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

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EXECUTIVE SUMMARY

The principle of **Energy Efficiency First** (EE1st) is gaining traction in the political debate. As set out in previous project reports (ENEFIRST 2020a, 2020c), the principle aims to consider and prioritise investments in demand side resources (e.g. building retrofits) 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** (MIs). It is often argued that taking thorough account of the EE1st principle in energy-related investment and policymaking means to incorporate MIs in the decision-making process to ensure a fair comparison of resource options. This concerns various decision-making instances – including the impact assessments prepared by the European Commission, infrastructure planning conducted by regulated network companies, up to individual building owners when assessing the costs and benefits of different building renovation options. However, a theoretical account of how the concepts of EE1st and MIs fit together is still missing.

The objective of this paper is twofold. First, based on an expert workshop and a literature review, it aims to **integrate the theoretical state of knowledge** on the concepts of EE1st and MIs. This involves questions of how various MIs can be aggregated in the form of cost-benefit analysis (CBA), multi-criteria analysis (MCA) and other **frameworks** to inform decisions on what resource options actually provide greater value. We argue that, in itself, each of these frameworks has important limitations, which is why none of them can replace human judgement. For instance, CBA has inherent problems in coming up with robust monetary estimates of individual MIs, while MCA struggles with ensuring objectivity and representative stakeholder involvement. Another important issue is how the **evaluation perspective** (societal, private, etc.) affects the selection of MIs that should ideally be taken into account in quantitative assessments. Each of these perspectives is shown to have distinct application areas and practitioners should make sure to apply a consistent perspective when quantifying and aggregating MIs to compare resource options in the scope of EE1st.

The second objective of this report is to address the ongoing lack of quantitative evidence on individual MIs, especially in the context of the EE1st principle. We substantiate the previously developed ENEFIRST scenarios (2022) with bottom-up estimates of MIs. The key idea behind this so-called **socio-environmental assessment** is to move away from the previously used indicator of energy system cost that is limited to capital costs, fuel costs and other financial metrics. By investigating two selected types of MIs, we obtain a more comprehensive picture of the true societal value of end-use energy efficiency in the building sector.

One type of MIs investigated are **air pollution and climate change impacts**. Even though the ENEFIRST scenarios are all set to reach the common objective of net-zero greenhouse gas emissions by the year 2050, we find significant differences in cumulative emissions and ensuing costs from both air pollutants and greenhouse gases. The inclusion of these cost estimates significantly enhances the cost-effectiveness of energy efficiency measures from a societal viewpoint. Another type of MIs in this assessment are **indoor comfort improvements**. A new method was developed to quantify comfort gains as a result of building retrofits for the entire building stocks of individual Member States. The results indicate significant comfort gains for countries with poor efficiency of the building stock in the base year. As a result of the modelled retrofit measures, the share of poorly heated floor space below 18°C can be reduced by more than 30 percentage points, with ensuing benefits for health, well-being and workforce productivity.

In conclusion, any model-based assessment or scenarios in the scope of the EE1st principle should be substantiated with quantitative and qualitative estimates of different MIs to ensure a **fair comparison of demand and supply side resources** and thus to enable informed decisions on technology investment.

1. INTRODUCTION

As set out in previous ENEFIRST reports (ENEFIRST 2020a, 2020c), the **Energy Efficiency First (EE1st) 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 decision 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.

While the EE1st principle is gaining momentum in European Union (EU) energy and climate policy, there is increasing interest in the idea that energy efficiency has economic, environmental and social impacts beyond mere energy and cost savings (Fawcett and Killip 2019). For example, energy efficiency in the building sector typically comes with comfort and health improvements. Cities can profit from reductions in local air pollution when reducing the need for energy supply. For society at large, there are overarching impacts in the form of employment gains, greenhouse emission reductions, and others (ENEFIRST 2021b). These impacts are referred to as **multiple impacts** (Ürge-Vorsatz et al. 2016), multiple benefits (IEA 2015), wider benefits (European Commission 2021c), non-energy benefits (Lazar and Colburn 2013) and other terms, but all share the same idea: policymaking and individual investment should look beyond the direct financial benefits of energy efficiency to acknowledge its true value.[1]

Supporters of the EE1st have long blended the idea of **multiple impacts (MIs) into the principle**. For example, Bayer et al. (2016b) call for a thorough inclusion of MIs in policy-related impact assessments. Shnapp et al. (2020) argue that cost-optimal levels of building energy performance requirements under the Energy Performance of Buildings Directive (European Union 2018b) should include MIs (e.g. reduced air pollution) to capture the societal value of energy efficiency and thus to legitimize more ambitious building codes. Changes in policymaking are foreseeable. In its proposal for a recast of the Energy Efficiency Directive (EED), the European Commission (2021f) asks Member States "promote […] the application of cost-benefit methodologies that allow proper assessment of wider benefits of energy efficiency solutions […]" (Art 3.3).

Despite these advances, MIs are only selectively captured and play a secondary role in policymaking and private investment (Thema et al. 2019). In response to this **need for robust analysis and reliable evidence**, there has been an increasing amount of literature in recent years, including the seminal work by the IEA (2015), several EU-funded research projects (MICAT, COMBI, IN-BEE, etc.) and other work. In this literature, much attention has been given to methods for quantifying individual MIs. For example, Reuter et al. (2020) present a set of 20 quantitative indicators to measure the environmental, economic and social impacts of energy efficiency. In this vein, Fawcett and Killip (2019) point out that robust methods for many MIs are either not yet available or insufficiently evidenced, especially for job creation and macro-economic benefits.

Providing evidence on individual MIs is one issue. Another is **weighing up the MIs 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 what options should be prioritized, invested in, or otherwise supported. **Table 1** provides examples of instances in the context of EE1st where a more comprehensive inclusion of MIs could lead to a **fairer comparison of demand-side and supply-side resources**. For example, the European Commission

[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 MIs exist for all resource options, not just end-use energy efficiency.

relies on impact assessments to inform major policy initiatives. Making MIs an integral part of these assessments delivers more evidence on the various benefits of energy efficiency and would be expected to result in stronger energy savings targets (Fawcett and Killip 2019). This would require changes in the Better Regulation guidelines and toolbox (European Commission 2021a, 2021b).

Table 1. Examples for possible integration of multiple impacts in the context of the EE1st principle

EPBD: Energy Performance of Buildings Directive; EED: Energy Efficiency Directive; TEN-E: Trans-European Networks for Energy

Decision-making level	Examples of decision-making instances in the scope of the EE1st principle	Key venues
State (EU and national)	**Impact Assessments** | Improve analysis and reporting of MIs to inform preferred options for policymaking	Better Regulation Guidelines and Toolbox (European Commission 2021a, 2021b)
	Ambition levels of building codes | Include MIs in definition of cost-optimality for minimum performance standards of new and existing buildings	EPBD (European Union 2010, Art. 2 to 5)
Cities and regions	**Local heating and cooling plans** | Assess potential for demand reduction and decarbonised heat supply with explicit consideration of MIs	EED proposal (European Commission 2021f, Art. 23.3)
	Comprehensive heating and cooling assessment | Inclusion of MIs in cost-benefit analysis to identify and deploy cost-efficient technology options	EED (European Union 2012, Art. 14.3)
Utilities	**Power & gas transmission network planning**: include demand-side resources and their MIs in CBA methodologies developed by ENTSO-E and ENTSOG	TEN-E Regulation (European Union 2013, Art. 11)
Consumers (households, firms, public buildings)	**Consultation for building owners** | Highlight MIs of renovation options in energy performance certificates, building renovation passports, and other information instruments	EPBD proposal (European Commission 2021g, Art. 10)
	Public procurement | Require the procurement of energy efficient goods and services in the public sector, based on integrated cost-benefit assessments and MIs of alternative resource options	Directive on public procurement (European Union 2014)

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 MIs to assess the trade-off between resource options in line with the EE1st principle**. Particular issues include the selection of suitable decision-support frameworks (cost-benefit analysis, multi-criteria analysis, etc.) as well as the proper application of different evaluation perspectives (societal, private, etc.). In addition, there is a lack of actual quantitative assessments on EE1st that demonstrate how MIs can be integrated in the assessment of demand-side and supply-side resources in the context of EE1st (ENEFIRST 2020c).

Against this background, the objective of this report is twofold. First, it aims to integrate the state of knowledge on the concepts of Energy Efficiency First and Multiple Impacts (**Chapter 2**). This involves a review of the **theoretical interlinkages between the two concepts**. The chapter also discusses the possible scope of different decision-support frameworks and evaluation perspectives in the context of the many venues relevant to the implementation of EE1st. This conceptual chapter is informed by a workshop conducted with 16 researchers and practitioners engaged in the subjects of MIs and energy efficiency. The list of workshop participants as well as the specific issues discussed are provided in **Annex: Workshop information**. Second, this report provides evidence on individual MIs quantified in the scope of the **model-based assessment** of EU scenarios developed in ENEFIRST (ENEFIRST 2021a, 2022) (**Chapter 3**). This work focuses on the MIs 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 MIs alters the possible conclusions to be drawn from model-based assessments. The report concludes with a general summary of the interlinkages between Energy Efficiency First and Multiple Impacts and an outlook to further research.

