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Energy Efficiency First and Multiple Impacts: integrating two concepts for decision-making in the EU energy system

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ABSTRACT

The principle of Energy Efficiency First (EE1st) has recently gained traction in the political debate. It aims to consider and prioritise investments in demand-side resources (e.g. end-use energy efficiency) whenever these cost less or deliver more value than default energy infrastructure (e.g. networks). Meanwhile, energy efficiency is increasingly associated with a variety of environmental, economic, and social benefits known as multiple impacts (MI). It is frequently argued that taking thorough account of the EE1st principle in energy-related investment and policymaking means to incorporate MI in the decision-making process to ensure a fair comparison of resource options. However, a theoretical account of how the two concepts fit together is still missing. Moreover, there is an ongoing lack of quantitative evidence on individual MI. The objective of this paper is twofold. First, based on an expert workshop and a literature review, it aims to integrate the state of knowledge on the concepts of EE1st and MI. This concerns the theoretical interlinkages between the two concepts as well as the possible role of different decision-support frameworks (e.g. cost-benefit analysis). Second, the paper provides evidence on the magnitude of selected MI from a model-based assessment for the EE1st principle in the EU-27. Three scenarios are compared for the MI of air pollution and indoor comfort. We find that factoring in MI certainly affects the trade-off between demand-side and supply-side resources, making it critical to include them in model-based assessments in the scope of EE1st.

Introduction

The Energy Efficiency First (EE1st) principle has recently been gaining momentum in the European Union's (EU) energy and climate policy. As set out in the EU Governance Regulation and other instances, the principle is meant to consider and prioritise demand-side resources (end-use energy efficiency, demand response, etc.) over supply-side resources (generation, networks, storage, etc.) whenever they cost less or deliver more value in meeting given objectives. The principle thus suggests that all available resource options in a given context (e.g. network planning) are assessed and valued on a fair basis so that, ultimately, energy needs are being met using the least-cost alternatives available.

Meanwhile, there has been increasing interest in the idea that energy efficiency has economic, environmental and social impacts beyond mere energy and cost savings (Fawcett and Killip 2019; IEA 2014). For example, energy efficiency in the building sector typically comes with comfort and health improvements. These effects are referred to as multiple impacts (Ürge-Vorsatz et al. 2016), multiple benefits (IEA 2014), wider benefits

(European Commission 2021a), non-energy benefits (Lazar and Colburn 2013) and other terms, but share the idea that policymaking and individual investment should look beyond the direct financial benefits of energy efficiency to acknowledge its true value.[1] Supporters of EE1st have long acknowledged the idea of multiple impacts (MI). For example, Bayer et al. (2016b) called for valuing the MI of energy efficiency when carrying out law, policy and project-related impact assessments.

Despite these advances, MI are only selectively captured and play a secondary role in policymaking and investment (Thema et al. 2019). In response, there has been an increasing amount of literature in recent years, including the seminal work by the IEA (2014), several EU-funded research projects (MICAT, COMBI, IN-BEE, etc.) and others. In this literature, much attention has been given to methods for quantifying individual MI (e.g. Reuter et al. 2020). In this vein, Fawcett and Killip (2019) point out that robust methods for many MI are either not yet available or insufficiently evidenced, especially for job creation and macro-economic benefits.

Evidence on individual MI is one issue. Another is weighing up the MI of energy efficiency against those of other resource options in the context of the EE1st principle. This requires some form of aggregation (e.g. in monetary terms) for decision-makers to assess the relative merits of resource options and thus to decide which of these should be prioritized, invested in, or otherwise supported. For example, making MI an integral part of the European Commission's impact assessments would deliver more evidence on the various benefits of energy efficiency and would be expected to result in stronger energy savings targets (Fawcett and Killip 2019).

However, overall, there is little guidance on how actors ranging from policymakers, over utilities, up to individual consumers in households and firms can, ex-ante, quantify and aggregate MI to assess the trade-off between resource options in line with the EE1st principle. A particular issues includes the selection of suitable decision-support frameworks (cost-benefit analysis, multi-criteria analysis, etc.) In addition, there is a lack of actual quantitative assessments on EE1st that demonstrate how MI can be integrated in the assessment of demand-side and supply-side resources in the context of EE1st (ENEFIRST 2020b).

The objective of this paper is twofold. First, it aims to integrate the state of knowledge on the concepts of EE1st and MI. This conceptual chapter is informed by a workshop conducted with 16 researchers and practitioners engaged in the subjects. Second, this paper provides evidence on individual MI quantified in the scope of the model-based assessment of EU scenarios developed in ENEFIRST (2021a). This work focuses on the MI of reduced air pollution and improved indoor comfort in response to the energy efficiency actions modelled for the EU building sector. It thus demonstrates how the inclusion of MI alters the possible conclusions to be drawn from model-based assessments.

Theory: Multiple impacts in the context of Energy Efficiency First

In this chapter, we describe the interlinkages between the concepts of Energy Efficiency First (EE1st) and Multiple Impacts (MI). Subsequently, we deal with the issue how the selection of cost-benefit analysis, multi-criteria analysis and other decision-support frameworks affects the scope and quantification of MI.

