
		Loans/Others										
29	All	Reduced interest rates (soft loans)				H	H	H		H		
30	All	Leasing of energy-efficient equipment				H	H			H		
		Fiscal/Tariffs										
		Tax Exemption / Reduction										
31	Building shell/Heating systems	VAT reduction on retrofitting investment			H	H		H		H		
32	All	VAT reduction on equipment					H	H		H		
33	All	Income tax reduction				H	H	H		H		
34	All	Income tax credit				H	H	H		H		
		Tariffs										
35	Electrical appliances/lighting	Linear electricity tariffs		H						H		
		Information/Education										
36	Building shell/Heating systems	Voluntary labelling of buildings/components (existent and new)						H	H	H		
37	All	Information campaigns (by energy agencies, energy suppliers etc)		H		H	H		H	H		
38	All	Detailed energy/electrical bill aiming at EE improvement		H						H		
39	All	Regional and local information centre on energy efficiency				H	H		H	H		
		Co-operative Measures										
40	Electrical appliances	Voluntary/negotiated agreements with producers of White / Brown Goods					H		H	H		
41	Electrical appliances	Voluntary/negotiated agreements with producers of ICT (e.g. on stand-by)					H		H	H		
42	All	Voluntary DSM measures of energy suppliers and distributors			H	H	H		H	H		
43	All	Technology procurement for energy-efficient appliances and buildings					H		H	H		
		Cross-cutting with sector-specific characteristics										
44	All	Eco-tax on electricity/energy consumption or CO_2 emissions								H	H	
45	All	Eco-tax with income (mainly) recycled to energy- efficiency. / renewables								H	H	
46	All	Eco-tax with income recycled to indirect labour cost								H	H	
47	All	Eco-tax with reduced rates for the industrial sector								H	H	
		Energy services										
48	Heating systems	Useful heat services			H					M		
49	Appliances	Renting of efficient appliances				M	H		M	M		

Note: High: the method is recommended, Medium: the method provides reliable results, Low: it is possible to use this method if the others are not possible

Annex 3. Evaluation methodology matrix for the tertiary sector

			Bottom Up With monitoring of the number of units/participants					BU/TD	BU/TD	Top Down		
			Direct measurement	Billing analysis	Enhanced engineering estimates	Mixed deemed and ex-post estimate	Deemed estimate unit savings	Stock modelling based on stock, market statistics, surveys	Monitoring of equipment diffusion/ specific consumption	Monitoring of specific consumption for whole sectors / end uses	Econometric modelling (e.g., I/O analysis with price elasticities)	Integrated bottom-up and top-down methods
			1	2	3	4	5	6	7	8	9	10
		Legislative/Normative										
		Mandatory Standards for Buildings										
1		Energy Performance Standards	L	H	H			H		H		
2		Minimum thermal insulation standards	L	H				H	H	H		
		Regulation for Building Equipment										
3		Minimum efficiency standards for boilers					H	H	H	H		
4		Periodic mandatory inspection of boilers	H				H			H		
5		Periodic mandatory inspection of HVAC	H				H			H		
		Other Regulation in the Field of Buildings										
6		Maximum indoor temperature limit(s)	L				H			H		
7		Energy efficiency regulation for public lighting				H				H		
		Legislative/Informative										
8		Mandatory energy efficiency certificates for buildings			H			H	H	H		
9		Mandatory audits in large tertiary sector buildings			H					H		
10		Mandatory audits in small tertiary sector buildings		H			H			H		
11		Mandatory appointment of an energy manager		H	H		H			H		
12		Mandatory Energy Action Plan for municipalities		H		H				H		
13		Mandatory annual energy report for municipalities		H			H		H	H		
		Financial										
		Grants / Subsidies										
14		For energy efficiency investment			H	H	H		H	H		
15		For investment in renewables		H	H		H		H	H		
16		For CHP investments					H		H	H		
17		For energy audits/training/benchmarking activities			H	H				H		
18		Financial incentives for architects who integrate EE measures			H				H	H		
		Soft Loans for Energy Efficiency, Renewables and CHP										
19		Reduced interest rates (soft loans)			H	H	H		H	H		
20		Preferential loan guarantee conditions			H	H	H		H	H		
		Fiscal/Tariffs										
		Tax Exemption / Reduction										
21		Tax reduction / Tax credit			H	H	H	H	H	H		
22		Accelerated depreciation			H	H	H	H	H	H		
		Information/Education/Training										
23		Voluntary labelling of office equipment							H	H		
24		Voluntary labelling of buildings			H			H	H	H		
25		Information campaigns (by energy agencies, energy suppliers, etc.)					H			H		
26		Regional and local information centre on energy efficiency				H	H		H	H		
27		Information/Training for top-level management / energy managers					H		H	H		
28		Governing by example	H	H		H			H	H	H	

			Bottom Up With monitoring of the number of units/participants							Top Down		Integrated bottom-up and top-down methods
								BU/TD	BU/TD			
			Direct measurement	Billing analysis	Enhanced engineering estimates	Mixed deemed and ex-post estimate	Deemed estimate unit savings	Stock modelling based on stock, market statistics, surveys	Monitoring of equipment diffusion/ specific consumption	Monitoring of specific consumption for whole sectors / end uses	Econometric modelling (e.g., I/O analysis with price elasticities)	
			1	2	3	4	5	6	7	8	9	10
29		Energy efficiency / renewables awards								H		
30		Voluntary energy audits	L	H	H					H		
		Co-operative Measures										
31		Voluntary agreements with actors of the building sector		H		H				H		
32		Voluntary agreements with public or private services		H		H				H		
33		Technology procurement for energy-efficient buildings / components							H	H		
34		Technology procurement for energy-efficient appliances							H	H		
		Cross-cutting with sector-specific characteristics										
35		Eco-tax on electricity/energy consumption or CO_2 emissions								H	H	
36		Eco-tax with income (mainly) recycled to energy efficiency / renewables								H	H	
37		Eco-tax with income recycled to indirect labour cost								H	H	
38		Eco-tax with reduced rates for the industrial sector								H	H	
		Energy services										
39		Useful heat sources		H	H	H				H		
40		Renting of efficient appliances				H	H	H		H		
41		Compressed air supply	H	H			H	H		H		
42		Cold supply		H				H		H		
43		Energy performance contracting		H	H	H		H		H		
44		Unsubsidised energy auditing			H			H		H		
45		Energy management services		H		H		H		H		

Note: High: the method is recommended, Medium: the method provides reliable results, Low: it is possible to use this method if the others are not possible