2. THEORY: INTEGRATING THE CONCEPTS OF ENERGY EFFICIENCY FIRST AND MULTIPLE IMPACTS

This chapter aims to integrate the theoretical concepts of Energy Efficiency First (EE1st) and multiple impacts (MIs). In a first step, we describe the interlinkages between these two concepts, arguing that MIs are a key element to a proper understanding of EE1st (**Chapter 2.1.1**). 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 MIs (**Chapter 0**). Finally, we examine how the evaluation perspective (private, societal, etc.) determines the scope of MIs that ideally should be considered (**Chapter 2.3**).

2.1.1 Conceptual background

In this chapter we explain how the concepts of EE1st and MIs are inherently linked. We begin with a brief recapitulation of the EE1st principle (**Chapter 2.1.2**). We then continue with describing the origins and current state of the scientific and policy discussion around MIs (**Chapter 2.1.3**).

2.1.2 Energy Efficiency First

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 academic literature (Rosenow et al. 2017; Pató et al. 2019b). In the year 2018, the EE1st principle has been formally introduced to EU policymaking as part of the Governance Regulation (European Union 2018c) and other legislation. More recently, with the Fit-for-55 package, the European Commission (2021d) aims to further embed the EE1st principle in the recast of the Energy Efficiency Directive, the Renewable Energy Directive and other instances. A thorough account of these proposed legislations is provided in ENEFIRST (2021b).

The growing significance of the EE1st warrants a more detailed look at what exactly the principle means and implies with a view to the topic of MIs. Previous work in ENEFIRST compared existing definitions of EE1st and provided a thorough conceptual understanding of the principle (ENEFIRST 2020a, 2020c). The core definition developed reads as follows (ENEFIRST 2020a, p. 21): "'*Energy 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*."[2]

This definition is illustrated as a conceptual framework in **Figure 1**. In essence, the principle is about:

(1) **Setting decision objectives** | EE1st is not merely about comparing technology options, but about doing so with respect to energy service and policy objectives. The former means providing energy services as the fundamental purpose of energy systems. As for the latter, energy security, energy efficiency, market integration, decarbonisation, and innovation are key elements of EU policy, as per the Energy Union framework (European Commission 2015). From an economic perspective, the principal objective of any

[2] The EU Governance Regulation provides a similar definition (European Union 2018c, Art. 2.18): "*'energy efficiency first' means taking utmost account in energy planning, and in policy and investment decisions, of alternative cost-efficient energy efficiency measures to make energy demand and energy supply more efficient, in particular by means of cost-effective end-use energy savings, demand response initiatives and more efficient conversion, transmission and distribution of energy, whilst still achieving the objectives of those decisions.*"

public policy is to bring about economic efficiency – typically operationalized as maximising total surplus received by all members of society (Mankiw 2017; Harris and Roach 2018). Altogether, energy service and policy objectives can be conceptualized as the functional units for any decision related to the EE1st principle, i.e. the aspects for which the trade-off between supplying and saving energy is to be solved.

(2) **Comparing resource options** | It is fundamental to EE1st that energy decision objectives can be addressed by supplying or saving energy. Demand-side resources comprise end-use energy efficiency, demand response and energy sufficiency. Improving supply-side energy efficiency is another critical resource option, e.g. reducing line losses in power networks. The principle thus acknowledges a multitude of resources to achieve decision objectives, epitomized in the statement that 'a kilowatt-hour generated is equivalent to a kilowatt-hour saved' (Eckman 2011).

(3) **Deploying resource options** | At its core, the EE1st principle calls for prioritizing demand-side over supply-side resources whenever these are more cost-efficient from a societal perspective in meeting decision objectives. This deployment of resource options requires involves actions by policymakers, regulators and, ultimately, individual investment and operation decisions on the supply and the demand sides of the energy system. As frequently discussed in ENEFIRST, implementing the EE1st principle 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.

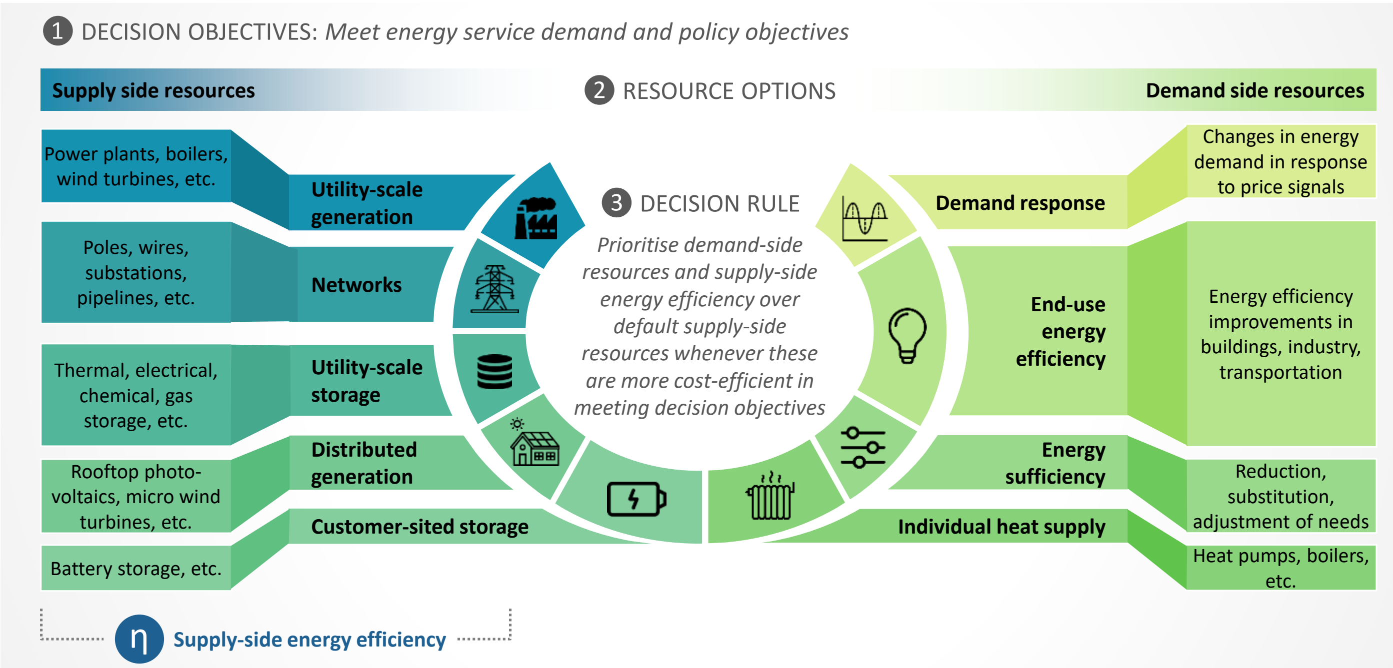

Figure 1. Conceptual framework of the Energy Efficiency First principle

Source: Mandel et al. (2022)

This framework suggests that resource options should be evaluated primarily from a societal perspective, which is different from private as well as state perspectives to investment appraisal. These differences are more thoroughly addressed in **Chapter 2.3**. What is important to highlight here that cost and benefits are not merely composed of tangible financial metrics, such as upfront investments (capital expenditures, CAPEX), fuel costs and operation and maintenance costs (operating expenses, OPEX). For many years, the energy efficiency literature has relied on engineering-economic analyses to calculate seemingly cost-effective levels of energy efficiency. These analyses essentially required data on CAPEX and OPEX as well as assumptions on discount rates (Jaffe and Stavins 1994; Gillingham and Palmer 2014). By now, it is increasingly acknowledged that individual energy technology investment and operation decisions are governed by many more factors beyond the basic economic metrics of CAPEX and OPEX.

On the one hand, energy efficiency sceptics list a variety of reasons why economic energy efficiency potentials may be overstated (Allcott and Greenstone 2012; Gillingham and Palmer 2014; Stadelmann 2017). This includes, for example, hidden costs, i.e. the time costs of finding or installing a more energy-efficient technology, processing incentive payments, and other intangible costs. These researchers also point towards rebound effects that would result in estimates of cost-effective energy savings to be biased upward. On the other hand, energy efficiency proponents have been taking up the idea that energy efficiency has many environmental, social and economic benefits, such as improved health, job creation, and energy security, and that currently these are not properly understood or taken into account in decision-making (Fawcett and Killip 2019). These multiple benefits or, more neutrally, multiple impacts (MIs) do not only occur at a societal level (e.g. reduced air pollution), but also at an individual or private level (e.g. comfort improvement for building owners as a result of thermal refurbishments).