Conceptual background

The EE1st principle has entered the political discussion in the EU almost a decade ago (Cowart 2014; Coalition for Energy Savings 2015). Ever since, the concept has been developed in reports oriented to practitioners (e.g. Bayer et al. 2016a) as well as in the academic literature (Rosenow et al. 2017; Pató et al. 2019). In 2018, the principle has been formally introduced to EU legislation as part of the Governance Regulation. More recently, with the Fit-for-55 package, the European Commission (2021b) aims to expand EE1st in the recast of the Energy Efficiency Directive, the Renewable Energy Directive and other instances.

[1] In line with Ürge-Vorsatz et al. (2016), throughout this report we use the term 'multiple impacts' to stress the fair comparison of resource options targeted by the EE1st principle and thus to acknowledge that MI exist for all resource options, not just end-use energy efficiency.

ENEFIRST (2020a, p. 21) developed the following definition of EE1st: "'*Efficiency First' gives priority to demand-side resources whenever they are more cost effective from a societal perspective than investments in energy infrastructure in meeting policy objectives. It is a decision principle that is applied systematically at any level to energy-related investment planning and enabled by an 'equal opportunity' policy design*."

This definition is illustrated in Figure 1 (Mandel et al. 2022). In essence, the principle is about:

(1) *Setting decision objectives* | Comparing technology options and solving the trade-off between them in the scope of EE1st requires common decision objectives, e.g. a common greenhouse gas reduction target.

(2) *Comparing resource options* | It is fundamental to EE1st that energy decision objectives can be addressed by supplying or saving energy. The principle thus acknowledges a multitude of resources to achieve decision objectives in the sense that a kilowatt-hour generated is equivalent to a kilowatt-hour saved.

(3) *Deploying resource options* | Implementing suitable combinations of resource options involves actions by policymakers, regulators and, ultimately, individual investment and operation decisions by producers and consumers. This requires a sound package of regulations, incentives and other policies to ensure that mostly private decisions on technology investment and operation are in line with what is best for society at large.

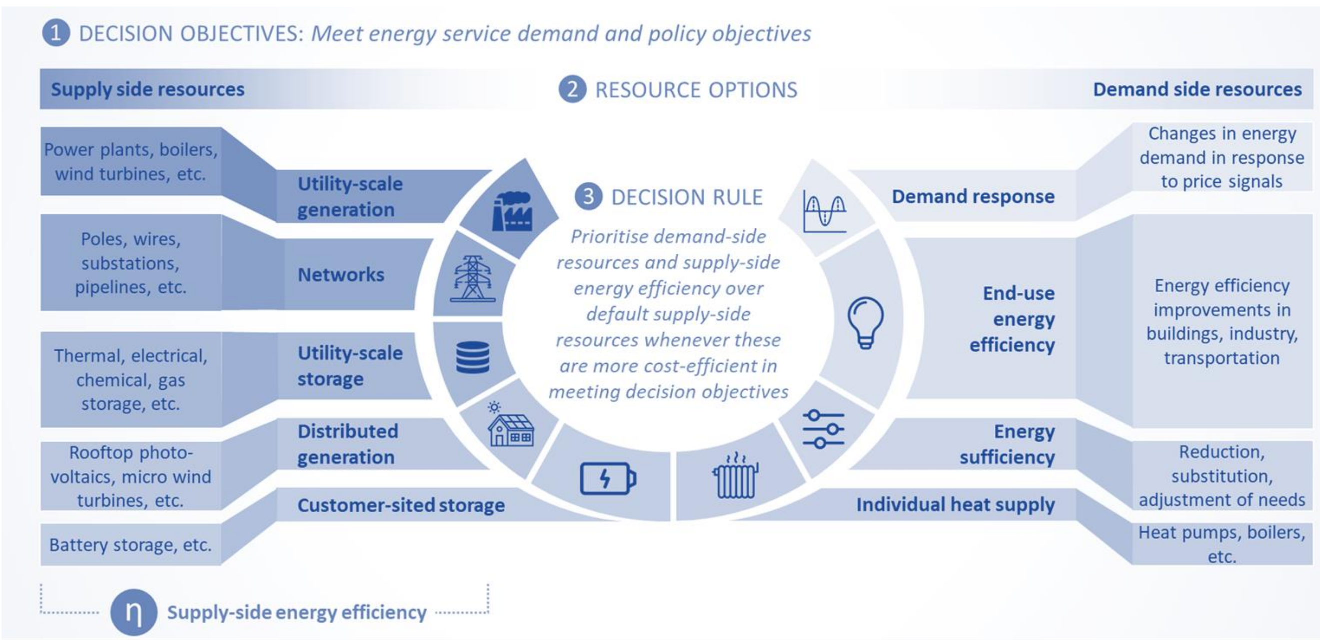

Figure 1. Conceptual framework of the Energy Efficiency First principle. Source: Mandel et al. (2022)