As such, the subject of multiple impact is significant to different decision-making levels of EE1st:

- At the **EU level**, policy formulation for new directives and regulations should be informed by impact assessments that evaluate costs and benefits for society at large, rather than from the private perspective of individual consumers (Bayer et al. 2016b). Besides revisiting the discount rates used for demand- versus supply-side resources (ENEFIRST 2020c), this also implies thorough quantification and inclusion of multiple impacts of energy efficiency and other technology options (Fawcett and Killip 2019).
- At the **local and regional level**, integrated municipal heat plans are being discussed as means to systematically assess the potential for end-use energy efficiency in buildings alongside possible upgrades of district or decentralised heating systems towards renewable heat supply (ENEFIRST 2021b). Again, to determine a viable combination of resource options, such an assessment should factor in multiple impacts. This includes both an aggregate societal perspective to determine whether the local community would be better off overall (e.g. including air pollution impacts), as well as a private perspective to assess whether investments in district heating systems or building renovations would be worthwhile and profitable for individuals and investors (e.g. indoor comfort improvement impacts).
- At the **private level**, individual consumers are concerned with the trade-off between saving energy through technical and behavioural measures as well as using energy in the form of heating systems, electrical appliances, etc. Some multiple impacts are not immediately relevant in this setting, such as reduced GHG emissions that are externalities from the individual perspective. Yet, there remain multiple impacts that are not properly taken into account by consumers, including reduced energy bills, increased property values, disposable income available, etc. This provides the rationale for behaviourally informed policies to resolve such irrationalities in decision-making, including building logbooks as a digital repository of potentially worthwhile building renovation options (ENEFIRST 2020b).

To conclude, multiple impacts are a key element in the concept of EE1st. They are certainly not limited to end-use energy efficiency and other demand-side resources but also arise for renewable energy supply and infrastructures in the form of reduced emissions, job creation, energy security, and more (Edenhofer et al. 2013; 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. To delve deeper into this issue, the following section elaborates on the origins and the state of research on multiple impacts.

2.1.3 Multiple impacts

The fact that energy efficiency measures in particular of building retrofitting may create 'multiple-impacts', going beyond the pure benefit of saving energy, energy expenses and greenhouse gas emissions has been recognised by numerous studies and authors (IEA 2015; Kerr et al. 2017; ENEFIRST 2021b). In this chapter, we will set the scene for the following chapters by discussing **origins of the discussion, terminologies, definitions** and how to cluster various multiple impacts in different **categories**.

The topic occurred strongly in the early 1990's in the **US**. Although studies showed clearly the existence of 'non-energy benefits', it turned out that neither public authorities nor utilities consider them appropriately in their cost-benefit analyses (Kerr et al. 2017). Moreover, the discourse of multiple impacts of energy efficiency is also linked to concept of energy efficiency as **"first fuel"**, aiming at providing a higher visibility to the fundamental role of energy efficiency and energy savings (IEA 2015). While a large part of the "multiple-impact" discussion is related to energy efficiency, the term and topic is also analysed in the broader context of climate change mitigation (Stechow et al. 2015; Ürge-Vorsatz et al. 2014).

In particular, the literature shows a strong focus on **multiple impacts of building renovation**. In particular, there is an increasing discussion to which extent the cost-optimality analysis according to the EPBD (European Union 2010, 2018b) should need to take into account these wider societal or economic benefits. The Commission Recommendation on building renovation (European Union 2019) states that '**wider benefits**' need to be included in the long-term renovation strategies, where the 2017 Long-term renovation strategies of Cyprus, the Czech Republic, Finland, Lithuania, Romania and Sweden are listed as "good practice examples of efforts to quantify the wider benefits of building renovation."

In order to assist financial institutions in scaling up their investments into energy efficiency, the Energy Efficiency Financial Institutions Group's (EEFIG) designed a toolkit. Within this toolkit, there is a separate section "Value and Risk Appraisal" in which multiple benefits to be taken into account when investing in energy efficiency are described (Shnapp et al. 2020). Fawcett and Killip (2019) conclude that multiple benefits can become relevant in policy decisions, in the sense that "arguments are most persuasive when linked to the values and priorities of decision-makers and politicians", in particular if energy efficiency is not one of their values in itself. Thus, the multiple benefits approach may facilitate "new narratives that speak engagingly and with relevance to different stakeholders" (Payne et al. 2019).

The term 'multiple impacts' has been used almost interchangeably with the terms 'co-benefits', **'multiple benefits'**, **'non-energy benefits'**, **'ancillary benefits'**, **'indirect costs'**, **'wider benefits'**, **'hidden benefits'** and **'adverse side-effects'** (Ürge-Vorsatz et al. 2016; Kerr et al. 2017; Thema et al. 2019). According to Kerr et al. (2017), who is mainly use the term 'non-energy benefits', initial studies tended to use the term 'co-benefits' which evolved in recent years towards the term 'multiple benefits', not necessarily emphasizing on any particular benefit. The IEA (2015) uses the term 'multiple benefits' in order "to reflect the heterogeneous nature of outcomes and to avoid pre-emptive prioritisation of various benefits." In this report, we follow the definition by Ürge-Vorsatz et al. (2016), using the term **multiple impacts "to denote all benefits and costs related to the implementation of low-carbon energy measures which are not direct private benefits or costs involving a financial transaction and accruing to those participating in this transaction."** In comparison to the term 'multiple benefits' or 'co-benefits', the term "multiple impacts" can be perceived in a more neutral way. This leaves the decision whether a certain impact should be classified as benefit to the reader and finally to the decision maker.

The discussion above showed some examples illustrating the wide range of literature in the context of multiple impacts of energy efficiency. Since the studies differ in their **focus, scope, method and objectives**, they also differ in the type of multiple impacts they are analysing and the way how they are structured. Still, the following examples show that the categories of multiple impacts of energy efficiency are similar:

- IEA (2015) provided a clustering of 'multiple benefits' according to following categories: (1) macroeconomic development, (2) public budgets, (3) health and well-being, (4) industrial productivity and (5) energy delivery.
- Ürge-Vorsatz et al. (2016) apply a classification by elements of a green economy: (1) improved human well-being, (2) improved social equity, (3) reduced environmental risks and (4) ecological scarcities.
- In the COMBI project, which aimed at developing a methodology for quantifying multiple impacts, the following classification of multiple impacts was applied (Mzavanadze 2018): (1) air pollution, (2) macro-economy, (3) energy poverty, (4) resources, (5) energy system) and Thema et al. (2019), slightly deviating from COMBI: (1) Air pollution, (2) resources, (3) social welfare, (4) economy and (5) energy system.
- Reuter et al. (2020) developed "a quantitative indicator approach including 20 indicators to measure the multiple benefits of energy efficiency". They distinguished following groups, similar to Pollitt et al. (2016): (1) environmental (including energy savings, emissions), (2) economic (innovation/competitiveness, macro-economic, micro-economic, energy security) and (3) social (quality of life, energy poverty). In **Figure 2** they highlighted the numerous interconnections between multiple benefits of energy efficiency.

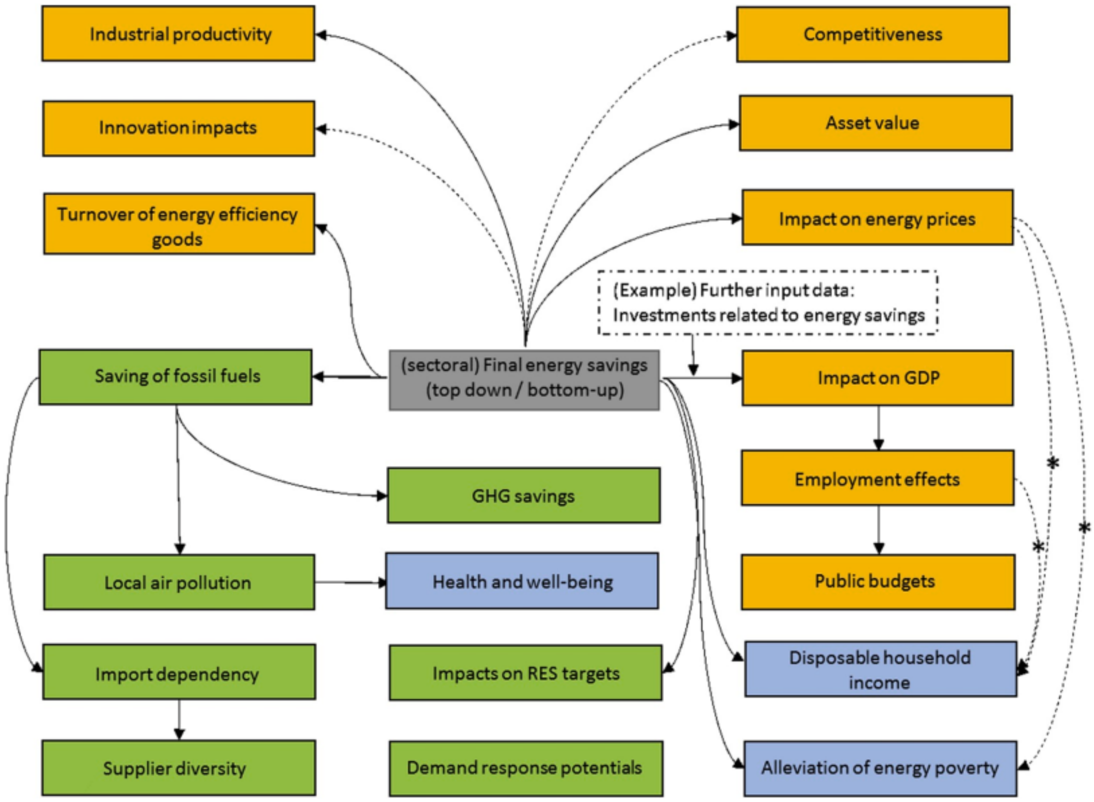

Figure 2. Overview of multiple benefits of energy efficiency and their interconnections

Source: Reuter et al. (2020) | Environmental: green, economic: orange, social: blue | [3]

[3] "Dashed arrows indicate that there is no direct relationship with the central indicator of final energy savings. This is the case for the indicators on innovation and competitiveness, or for demand response potentials. For some other indicators linked

The following studies had a particular focus on efficiency improvements in the building sector. Pollitt et al. (2016) studied positive and negative impacts of **improvements in energy efficiency in buildings** in the European Union. They cluster impacts in following three categories: (1) Economic impacts (including macro economy, public budgets, industrial competitiveness and the value of buildings), (2) social impacts (including health and energy poverty) and (3) environmental impacts (including GHG-emissions, demand for materials, water consumption and land use of the power sector).

Some of the studies mentioned above, carry out **monetization** of some of the effects (e.g. Pollitt et al. 2016). This is also done in Shnapp et al. (2020) who analysed and discussed methodologies for the inclusion of multiple benefits in a cost/benefit assessment of energy efficiency policy. They focus on the building sector and distinguish: (1) Micro-multiple benefits, including different impacts in terms of building physics, economics and user wellbeing and (2) macro-multiple benefits, comprising environmental, social and economic impacts. They also relate these impacts to Sustainable Development Goals (SDGs). The fact that the co-benefits contribute to 10 out of 17 SDGs shows the broad range of potential impacts.

Overall, while the detailed categories and structure of multiple impacts slightly differs, there is a strong overlap in the used concepts. Freed and Felder (2017) and Ürge-Vorsatz et al. (2016) discussed that multiple impacts may also be categorized regarding the recipient/beneficiary. For the case of building retrofitting, this might be building owners, building occupants, employees, companies operating and using buildings, technology providers and upstream supply companies and society as a whole. More detailed examples of multiple impacts in the context of the building sector as discussed in other studies, in particular the COMBI project are also discussed in (ENEFIRST 2021b).

2.2 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 MIs.[4] **Cost-benefit analysis** (CBA) is one possible framework, assessing all positive (benefits) and negative (costs) effects of resource options (Atkinson et al. 2018; Sartori et al. 2015) (**Chapter 2.2.1**). **Multi-criteria analysis** (MCA) is another common framework for bringing together a variety of MIs (IEA 2015) (**Chapter 2.2.2**). In practice, most of the literature on energy and climate policies is framed within either CBA or MCA (Ürge-Vorsatz et al. 2014; Atkinson 2015). Table 2 compares the essential features of these frameworks. However, both CBA and MCA have inherent methodological issues that give rise to a range of **miscellaneous frameworks** (**Chapter 2.2.3**).

with dashed arrows and marked with an asterisk, such as energy prices and employment, there are second order impacts on other indicators." (Reuter et al, 2020)

[4] One may also call these policy formulation tools (Turnpenny et al. 2015), decision tools (Munda 2019), or key methodologies relating to the assessment, quantification and monetisation of MIs (Ürge-Vorsatz et al. 2015).

Table 2. Comparison of decision-support frameworks in the scope of the EE1st principle

Source: Compiled from Browne and Ryan (2011), Ürge-Vorsatz et al. (2015), Atkinson (2015)

		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 MIs; 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

2.2.1 Cost-benefit analysis

Cost-benefit analysis (CBA) is also referred to as 'benefit-cost analysis', 'project evaluation' or 'project appraisal'. An illustration of its practical use is given in **Box 1** . Its theoretical foundations of lie in **welfare economics** that is concerned with how people's wellbeing is affected by policy actions and how these people value losses and gains. The central assumption in CBA is that gainers can potentially compensate losers and still be better off (Atkinson 2015).[5] This leads to the notion in CBA theory to select those alternatives that provide the greatest **net benefits to society**, i.e., benefits minus costs (Atkinson 2015; European Commission 2021a).[6] It is important to note that there is no single definition of these net benefits in the energy literature in terms of what cost and benefit items they comprise. In practice, costs and benefits are

[5] The idea of hypothetical compensation as a rule for deciding on options in real-life contexts is formally established in welfare economics as the Kaldor-Hicks compensation principle (Hicks 1939, 1943; Kaldor 1939). The compensation principle loosens the restrictive condition known as the "Pareto condition", whereby an outcome is supported if at least some people actually gain and no-one actually loses. See Atkinson et al. (2018) for a detailed account of these foundations to CBA.

[6] CBA generally examines social justification for investments. This is distinct from a financial assessment which looks at the bottom-line for the implementing actor (e.g. building owner). In many instances, however, economic appraisals will consist of both social CBA and the financial case, such as with funding provided under the Structural Cohesion Fund (Sartori et al. 2015; Atkinson 2015).

represented by different items depending on the type of modelling approach and level of analysis being pursued (Cohen et al. 2019).

Aggregation of different MIs to a common figure of **net-benefits** in CBA requires a common metric. This is done through monetization, i.e., attaching a monetary value to physical metrics that reflects their costs or benefits for society (Atkinson et al. 2018). While monetization is not complex in arithmetic terms, its challenge lies in **attaching money values to impacts** for which there typically is no market value. There exists a variety of valuation techniques for this purpose. These range from direct market valuation (e.g. valuing health benefits at prevailing applicable health services costs), to willingness to pay (WTP) and willingness to accept (WTA) approaches (Ürge-Vorsatz et al. 2015; Atkinson et al. 2018). WTP and WTA can be measured via revealed preference methods, e.g. measuring the expenses that homeowners pay for improved thermal comfort. Other valuation techniques elicit money values via stated preference methods, e.g. asking people about the value they place on thermal comfort (Atkinson 2015; Ürge-Vorsatz et al. 2014).

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 MIs. 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 MIs in CBA constitutes double-counting and thus potential overestimation of total impacts. Thorough analysis of impact causalities and overlaps is thus needed. A dedicated method to account for interrelations between MIs is the **multiple impact pathway mapping** approach (Ürge-Vorsatz et al. 2014; Ürge-Vorsatz et al. 2016). At its core, the approach suggests the creation of a map that illustrates all relevant MIs for the given case, their interaction and, finally, those end-points that should be monetized. In sum, there is a clear need for updated empirical research that can be used in CBA to monetize and thus account for MIs (Freed and Felder 2017).

A noteworthy aspect of CBA is its dealing with **distributional aspects**. By default, according to the Kaldor-Hicks principle in CBA and underlying welfare economic theory, it is justifiable for society as a whole to make some worse off if this means a greater gain for society at large. The emphasis of conventional CBA is thus 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), which may seem unreasonable considering the extensive socio-economic changes in the energy system.

Another distributional issue in CBA surrounds **discounting** by relating to the notion of intergenerational equity. The higher the discount rate used in CBA, the more decisions are shifted towards actions that bring more immediate net benefits. In turn, impacts occurring relatively far into the future receive less and less weight for any positive discount rate. The choice of discount rates for decisions with long-term consequences is thus inherently controversial (Atkinson 2015). The subject of discounting in the context of the EE1st principle is comprehensively dealt with in a previous report of the ENEFIRST project (ENEFIRST 2020c). The need for **public participation** of citizens and other stakeholders is broadly recognized in the literature on decision-support frameworks (Munda 2019). In CBA, the quantification and monetization of impacts primarily relies on scientific expertise, rather than stakeholder involvement. This expertise, however, involves comprehensive empirical research to determine money values for different impacts.

Box 1. Cost-benefit analysis in practice

The European Horizon 2020 research project COMBI ("Calculating and Operationalizing the Multiple Benefits of Energy Efficiency in Europe") not only developed methods for impact quantification and monetization, but also dealt with the aggregation of individual impacts in a CBA framework. Particular attention was given to systematically identifying interactions among impacts. Where interactions could not be ruled out, impacts were not incorporated in the CBA. Ultimately, eleven monetized impacts were included in the COMBI CBA framework (Thema et al. 2019).

This framework was applied to a set of scenarios for the EU to assess MIs in the year 2030 that result from end-use energy efficiency measures. The scenarios were based on 21 energy efficiency improvement actions in the buildings, transport and industry sectors (Chatterjee et al. 2018). **Figure 3** shows results for selected measures as annualised net present value (white bar) resulting from costs (investments, grey) and benefits (colours). Almost all of these measures are cost-effective from society's viewpoint as benefits exceed costs. Overall, the MIs of the measures quantified in COMBI amount to 60 bn EUR/a plus 106 bn EUR/a of energy cost savings, i.e. MIs add about 57% of energy cost savings to benefits (Thema et al. 2019).