Cost and benefits in the scope of EE1st are not merely composed of tangible financial metrics, such as upfront investments, thus recognizing that technology investment and operation decisions are governed by a variety of MI. This is relevant at different levels of decision-making in the context of EE1st:

- At the *EU level*, policy formulation should be informed by impact assessments that evaluate costs and benefits for society at large, rather than from the private perspective of individual consumers. Besides revisiting the discount rates used for demand- versus supply-side resources, this also implies thorough quantification and inclusion of MI of end-use energy efficiency and other resource options.
- At the *local and regional level*, municipal heat plans are being discussed as means to systematically assess the potential of building retrofits alongside possible upgrades of district or decentralised heating systems (ENEFIRST 2021b). Again, such an assessment should factor in multiple impacts, both for the local community overall (e.g. reduced air pollution) and for individual consumers (e.g. indoor comfort improvements).

- At the *private level*, some MI that constitute externalities are not immediately relevant (e.g. greenhouse gas reductions) from a rationality viewpoint. Yet, there remain important MI (e.g. increased property values), which provide the foundation for behaviourally informed policies to resolve such irrationalities.

In sum, MI are a key element in the concept of EE1st. They are certainly not limited to end-use energy efficiency but also arise for renewable energy supply and infrastructures in the form of reduced emissions, job creation, energy security, and more (e.g. U.S. EPA 2018). The key proposition of the EE1st principle is to level the playing field between these resource options in different levels of decision-making by taking into account their full range of costs and benefits and thus to ensure a fair comparison.

Decision-support frameworks

There are different decision-support frameworks that can be used to inform decisions about demand- and supply-side resource configurations in the context of EE1st and MI, also referred to as policy formulation tools (Turnpenny et al. 2015) or decision tools (Munda 2019). In practice, most of the literature is framed within either cost-benefit analysis (CBA) or multi-criteria analysis (MCA) (Ürge-Vorsatz et al. 2014; Atkinson 2015). Table 1 compares the essential features of these frameworks. Meanwhile, both CBA and MCA have inherent methodological problems that give rise to a range of miscellaneous frameworks discussed in this chapter.

Table 1. Comparison of decision-support frameworks in the scope of the EE1st principle

		Cost-benefit analysis (CBA)	Multi-criteria analysis (MCA)
Outline	Approach	Quantification of impacts as costs and benefits expressed in monetary units	Merging of quantitative and qualitative impacts through scoring and weighting
	Theoretical foundations	Welfare economics	Operational research
	Aggregation of impacts	Monetization	Scoring, weighting
	Performance indicator	Net benefits	Decision ranking
Selected issues	Monetization	▶ Need for monetization to express costs and benefits in single metric	▶ No need for monetary valuation
	Overlapping impacts	▶ Expression in single monetary unit requires thorough check for overlaps and double-counting	▶ Overlaps can be a problem if multiple similar metrics are used on criteria
	Stakeholder involvement	▶ Possible but not required	▶ Formal part of decision-making process
	Distributional effects	▶ Not a standard feature of CBA, but suitable methods exist	▶ Can be clearly accommodated
	Discounting	▶ Controversial selection of discount rates in assessing costs and benefits	▶ No dealing with issues of time and discounting
Practical use	Possible coverage of impacts	▶ Advanced methods for nearly all relevant MI; broader problem is overlaps	▶ Wide applicability to different impacts, also integrating non-quantifiable ones
	Ease of use	▶ Dedicated methods and expertise needed per impact	▶ Lengthy consensus necessary to value impacts and impute weightings
	Ease of communication	▶ Simple: ability to express all impacts in single unit	▶ Intransparent and subjective if scoring and weighting is primarily based on experts' preferences

▶ problematic | ▶ occasionally problematic | ▶ unproblematic

Cost-benefit analysis

The foundations of CBA lie in welfare economics, with the fundamental principle to select those alternatives that provide the greatest net benefits to society, i.e., benefits minus costs (Atkinson 2015). Aggregation of different MI to a common figure of net-benefits in CBA requires monetization, which is challenging with impacts for which there is no market value. There exists a variety of valuation techniques for this purpose, ranging from market valuation over willingness to pay and willingness to accept approaches (Ürge-Vorsatz et al. 2015; Atkinson et al. 2018). Monetization is inherently controversial because of ethical concerns, e.g. in determining the value of a life in high- versus low-income countries. This goes hand in hand with the issue that different monetization methods typically yield different results (Ürge-Vorsatz et al. 2016; Gamper and Turcanu 2015). Besides the need for monetization, the aggregation of impacts in a single metric of also leads to the issue of overlaps and interactions between different MI. For example, thermal retrofit measures in buildings typically improve indoor air quality usually in terms of reduced humidity. This, in turn, affects human health and productivity that ultimately also affect economic effects like disposable income or public budget (Chatterjee et al. 2018). Summing up overlapping MI in CBA constitutes double-counting and thus potential overestimation of MI (Ürge-Vorsatz et al. 2014; Ürge-Vorsatz et al. 2016).