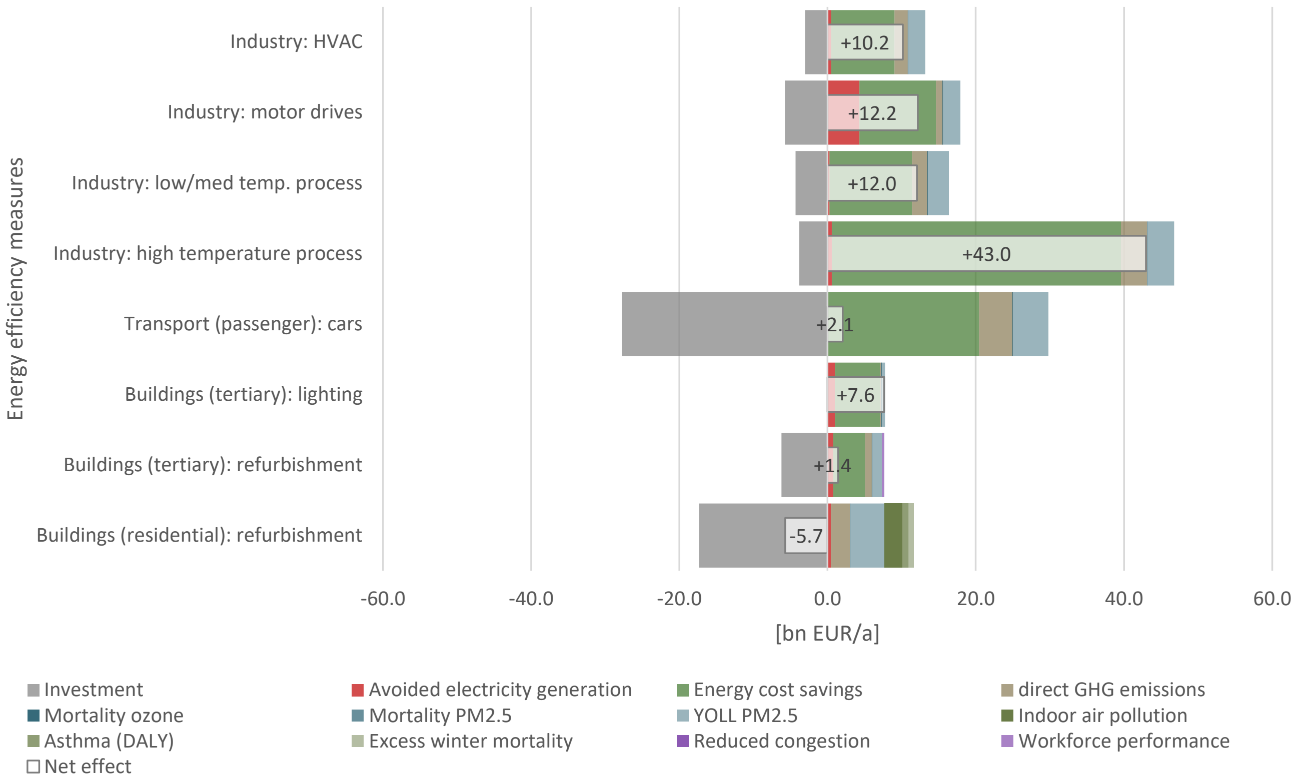

Figure 3. Annualised net present value of energy efficiency measures in the COMBI project.
Source: https://combi-project.eu/charts/

The project thus clearly demonstrates how the inclusion of multiple impacts can substantially alter CBA results. In turn, omitting multiple impacts in CBA reduces the cost-effectiveness of energy efficiency actions below their actual value, potentially leading to sub-optimal levels from a societal viewpoint.

In practice, CBA is traditionally used in ex-ante appraisal of **discrete projects** that have economic and social consequences across a significant area and population (Atkinson 2015). An example is the CBA 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 in **Chapter 2.2.3** as they also involve elements of multi-criteria analysis (MCA).

CBA is also widely used as part of the **policy formulation** process in assisting policymakers understand the impacts of a policy, particularly if total costs and benefits can be identified, quantified and monetized (Browne and Ryan 2011). For example, the Energy performance of buildings directive (EPBD) (European Union 2010, 2018b) 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.

With a view to discussions on the EEE1st principle, CBA is prominently featured in official documents. The Commission guidelines on the EEE1st principle (European Commission 2021c) include a dedicated chapter on CBA, emphasizing the use of a societal perspective and the inclusion of 'wider benefits' in carrying out CBA. It also highlights the role of regulators in defining CBA methodologies for specific areas. More recently, in its proposal for a recast of the Energy Efficiency Directive (EED) (European Commission 2021f, 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.[7]

All in all, the general 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 MIs 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 in meeting planning and policy objectives*" (ENEFIRST 2020a). In turn, despite ongoing methodological advances, it can be doubted whether CBA can ever provide an exhaustive account of all relevant MIs in a single monetized metric. This shortcoming provides the essential rationale for MCA.

2.2.2 Multi-criteria analysis

MCA is also known as multi-criteria decision analysis (Cohen et al. 2019; IEA 2015), multi-criteria evaluation (Munda 2019), or multi-criteria decision making (Siksnelyte et al. 2018). It is a decision-support framework to handle multi-factorial decision problems that affect several stakeholders and where an where an equitable, inclusive and transparent decision process is sought (Gamper and Turcanu 2015). The theoretical foundations of MCA lie in the fields of operational research and management science. Its methodological key principle is 'incommensurability', i.e. the notion that different options cannot simply be compared and that a

[7] Recital 14 of the EED proposal specifies that 'major investment decisions' are about any investment above EUR 50 million (or EUR 75 million for transport infrastructure projects) that affect energy use or supply.

plurality of dimensions and perspectives is needed to inform decisions. Figuratively speaking, while CBA considers the aggregation of apples and oranges possible, MCA disagrees with this view (Munda 2019).

To assess the worth of different resource or policy options, CBA requires the aggregation all impacts to a common monetary metric. In turn, MCA aggregates metrics (e.g. number of jobs gained) on **multiple evaluation criteria** (e.g. macroeconomic impacts) into scores or other indicators of overall performance, without the need to transform them to a common unit (Gamper and Turcanu 2015). The criterion 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).[8]

MCA as a decision-support framework is well adapted to the **concept of MIs** as it recognises the multidimensional nature of sustainability and social issues that should be considered in energy policy (IEA 2015). **Box 2** provides an example of using a MCA framework in the context of multiple impacts. A more general overview of MCA in practice is given by (Siksnelyte et al. 2018). The overall premise in MCA is similar to CBA – if only a subset of MIs is assessed, this can create a negative bias in a way that the societal value of energy efficiency and other resource options is underestimated (Ürge-Vorsatz et al. 2016). **Overlaps** among MIs 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 clearly 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. Some MCA methods are specifically designed for opening up the decision making process to participation, e.g., multi-criteria mapping (Gamper and Turcanu 2015). 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, compared with CBA, MCA can be more useful in developing potential social compromise solutions and legitimizing decision outcomes by making a complex situation more transparent (Browne and Ryan 2011).

However, similar to the selection of money values in CBA, MCA may also involve a significant degree of **subjectivity** (Gamper and Turcanu 2015; Browne and Ryan 2011). In practice, representative stakeholder involvement processes in MCA 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 persistent contrary value judgements (Gamper and Turcanu 2015). There are also inherent methodological issues in CBA in specifying how each impact will be assigned a score and general issues surroundings the use of weights (Browne and Ryan 2011).

[8] In practice, there is a range of MCA methodologies, each of them evaluating alternatives by different means. Some techniques rank options, some identify a single optimal alternative, others differentiate between acceptable and unacceptable alternatives (Ürge-Vorsatz et al. 2015; Munda 2019).

Box 2. Multi-criteria analysis in practice

Dirutigliano et al. (2017) demonstrate how MCA can support decision-making in the scope of urban planning with an explicit consideration of non-monetary impacts. The authors investigate what building retrofitting alternatives to generate both economic and socio-environmental benefits. They apply the PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) method to a case study in the city of Torino for outranking five different alternatives for building refurbishment that allow achieve 20% energy savings.

Multiple criteria are assessed in the analysis, including investments and operating costs, as well as internal comfort, real estate value, system reliability and other socio-environmental aspects frequently referred to in the literature on MIs. Technology alternatives assessed include demand-side (e.g., window replacement, insulation of envelope) as well as supply-side resources (e.g. solar thermal plant). These technology alternatives are assessed against the criteria defined and then attached weights that are determined in an expert panel with urban planners and building experts. Based on this approach, the most favourable technology alternative is found to be a standard envelope renovation with an additional control system, characterized by significant comfort improvement and acceptable costs. As such, MCA can provide considerable help to building designers, planners and decision makers for ranking complex design energy options.

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 2015; Gamper and Turcanu 2015). As noted above, MCA is becoming protracted and complicated the more diverse stakeholders are involved. Larger consultation processes with a claim to representativeness can thus hardly be realised, e.g. in the scope of EU-wide impact assessments.

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 EEE1st 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 MIs. The provisions set out in the EED recast proposal (European Commission 2021f, 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 MIs.

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.

2.2.3 Miscellaneous frameworks

From the discussion above, it is clear that estimating all MIs 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: “The discourse on energy efficiency is so strongly coloured by its historical association with CBA, that we believe a rethink is necessary and overdue. The message is not to throw away the traditional analytical tools, but to add new tools and skills to the analysts’ available resources.”

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 MIs of energy efficiency. The tool covers 15 categories of MIs, 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 MIs 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 MIs indicators. The MIs are classified into three groups: 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 hence, by default, cannot be aggregated. However, they can be useful inputs for aggregation in the scope of CBA or MCA.
- Langenheld et al. (2018) use a semi-quantitative approach to ascertain MIs for their scenarios on the German building sector. Their scope of MIs not only includes benefits (e.g. employment effects), but also intangible issues and risks (e.g. substantial market ramp-up of insulation materials). Individual MIs are either quantified in their physical units or described qualitatively. As such, the approach allows for enhancing the plausibility and credibility of otherwise purely cost-based scenarios.
- As noted by Fawcett and Killip (2019), case studies can also be powerful tools in the task of communication and persuasion. Careful presentation of good quantitative data is necessary but insufficient. It is the combination of numbers with more particular account or stories of change which make the case fully.

These **miscellaneous frameworks** can be useful to raise awareness, interest and knowledge among different stakeholders on the MIs of energy efficiency, and thus bring attention to values that otherwise would have been neglected (Persson and Landfors 2017). However, they cannot aggregate various MIs 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 others. Yet, the frameworks described in this chapter can complement each other to lead to more informed decisions MIs (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 within 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 (ENTSO-E 2018). 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), MIs 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).

2.3 Evaluation perspectives

The approaches to decision-making described in **Section 0** can be applied by different actors with different perspectives. The implementation of the EE1st Principle requires making judgements about the relative cost-effectiveness of demand side actions amongst the set of actions available to decision makers. The societal perspective (**Section 2.3.1**) would be expected to be taken by public authorities, when making policy decisions. Taking account of the full range of significant costs and benefits enables public authorities to assess relative cost-effectiveness more accurately. The boundaries of society and the competences of public authorities may influence the range of impacts assessed. The private perspective (**Section 2.3.2**) would be expected to be taken by private companies and households, although societal concerns may influence their decision-making processes. Raising awareness amongst the private sector of the multiple benefits associated with energy efficiency investments may form part of a cost-effective policy strategy. In the energy sector, the rules governing the remuneration and decision-making processes of regulated businesses can affect the range of impacts assessed. The public budget perspective (**Section 2.3.3**) focuses solely on the financial flows to and from the public sector. This may be important in ensuring cross-governmental support for energy efficiency actions that have impacts across sectors and government departments.

2.3.1 Societal perspective

The societal perspective should be expected to be used by governmental organisations when making decisions. The appraisal of options would include all significant positive and negative impacts that affect **social welfare and wellbeing**. Society can be defined as comprising the entire population that is served by the government (HM Treasury 2020). The boundaries of society can be different across time and space, depending on the impacts being considered. Where impacts have long-term horizons and inter-generational implications, e.g. irreversible environmental changes brought about by greenhouse gas emissions, the standard methods of **discounting** – accounting for the present value of societal welfare changes – may be insufficient in representing the full societal perspective. In such cases, excluding the pure rate of social time preference from discount rates may be appropriate (HM Treasury 2020). Undertaking sensitivity analysis on the discount rate can also help to expose intergenerational trade-offs (European Commission 2021b).

The effects of most impacts are likely to be largely felt within the boundaries of the geographical area under the control of the governmental organisation making the decision. However, for some environmental impacts, particularly climate change, the impacts of one government's decisions will have **implications for all societies**. The benefits of reducing carbon emissions will be felt across all societies while the majority of the abatement costs will be borne by the society directly affected by the government's decision. In the United Kingdom, this issue was addressed in the Climate Change Act Impact Assessment by providing estimates of the benefits in two different scenarios, one in which only the UK acted and the other in which the world took equivalent abatement action (DECC 2009). This approach does not attempt to estimate the benefits of avoiding carbon emissions (avoided damage and adaptation costs) in the society in question, instead attributing benefits based on the social cost of carbon. In reality, the avoided costs of carbon emissions are likely to be more concentrated in some societies than others. Avoiding damage and adaptation costs in some of those societies may have value to the government in question, particularly if they have overseas development objectives in lesser developed countries.

The societal perspective taken may depend upon the **geographical and policy competence** of the public authority making decisions. At the supra-national level, the EU has broad geographical coverage, taking into account cross-border effects and broad, but limited, policy competence, granted through treaty by its Member States. The EU Commission, when proposing regulations and other initiatives with significant impacts, must undertake impact assessments, taking into account the potential economic, social and environmental impact, as well as the costs and benefits of the proposals (European Commission 2021a). The full effects of a policy proposal must include estimates of its impacts inside and outside the EU. The impact assessment process for regulatory proposals involves first screening 35 key impacts, cutting across the environment, economic and social fields, before making a well-justified judgement on which impacts to focus for more in-depth analysis, based on the application of the principle of proportionality. This judgement should take into account the likely magnitude of the impacts, the relative size of the impacts on segments of society, their interaction with the achievement of other EU horizontal objectives and policies, and the potential for sensitivities or diverging views (European Commission 2021b).

The EU **2030 Climate Target Plan Impact Assessment** (European Commission 2020) considered at a high level, meeting higher levels of climate ambition using different combinations of carbon pricing, regulation and intensification of efforts across policy domains, including energy efficiency. The assessment provided the evidence base for the development of the legislative measures set out in the Fit for 55 Package in 2021 and its primary focus was on greenhouse gas emission reductions. It also assessed and quantified air pollution benefits from reductions in energy consumption and shifts to non-emitting renewables, using the GAINS model. Reductions in **air pollution control costs and health damages** from lower rates of premature mortality were calculated for some, but not all of the assessed policy combinations. Other air pollution benefits were noted but not monetised, including reduced morbidity and its associated economic impacts and reduced ecosystem damages. The impacts on biodiversity were discussed qualitatively. Energy security and macroeconomic impacts were assessed, including impacts on employment and on changes in the welfare of households by income decile (European Commission 2020).

Table 3. Summary of Key Costs and Benefits in the UK's Energy Company Obligation ECO3: 2018-2022 Impact Assessment

Source: Adapted from BEIS (2018)

	Costs	Benefits
Monetised | included in cost-benefit analysis	Installation costs (materials and labour)	Comfort taking (valued at retail price)
	Operational costs (servicing and maintenance)	Energy savings (valued at wholesale price)
	Administration costs (government and supplier)	Carbon emissions reductions (valued differently inside and outside EU ETS)
	Supplier search costs	Air quality improvements (valued using avoided damage cost estimates of the impacts of emissions of nitrous oxide (NO_X), sulphur dioxide (SO_2), ammonia (NH_3) and particulate matter (PM_{10}) on human health (mortality and morbidity), immediate environmental impacts (e.g. acidification and soil eutrophication) and long-term environmental impacts (including climate change).
	Opportunity costs of household finance	
	Hidden costs (household time / clean-up / redecoration / disruption)	
	Natural boiler replacement cost savings (negative costs). (Boilers replaced through the scheme are estimated to be replaced at lower cost than if replaced individually, owing to bulk delivery savings).	
Monetised | excluded from cost-benefit analysis	-	Health impacts associated with higher indoor temperatures (not included owing to their unquantified overlap with comfort taking).
Monetised | included in distributional analysis using equity weighting	Supplier delivery costs (including economic rent) passed through on all customers' bills through energy prices	Value to society of lower energy bills in low income, vulnerable and fuel poor households
	Household investments	
Not monetised | included in qualitative discussion	-	Innovation in energy efficiency materials and installation techniques
		Improvement in security of energy supply
		Macroeconomic benefits
		Reductions in energy system costs
		Community impacts

At the **policy programme level**, impact assessments may consider a narrow or broad set of impacts when providing the evidence base for decision makers. Amongst energy efficiency policy measures, energy efficiency obligation schemes (EEOS) are amongst the most significant, in terms of their costs and benefits. In the UK, the impact assessment for the third phase of the Energy Company Obligation (ECO3), which runs from 2018-2022 and focuses only on residential energy efficiency improvements, recognised a broad range of impacts. Not all of the impacts were monetised and, of those, some of the health impacts were not included in the cost benefit analysis calculation owing to their overlap with the benefits of comfort taking (**Table 3**). Amongst the impacts that are recognised but not monetised, health system impacts are notable by their absence. Nevertheless, the approach taken is a good example of a multiple impact approach to cost benefit analysis, nested within a broader recognition of wider impacts.

In the societal perspective, the net societal benefit should be the sum of all **private and public benefits minus the sum of all private and public costs**. Costs and benefits can also be weighted to reflect the relative welfare implications of policy changes at different points of the income distribution (see also **Chapter 2.2.1**). For example, an energy efficiency policy measure aimed at reducing the energy bills of households on low incomes will have equity implications that would not be picked up in standard cost-benefit analysis but, by definition (given the policy objective) are valued by society. In such cases, it makes sense to estimate this value through equity weighting, given that the value of costs and benefits are worth more to those on lower disposable incomes. In the UK ECO3 Impact Assessment, described above, the difference between the sum of the equity-weighted and non-weighted energy bill reductions to households is presented as the "value to society of lower energy bills in low income, vulnerable and fuel poor households" (BEIS 2018).