A noteworthy aspect of CBA is its dealing with distributional aspects. By default, the emphasis in CBA is on securing overall benefits rather than their distribution (Atkinson 2015). Nonetheless, there are approaches in CBA to deal with the benefits received and costs incurred by different societal groups. The most widespread one is to attach weights to different income groups. Yet, it is not always clear how to derive such weights and who should attach them. In turn, not using any weighting system means assuming that the existing distribution of income is ideal (Munda 2019). Another distributional issue in CBA surrounds discounting in terms of intergenerational equity. The higher the discount rate, the more decisions are shifted towards actions that bring more immediate net benefits. The choice of discount rates for decisions with long-term consequences is thus inherently controversial (ENEFIRST 2020b).

An good example of CBA in practice is the methodologies used for the development of the ten-year network development plans (TYNDP) on cross-border transmission network projects (ENTSO-E 2018; ENTSOG 2019). These methodologies will be discussed in more depth below. CBA is also widely used as part of the policy formulation (Browne and Ryan 2011). For example, the Energy performance of buildings directive (EPBD) requires Member States to set minimum energy performance requirements for the energy efficiency of new buildings and existing buildings undergoing major renovation. The requirements are based on cost-optimal levels of energy performance over the building lifecycle. Shnapp et al. (2020) argue that these lifecycle costs are often based on a private perspective and thus do not factor in the wider societal benefits of energy efficiency, e.g. reduction of air pollution. They recommend that the cost-optimality methodology in the EPBD is evolved to ensure that an adequate consideration of such benefits is included to better represent the societal value of energy efficiency and thus to legitimize more ambitious performance requirements.

CBA is prominently featured in discussions on EE1st. The Commission guidelines on the EE1st principle (European Commission 2021a) include a dedicated chapter on CBA, emphasizing the use of a societal perspective and the inclusion of ‘wider benefits’. More recently, in its proposal for a recast of the Energy Efficiency Directive (EED) (European Commission 2021c, Art. 3), the European Commission calls on Member States to “ensure the application of cost-benefit methodologies that allow proper assessment of wider benefits of energy efficiency solutions” in planning, policy and major investment decisions. All in all, the advantage of CBA lies in its analytical rigour and sophistication. In recent years, there has been a wealth of research dedicated to the theoretical and methodological aspects of CBA, resulting in various guidebooks (Atkinson et al. 2018; Sartori et al. 2015) and journal publications (Thema et al. 2019) that provide a solid foundation for applications in the context of MI and the EE1st principle. In addition, CBA can be directly related to the EE1st principle’s decision rule of prioritizing demand-side resources whenever these are "*more cost-effective from a societal perspective than investments in energy infrastructure* " (ENEFIRST 2020a). In turn, despite ongoing methodological advances, it can be doubted whether CBA can ever provide an exhaustive account of all relevant MI in a single monetized metric. This shortcoming provides the essential rationale for MCA.

Multi-criteria analysis

MCA is also known as multi-criteria decision analysis (Cohen et al. 2019; IEA 2014), multi-criteria evaluation (Munda 2019), or multi-criteria decision making (Siksnelyte et al. 2018). Its theoretical foundations lie in the fields of operational research and management science. To assess the worth of different options, MCA aggregates metrics (e.g. number of jobs gained) on multiple evaluation criteria (e.g. macroeconomic impacts) into scores of overall performance, without the need to transform them to a common unit (Gamper and Turcanu 2015). The scores can be quantitative (measured on interval or ratio scales) or qualitative (measured on nominal or ordinal scales) (Munda 2019). In the simplest of MCA, the final outcome is a weighted average of these scores, with the option providing the highest weighted score being the one that should be selected (Atkinson et al. 2018).

MCA as a decision-support framework is well adapted to the concept of MI as it recognises the multidimensional nature of socio-environmental issues that should be considered in energy policy (IEA 2014). Overlaps among MI and corresponding double-counting can pose a problem in MCA if this issue is not made explicit and if inappropriate weights are used to account for overlaps (Ürge-Vorsatz et al. 2014). Another difference to CBA is that MCA does not explicitly deal with issues of time in terms of discounting. Also, distributional implications are usually chosen as one of objectives in MCA and hence equity concerns can be easily accommodated (Atkinson 2015; Gamper and Turcanu 2015). Stakeholder involvement, while optional in CBA, is an important element of MCA. In practice, scoring and weighting tend to be based on experts' preferences, but can also incorporate public deliberation. Different modes of engagement may be employed, ranging from individual consultations, to small group meetings, to larger information workshops, to electronic communications and internet platform-based interactions (Cohen et al. 2019). As such, MCA can be more useful than CBA in developing social compromise solutions and legitimizing decision outcomes (Browne and Ryan 2011).