At the **local level**, public sector decision makers may have a different set of priorities to national governments making country-wide policy assessments. Local authorities tend to have a more limited set of responsibilities than national policy makers; they may also have objectives related to local air pollution, the local economy and improving the performance of specific buildings (e.g. to reduce energy poverty amongst social housing tenants), without having objectives related to the energy sector. The H2020 EERAdata project provides tools to enable local decision makers to make informed decisions when planning, renovating and constructing buildings, taking into account evidence on the multiple impacts of energy efficiency measures (see **Box 3**).

Box 3. The H2020 EERAdata project

Source: Botzler (2021)

The H2020 EERAdata project supports decisions and renovation action to prioritise investments in energy efficiency. It is working with three pilot local authorities to create a decision support tool to identify building stock that could be made more sustainable and energy efficient, enabling local decision makers to take a holistic view of the impacts of investments in buildings energy efficiency. The decision support tool incorporates energy sector, economic, social and environmental parameters in its socio-economic assessment module. Indicators covering job creation, macroeconomic impacts, public budget, fuel poverty and outdoor air pollution, amongst others, have been developed, along with variables related to the private perspective, such as comfort, well-being and health. Where possible, the variables are quantified and attributed monetary values, to enable a cost-benefit analysis or to provide additional information for a multicriteria analysis.

The societal perspective should be used in public decision making. It considers all costs and benefits, to the extent that they are significant, across the economic, social and environmental dimensions. If **a cost-benefit analysis** is employed, a social discount rate should be used, ensuring that long-run costs and benefits are given an appropriate weighting, from the perspective of society. Not all impacts are quantifiable with the same degree of accuracy. However, attempts should be made to do so in cost-benefit analyses, with appropriate sensitivity analyses. A zero value, is less likely to be accurate than an estimate made on the basis of limited information. **Some of the private impacts should not be included** in the societal perspective as they are transfers between different parts of society (e.g. tax payments and revenues) or the results of combinations of impacts (e.g. changes in asset values). However, these may be included in supporting distributional analyses and can help in informing supporting policy measures aimed at mobilising private investment and behaviour change. The private perspective is the subject of the next sub-section.

2.3.2 Private perspective

To understand most investment decisions, the private perspective is important (Thema et al. 2019). Governments wishing to achieve public policy objectives through private sector actors should be aware of the ways in which decisions are made and their impacts. **Private companies** would be expected to account for the costs and benefits to them, insofar as it is worth carrying out assessments, although they may choose to pursue some purely philanthropic programmes alongside their core business activities (Kasturi Rangan et al. 2015). Public authorities wishing to implement the EE1st principle in the energy sector through **regulated private companies**, e.g. energy network utilities, would be faced with various alternative courses of action.

Policy makers could regulate to ensure that investments in energy efficiency are carried out to the extent that government planning assessments suggest is desirable (taking into account multiple impacts) and compensate regulated entities accordingly, i.e. central planning with **performance-based regulation** (Pató et al. 2019a). This would by-pass the issues identified above with assessments undertaken only from the private perspective, as it could incorporate MIs. However, it would have distributional implications in that the customers of the regulated entities (i.e. energy bill payers) would be expected to pay the costs of achieving a wider set of societal objectives beyond the energy sector. This would be more regressive than using general taxation, given the incidence of the tax burden relative to the distribution of energy bill payments. A potential way to overcome these **distributional issues** would be to enable other funding streams, for example designed to meet health sector objectives, to co-fund the achievement of energy utility companies' energy efficiency performance indicators amongst targeted groups. An example of this type of approach can be seen in the French White Certificate programme, where energy utilities are required to meet energy saving targets that aim to meet broader socio-economic objectives, including a sub-target for energy savings amongst energy poor households. Over the course of the the programme, additional subsidies, for example through tax rebates, have been used to reduce costs passed through to bill payers (ADEME 2019).

To **avoid the potential for distributional inequities**, policy makers could instead limit cost benefit analyses to energy system impacts and, if external impacts are not internalised within energy prices through taxation, other energy-related impacts that are felt within the geographical boundaries, e.g. local air quality impacts. This approach is taken in some parts of the United States, where a variety of cost-effectiveness tests are used to assess the ambition of utility programmes. In some states, a simple Utility Program Administrator Cost Test (UCT) is used, that limits the costs and benefits assessed to those that affect the utility's operations and provisions of services to their customers. Where environmental impacts associated with energy are regulated separately, the avoided costs of compliance with these regulations are usually factored into UCTs. Wider societal environmental and health impacts are included in a smaller but growing number of states, often through "adders" which are applied to the sum of other quantified benefits (ACEEE 2018).

Public authorities aiming to persuade **private actors in the commercial and residential sectors** to invest in energy efficiency might also devote resources to raising awareness of the multiple private benefits to these groups, to enable more take up of energy efficiency incentives and to leverage more private investment. The H2020 Mbenefits project developed a multiple benefits approach to "selling" energy efficiency amongst commercial organisations. This identified three critical pillars when appealing to senior managers: cost reductions (beyond energy); improvements to the "value proposition"; and risk reduction (see **Box 4**).

Box 4. The H2020 Mbenefits project

Source: Berger et al. (2021)

The H2020 Mbenefits project provided energy experts with a set of tools to enable them to "sell" energy efficiency to commercial sector decision makers. They found that projects that can contribute positively to value, risk reduction and cost reduction generally align with senior managers' interests. The tools that were developed included an evaluation toolkit, a set of tips and solutions for effective communication, a user manual on evaluation and a "Serious Game", aimed at an already highly qualified audience, designed to allow energy managers and practitioners to improve the business case for energy efficiency projects, thanks to their focus on non-energy benefits.

The **multiple impacts of buildings energy efficiency of most interest to commercial and tertiary sector building owners** would likely relate to maintenance and operations costs, asset and rental values, and improved tenant retention (or labour force retention, if they are owner-occupiers). Many of these impacts in turn stem from improved indoor environmental quality, in the fields of thermal comfort, lighting, noise and indoor air quality (Kockat et al. 2018). In the residential sector, many of the same multiple impacts are relevant. Building landlords benefit from higher asset values (Zancanella et al. 2018), better rentability and higher tenant satisfaction and retention; building residents are more likely to be satisfied owing to lower energy costs, higher thermal comfort, less noise pollution and less frequent disturbance from building maintenance; while both owners and tenants face lower risks from climate policy, whether that be regulatory (on building owners) or market-based (on tenants through higher carbon prices).

2.3.3 Public budget perspective

Public sector decision makers should use the societal perspective when comparing options for achieving societal goals. The State represents society's interests. Governments might look at the implications of energy efficiency and alternatives on the distribution of costs and benefits, including to public budgets. However, this should not affect the assessment of the net present value of options to achieve energy policy objectives.[9] A public budget perspective would focus only on the **financial flows to and from the public sector**. Nevertheless, policy makers in individual government departments often need to make policy decisions within **budgetary constraints** set out by the financial department or ministry. Therefore, it can be difficult to justify policy interventions on the basis, in part, they create budgetary savings in other departments, such as in health, or indeed finance departments. In these situations, taking the public budget perspective may be helpful in making the case in internal government negotiations over funding levels for energy efficiency programmes. Public sector decision makers also often need to ensure that they are delivering **"value for money" of public funds**, i.e. finding the optimum combination of whole-life cost and quality (or fitness for purpose) to meet policy requirements (Jackson 2012). It may be possible to meet societal objectives through a different combination of financial support and information-based policy measures, for example if raising awareness of the private benefits of energy efficiency actions would mean more independent take-up and fewer financial subsidies. Evaluations of energy efficiency policy measures might also have a focus on their public budget implications, particularly if they involve tax-based incentives. One such example would be the Italian National Recovery and Resilience Plan, which included a 110% tax rebate for energy efficiency (https://www.governo.it/it/superbonus) investments.

[9] In a period of fiscal stress, a government might choose to reflect its cost of borrowing by placing more weight on the financial costs and benefits to the state, affecting the ranking of options.

2.3.4 Comparison of evaluation perspectives

To conclude this chapter, **Table 4** compares the evaluation perspectives presented above, based on the example of publicly funded subsidy programmes for energy efficiency measures.