Similar to the selection of money values in CBA, MCA may also involve a significant degree of subjectivity. Representative stakeholder involvement processes are costly and time-consuming. This is why they are prone to inclusion of only experts and authorities in estimating relative importance weights and in judging the contribution of each option to each performance criterion, while neglecting actors from civil society. In other cases, the constellation of stakeholders may lead to a stalling of the overall decision subject due to contrary value judgements (Gamper and Turcanu 2015). There are also inherent methodological issues in MCA related to the assignment of score and general issues surroundings the use of weights (Browne and Ryan 2011).

In practice, MCA can be chosen as an energy planning tool by displaying trade-offs among criteria so that planners, regulators and the public can understand the advantages and disadvantages of alternatives. MCA can also facilitate compromise and collective decisions, recognising that a mix of different data types makes it difficult to show clearly whether benefits outweigh costs in the sense of CBA (IEA 2014; Gamper and Turcanu 2015). As noted above, MCA is becoming protracted and complicated the more diverse stakeholders are involved. Larger consultation processes, e.g. in the scope of EU-wide impact assessments, can thus be hardly realised.

However, MCA can be an interesting decision-support framework, especially for local energy planning processes. There is experience in some EU Member States with municipal heat roadmaps and renovation strategies. Ideally, from the perspective of the EE1st principle, these roadmaps should take into account both demand reduction in buildings and the upgrade of district or decentralised heating systems towards renewable heat supply (ENEFIRST 2021b). MCA could be used to find an optimal balance between these technology options, under consideration of not only monetary costs, but also a variety of MI. The provisions set out in the EED recast proposal (European Commission 2021c, Art. 23.6) suggest the development of 'local heating and cooling plans' in municipalities greater than 50,000 inhabitants. This is a promising opportunity for establishing MCA as a dedicated decision-support framework in the scope of EE1st and MI.

In sum, MCA has two key advantages that go beyond the properties of CBA (Ürge-Vorsatz et al. 2014; Gamper and Turcanu 2015). First, it provides a framework to merge quantitative and qualitative impact indicators. This allows consideration of impacts where monetary data is not available or cannot be approximated. Second, it allows incorporation of stakeholders' preferences into decision-making through the process of criteria weighting. It thus embeds the decision-making in a structured process of deliberation and discussion, which may promote convergence toward more legitimate decision-making.

Miscellaneous frameworks

It is clear that estimating all MI in monetary terms in the scope of CBA is clearly not feasible owing to methodological and data constraints. MCA also has many practical shortcomings related to time and resources needed to organize representative stakeholder involvement. As noted by Fawcett and Killip (2019), simplified tools can potentially be of larger value to decision-makers than incomplete or biased comparisons. A range of miscellaneous tools and frameworks can complement or replace the need for dedicated CBA and MCA. Many of these frameworks rely on scoreboards or composite indicators:

- Persson and Landfors (2017) present a tool for visualizing the MI of energy efficiency. The tool covers 15 categories of MI, each of which is estimated for the two dimensions of magnitude (positive, neutral, negative, none) and governance level (individual, local, national, global). The estimation of these ordinal variables is backed by expert interviews. The tool is visualized in the form of a pie chart diagram, showing the MI for selected projects in Sweden, e.g. deep renovations of buildings in a given municipality.
- Reuter et al. (2020) develop an indicator approach for 20 MI indicators, grouped as environmental (e.g. energy savings), economic (e.g. employment), and social (e.g. health). Each indicator is determined based on dedicated methods and calculated for 29 European countries. The indicators are expressed in physical units (e.g. tons of CO_2) and can thus serve as inputs for aggregation in the scope of CBA or MCA.
- Langenheld et al. (2018) use a semi-quantitative approach to ascertain MI for their scenarios on the German building sector. Their scope of MI not only includes benefits (e.g. employment effects), but also intangible issues and risks (e.g. substantial market ramp-up of insulation materials). Individual MI are either quantified in their physical units or described qualitatively.

Such miscellaneous frameworks can be useful to raise awareness, interest and knowledge among different stakeholders on the MI of energy efficiency, and thus bring attention to values that otherwise would have been neglected (Persson and Landfors 2017). However, they cannot aggregate various MI and thus to indicate whether one configuration of demand- and/or supply-side resources is more beneficial than another. As such, in itself, they are of limited value for specific decisions in the scope of the EE1st principle, such as impact assessments, infrastructure investment, and more. Yet, the frameworks described in this chapter can complement each other to lead to more informed decisions under consideration of MI (Munda 2019; Ürge-Vorsatz et al. 2015). For example, MCA can build on results of CBA by incorporating some monetary values.

This complementarity is well illustrated in use of CBA and MCA in cross-border network planning. The European Network of Transmission System Operators for Electricity (ENTSO-E) and gas (ENTSOG) are mandated to produce a non-binding EU-wide ten-year network development plan (TYNDP) every two years. Each network development project included in the TYNDPs is assessed using the pan-European cost-benefit analysis methodologies for power (ENTSO-E 2018) and gas (ENTSOG 2019). respectively. More specifically, projects are assessed using a combined CBA and MCA approach in which both qualitative assessments and quantified, monetised assessments are included. In such a way, a wide range of costs and benefits can be represented, including system cost, societal well-being as a result of renewable energy integration and reduced CO_2 emissions, security of supply, and more. Network development projects with extraordinary performance under the TYNDP can be designated as Projects of Common Interest (PCIs) and profit from financial support and other benefits under the Connecting Europe Facility (CEF).

Overall, outputs from CBA, MCA and other decision-support frameworks are only one input to actual decisions and, ultimately, none of the frameworks is substitute for human judgement. As empirical work with practitioners demonstrates (Fawcett and Killip 2019), MI arguments are most persuasive when linked to the values and priorities of decision-makers. Different contexts and different benefits are more or less salient for different stakeholders in the sense of being important, relevant and timely. For example, communications with citizens might focus on their energy bills, air quality or local jobs; whereas with business the competitiveness benefits are more likely to be highlighted (Fawcett and Killip 2019).

Practice: Multiple impacts in model-based assessment for EU-27

In this chapter, we demonstrate how the inclusion of selected MI can affect the outcomes of model-based assessments in the context of EE1st. We begin with relevant background information, followed by individual assessments of the MI of indoor comfort and air pollution.

Background

The EU aims to be climate-neutral by 2050 and the building sector is of vital importance to meet this target because it is responsible for 36% of greenhouse gas (GHG) emissions in the EU (European Union 2018). As the EE1st principle suggests, demand-side resources (end-use energy efficiency, demand response, etc.) should be considered alongside supply-side resources (generation, networks, storage, etc.) to achieve an economically efficient and socially equitable transition to a net-zero economy. Energy systems modelling is a significant tool to quantify the trade-offs between resource options in the context of EE1st. By determining cost-optimal transitions or a range of alternative scenarios, it can assist decision-makers in making informed decisions on future technology investment, system operation as well as policy design (ENEFIRST 2020b).

In ENEFIRST (2021a) we developed a methodological concept for a model-based assessment. Its objective is to determine what level of demand-side and supply-side resources should be deployed to provide the greatest value to the EU's society in transitioning to net-zero GHG emissions for the building sector by 2050. A set of four bottom-up energy models is applied to ascertain the energy system costs of the building sector and energy supply (electricity, heat, gas). Three scenarios are calculated, each of these scenarios is geared to reach the 2050 target of net-zero emissions. However, the scenarios differ in terms of the level of end-use energy efficiency measures in buildings and the associated deployment of energy conversion and network capacities:

- The *Low Efficiency in Buildings* (LOWEFF) scenario assumes building decarbonisation primarily via the use of renewable energy sources. It reflects a future in which the EE1st principle is not comprehensively applied.
- The *Medium Efficiency in Buildings* (MEDIUMEFF) scenario is characterized by a balanced deployment of energy efficiency measures in buildings and supply-side generation and network infrastructures.
- The *High Efficiency in Buildings* (HIGHEFF) scenario considers end-use energy efficiency measures in buildings as the most favourable decarbonisation option for the European energy system by 2050.

In sum, the scenarios demonstrate the value of end-use energy efficiency in buildings in view of net-zero GHG emissions. This analysis can thus help ascertain the difference between a very comprehensive implementation of the EE1st principle and a more limited and less ambitious implementation.

By default, the principal performance indicator in this assessment is energy system cost, consisting of (a) capital expenditures for various building efficiency measures as well as for supply side assets (generation, networks, storage). In addition, energy system cost comprises (b) operating expenses for fuels, maintenance, personnel, and other cost items. As such, the energy system cost indicator ignores the variety of environmental, social, and economical MI of resource options and, based on related studies (Thema et al. 2019), it is likely to underestimate the socially optimal ambition level for end-use energy efficiency in the building sector. This is why in this chapter we supplement the indicator with selected MI. Owing to time and data constraints, this does not cover all relevant MI, but demonstrates methods that can be used to attribute values to MI. For air pollution we apply direct monetisation. For indoor comfort we rely on a proxy approach.

Impact #1: Air pollution

Air pollution is considered the second biggest environmental concern for Europeans, after climate change, as it causes harm to human health, ecosystems, agricultural crops, and other receptors. In response, the EU has been active for decades to improve air quality, but it remains poor in many areas and a significant share of EU population lives in areas that exceed air quality standards (González Ortiz et al. 2020). Only few studies deal with the effects of building retrofits and other end-use energy efficiency measures on air pollution emissions and impacts are monetized only in few cases (Mzavanadze 2015).

In this work, we estimate the impacts of air pollution on four receptors: human health damage (mortality and morbidity); biodiversity losses (eutrophication and acidification); crop damage (agricultural yields); and material damage (building structure deterioration). Our approach is based on direct monetization using cost rates per air pollutant and receptor. This involves the following methodological steps:

(1) *Assessment of primary energy consumption by energy carrier* [kWh_{th}] | Based on the model-based assessment described above, we have disaggregated data on primary energy consumption by energy carrier (e.g. natural gas), emission source (e.g. power plant), EU country, and scenario for the period 2020–2050.

(2) *Compilation of air pollution emission factors* [$t_{emission}/kWh_{th}$] | Based on data from the European and German Environmental Agencies (EEA 2019; Lauf et al. 2021), each energy carrier is assigned an emission factor, differentiated by pollutant (e.g. sulfur dioxide, SO_2).

(3) *Estimation of total emissions* [$t_{emission}$] | Primary energy consumption by energy carrier is multiplied with the respective emission factors to yield the total emissions by pollutant.

(4) *Compilation of cost rates* [$EUR/t_{emission}$] | Cost rates by pollutant, emission source and receptor (e.g. human health) are available from Matthey and Bünger (2019) for Germany. We apply these cost rates to the remaining EU countries by correcting for differences in gross domestic product per capita, assuming that the willingness to pay for avoiding health damage increases with income.

(5) *Estimation of total damage costs* [EUR] | Multiplication of total emissions and cost rates yields total damage costs by country, pollutant, and receptor. These values are included in the indicator of energy system cost.

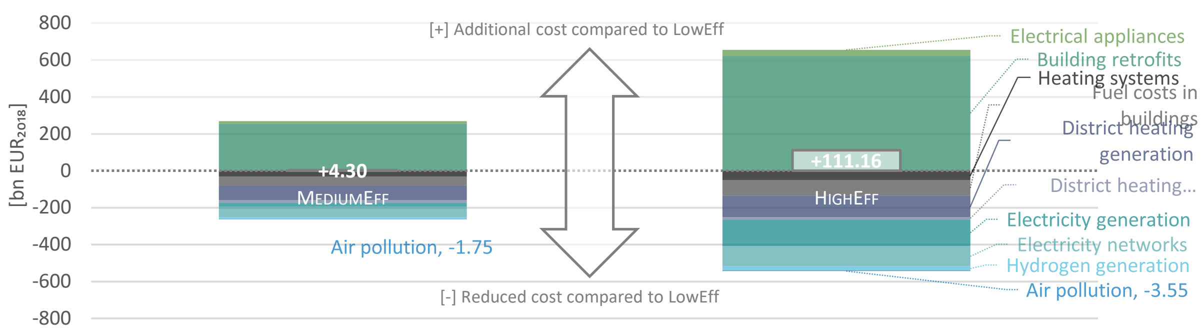

Figure 2. Cumulative differential cost compared to LowEff scenario for EU-27 (2020–2050) by cost item [billion EUR]

Figure 2 displays energy system cost including monetized air pollution for the EU-27 until 2050. As more thoroughly described in ENEFIRST (2022), the additional cost for energy efficiency (building renovation, electrical appliances) relative to the LOWEFF scenario amounts to EUR 367.5 billion (MEDIUMEFF) and EUR 895 billion (HIGHEFF). This cost is partly offset by reduced cost for electricity, gas and heat supply. Without factoring in air pollution damage, the energy efficiency measures in MEDIUMEFF would be hardly cost-effective (-7.6 bn EUR). Conversely, when including damage costs, the numbers suggest that the inclusion of air pollution damage cost in a CBA framework can enhance the attractiveness of building efficiency measures. Note that all three scenarios reach net-zero GHG emissions by 2050, but the different transition pathways towards this target involve different levels of air pollution.

Impact #2: Indoor comfort

The literature mentions the increase of comfort and related follow-up impacts (health, productivity, well-being) as one of the MI of building retrofits (MacNaughton et al. 2017; Al Horr et al. 2016; Lan et al. 2010). Thus, when it comes to making the EE1st principle operational, it needs approaches to consider these MI. Here we propose and apply a method how to provide a quantitative estimation – even though no monetization – of the co-benefits associated with different scenarios of building retrofitting. User behaviour significantly impacts actual energy use, in particular in the building sector (e.g. Holzmann et al. 2013). The literature lists different reasons for behaviour-induced consumption differences like window opening behaviour (Fabi et al. 2012; Sorgato et al. 2016), thermostat and temperature settings, due to different indoor temperature and comfort preferences (Mora et al. 2018; Huebner et al. 2015), socio-economic characteristics and related occupancy patterns (Gram-Hanssen 2013; Huebner et al. 2015). The explanations of behavioural patterns are very different in terms of measures, actions, triggers and reasons. However, in the end they can be reduced to a resulting effective indoor-temperature, which has an impact on the energy consumption.

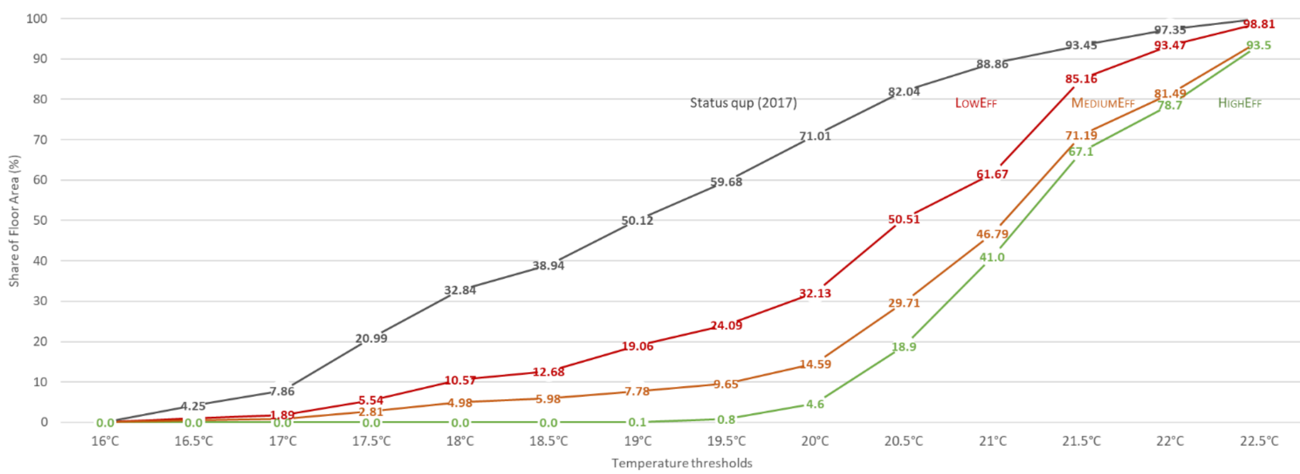

Figure 3. Floor area weighted average of effective indoor temperature for residential sector, Germany

According to Loga et al. (2003), behavioural patterns and resulting effective indoor temperature depends on building envelope efficiency and size of dwellings. This function is implemented in the building stock model Invert (Müller 2015; Kranzl et al. 2019), which we used to develop energy demand scenarios in buildings (LowEff, MediumEff, HighEff) in EU-27. For these scenarios, we derived effective indoor temperature of residential buildings (weighted by heated floor area) during the heating season. The share of floor areas heated between 13°C-25°C for each country was added up cumulatively. In Figure 3 below we show the case of Germany. The temperature in the 20% share of the floor area with the lowest effective indoor temperature increases by about 1.5°C from the low-efficiency scenario to the high-efficiency scenario during the heating season (2050). The share of floor area with an effective indoor temperature of 18.5 or lower is 20 ppt lower in HighEff than LowEff (2050). While the related comfort increase is often described as rebound effect, and thus counteracting energy efficiency measures, we understand the results as a clear MI with the corresponding positive follow-up impacts. While the results do not provide a monetization of the scenario impacts, we propose that additional costs that may be incurred by HighEff are being compared to the non-monetized MI like the one presented here.

Conclusion

The objective of this paper was to integrate the state of knowledge on the concepts of Energy Efficiency First (EE1st) and Multiple Impacts (MI). In the first part, we described the interlinkages between the two concepts. MI are an integral element of EE1st as the principle aims to prioritize demand-side (e.g. end-use energy efficiency) over supply-side resources (e.g. power network) in energy-related investment and policymaking whenever they provide greater benefit to society and individuals in meeting decision objectives. Solving the trade-off between resources options implies a fair comparison that is not limited to financial costs and benefits, but also factors in intangible socio-environmental effects in the form of various MI. It was also pointed out that assessing the relative merits of resource options in impact assessments, infrastructure investment and other decision-making contexts requires some form of aggregation of MI. Relevant decision-support frameworks for this purpose include cost-benefit analysis, multi-criteria analysis and a range of miscellaneous indicator-based approaches. We argue that, in itself, each of these frameworks has critical limitations and, ultimately, none of them can replace human judgement. Nonetheless, we do see an important contribution in EE1st in that the principle aims to make explicit the trade-off between demand-side and supply-side resources from private and societal perspectives. Questions of what decision-support framework are most conducive to a given decision-making context (e.g. network planning) will have to be deliberated on a case-by-case basis.

In the second part, we provided evidence on the selected MI of air pollution and indoor comfort. Our analysis covers three model-based scenarios (LOWEFF, MEDIUMEFF, HIGHEFF). Each of these is set to reach the 2050 target of net-zero emissions in the EU-27, but features different ambition levels for end-use energy efficiency in residential and non-residential buildings. First, we showed that the inclusion of air pollution impacts in monetized form improves the cost-effectiveness of building retrofits and other end-use energy efficiency measures from a societal viewpoint. The monetized benefit of air pollution mitigation is estimated at 1.75 to 3.55 bn EUR for the EU-27 in the period 2020–2050 relative to LOWEFF, i.e the scenario with modest energy efficiency requirements in buildings. This underlines that the pathway towards net-zero GHG emissions by 2050 can be critical in terms of air pollution and other MI that accrue on the way. Second, we provided a quantification in physical units of indoor comfort impacts in response to building retrofits. Based on the model developed, the effective indoor-temperature as a proxy for comfort clearly increases with higher building performance standards. While this can be framed as a direct rebound effect, we point out that comfort increases have manifold follow-up impacts that require closer investigation, including morbidity, mortality, workforce productivity, and others.

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