Table 4. Comparison of evaluation perspectives (publicly funded subsidy programme)

	Societal perspective	Private perspective	Public budget perspective
Rationale	Calculating the costs and benefits to **society** as a whole	Calculating the costs and benefits to **programme participants**	Calculating the costs and benefits to the **public sector**
Benefits (energy system)			
Avoided energy costs	X	-	-
Avoided capacity costs	X	-	-
Avoided network costs	X	-	-
Avoided costs of environmental compliance [(a)]	X	-	-
Avoided utility billing costs [(b)]	X	-	-
Energy price reduction [(c)]	-	-	-
Participant bill savings	-	X	-
Avoided participant equipment maintenance	X	X	-
Benefits (non-energy)			
Avoided environmental damage [(d)]	X	-	-
Participant comfort taking [(e)]	X	X	-
Participant health benefits (beyond comfort) [(f)]	X	X	-
Avoided participant healthcare costs [(g)]	X	X	-
Avoided public sector healthcare costs [(g)]	X	-	X
Poverty alleviation [(h)]	X	X	X
Improved business profitability [(i)]	X	X	-
Property values [(j)]	-	X	-
Macroeconomic impacts [(k)]	X	-	-
Energy security [(l)]	X	-	-
Costs			
Measure costs: financial incentive [(m)]	X	-	X
Measure costs: participant contribution [(m)]	X	X	-
Programme administration costs	X	-	X
Participant hidden costs (e.g. hassle, time)	X	X	-
Other impacts			
Tax revenues [(n)]	-	-	X

[(a)] For example, the costs of purchasing emissions trading allowances.
[(b)] Calls to distressed customers, disconnections and reconnections should all decrease for participants with lower bills.
[(c)] This benefit is experienced by all energy consumers and is a function of the cost reductions set out in the rows above. It could be included in a distributional analysis of the impacts of an energy efficiency programme or policy portfolio.
[(d)] Not including emissions covered by emissions trading schemes, to the extent that the trajectories of the systems' caps adequately reflect an optimal trajectory for emissions, given the costs of mitigation and the costs of environmental damage.

[e] Participants may take some of the benefits of energy efficiency improvements in the form of higher internal temperatures, as well as experiencing fewer drafts and more steady temperatures. Newer equipment may make less (or more) noise and have aesthetic characteristics that could improve (or worsen) participant experiences.
[f] To the extent that environmental damage costs cause health costs in society (beyond programme participants), e.g. through the release of pollutants that affect local air quality, both health benefits and avoided healthcare costs to non-participants may also arise.
[g] Avoided healthcare costs are split between participants and the public sector. The extent of public sector healthcare coverage varies between countries, but emergency healthcare (e.g. for an urgent respiratory condition) would typically be funded by the public setor.
[h] Poverty alleviation would not feature in a traditional cost benefit analysis, but if a policy objective, could be proxied through the use of equity weights.
[i] Commercial sector participants may find that there are improvements in staff performance as a result of improved comfort, lighting etc. both in terms of output per hour worked and hours worked (fewer sick days). Broader macroeconomic societal benefits from improved productivity (and associated international competitiveness) would be experienced through lower consumer prices.
[j] Improvements in the energy efficiency of buildings can lead to increased property sale and rental values. This is a distributional impact (also a cost for renters / buyers, reflecting the relative benefits of occupying a more energy efficiency building).
[k] Macroeconomic impacts (on national income, employment, trade balances) depend upon many factors the structure of economies, the labour-intensity of the energy efficiency measures and the extent to which there are idle resources that can be directed towards energy efficiency projects without crowding out other activity. To the extent that policy measures induce cost-effective energy efficiency actions that would otherwise not have been undertaken, overcoming barriers and market failures, and the net benefits are sufficiently reflected in market prices, national income should increase in the long-run. Moreover, positive employment impacts of energy efficiency can lead to lower welfare system costs.
[l] Energy efficiency reduces reliance on imported fuels.
[m] Investment costs are split between participants, who typically bear some of the costs, and the public sector, typically through a subsidy or tax incentive.
[n] Changes in tax revenues have a distributional impact. Revenues will fall with lower energy consumption (and fewer environmental emissions, to the extent that they are taxed) and lower energy prices (as value added tax is levied as a percentage of energy prices). These falls will be (in part / more than) offset by higher revenues if economic activity increases because of efficiency gains.

Summary | Chapter 2 | Theory: Integrating the concepts of Energy Efficiency First and Multiple Impacts

This chapter set out to integrate the theoretical concepts of **Energy Efficiency First** (EE1st) and **multiple impacts** (MIs). In the first part, we described the **interlinkages** between the two concepts. MIs 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. Implementing the EE1st principle implies making a **fair comparison** between resources that is not limited to financial costs and benefits, but also factors in intangible socio-environmental effects in the form of various MIs.

In the second part, we argued that assessing the relative merits of resource options in impact assessments, infrastructure investment and other decision-making contexts requires some form of **aggregation of MIs**. 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 themselves, each of these frameworks has critical limitations and, ultimately, none of them can replace human judgement. Questions of what decision-support frameworks 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 general, a **CBA** framework is warranted wherever costs and benefits can be rigorously quantified and monetized. **MCA** frameworks are promising wherever an equitable, inclusive and transparent decision process is sought. Both types of frameworks can be informed by a range of miscellaneous indicator-based approaches.

Finally, the relation between the **evaluation perspective** (societal, private, public budget) on the scope of MIs that should ideally be considered was discussed. The **societal perspective** factors in all economic, social and environmental impacts and is the lens through which public sector decision makers should analyse alternative options for meeting policy objectives. In a CBA, costs and benefits should be weighted using a social discount rate, to ensure that future impacts are accounted for appropriately. The **private perspective** considers only those impacts experienced by the private actors making their assessments. It is important to be aware of the private perspective, particularly when the achievement of policy objectives is dependent upon the actions of regulated utilities. Multiple private benefits may arise from energy efficiency investments, some of which will not be captured in the societal perspective, as they are transfers between elements of society (e.g. increases in asset values). Public sector decision makers wishing to optimise their policy portfolios may wish to devote resources to raising awareness of the private impacts if this could leverage private sector investment in energy efficiency. Improving the value for money to the state (representing society) may be an important objective for policy makers. As such, **the public budget perspective** may be an important consideration for public sector decision makers. Understanding the broader impacts of MIs on public budgets (e.g. on public sector health systems and finance departments) could be important in building a cross-governmental consensus for supporting energy efficiency.

3. PRACTICE: MULTIPLE IMPACTS IN MODEL-BASED ASSESSMENT FOR EU-27

As described in ENEFIRST (2021a), the project team designed a set of three **scenarios for a carbon-neutral building stock for the EU in 2050**. In ENEFIRST (2022), these scenarios are analysed in terms monetary energy system cost – referred to as a techno-economic assessment. After some **background information** (**Chapter 3.1**), this chapter complements the previous work with a socio-environmental assessment, providing detailed estimates for the selected MIs of **air pollution and climate change damage** (**Chapter 3.2**) and **indoor comfort** (**Chapter 3.3**).

3.1 Background and objective

The EU aims to be climate-neutral by 2050 and the building sector is of vital importance to meet this target. 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 2020c).

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, hydrogen). **Three scenarios** are calculated, each of these is set 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 supply-side resources:

- The *Low Efficiency in Buildings* (**LOWEFF**) scenario assumes building decarbonisation primarily via the use of renewable energy sources. It reflects a future in which EE1st 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 (i) capital expenditures for various building efficiency measures as well as for supply side assets (generation, networks, storage). In addition, energy system cost comprises (ii) 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 MIs 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. Against this background, in this chapter we supplement the indicator with **selected MIs**. Owing to time and data constraints, this does not cover all relevant MIs, but demonstrates methods that can be used to attribute values to MIs. For air pollution and climate change we apply direct monetisation in a CBA-type framework. For indoor comfort we rely on an indicator-based approach.

3.2 Impact 1: Air pollution and climate change impacts

Air pollution is considered the second biggest environmental concern for Europeans, after climate change. It results from different pollutants like sulphur dioxide (SO_2), nitrogen oxides (NO_X), particulate matter (PM_{10} and $PM_{2.5}$), F-gases, heavy metals, and volatile organic compounds (VOCs). Together with greenhouse gases, these affect the composition of air and eventually cause harm to health and ecosystems, and the entire economy (González Ortiz et al. 2020; Mzavanadze 2015; Matthey and Bünger 2019):

- **Human health damage** | Heart disease and stroke are the most common reasons for premature death attributable to air pollution, followed by lung diseases and lung cancer (González Ortiz et al. 2020).[10] Exposure also leads to reduced lung function, respiratory infections and asthma. Maternal exposure to ambient air pollution is associated with adverse impacts on fertility, pregnancy, and new-borns.
- **Biodiversity losses** | Nitrogen oxides (NO_X) and ammonia (NH_3) emissions disrupt terrestrial and aquatic ecosystems by introducing excessive amounts of nitrogen nutrient. This leads to eutrophication that can lead to changes in species diversity and to invasions of new species. NO_X, together with SO_2 also contribute to acidification of water bodies, causing loss of biodiversity.
- **Crop damage** | Ground-level ozone (O_3) damages agricultural crops, forests and plants by reducing their growth rates and yields and has negative impacts on biodiversity and ecosystem services. Acidifying substances (SO_2 and NO_X) result in changes in the chemical composition of soil, affecting its fertility.
- **Material damage** | Air pollutant deposition on buildings may cause building structure deterioration, depending on the building materials. Damage includes corrosion (mainly caused by SO_2 and NO_X), biodegradation and soiling (caused by particles), and weathering and fading of colours (caused by O_3).
- **Climate damage** | Greenhouse gas emissions lead to various fundamental changes to the planet, with adverse impacts on human livelihoods and well-being related to changes in precipitation patterns, more droughts and heat waves, storms, sea level rise, reduced agricultural yields, and other effects.

Together, these impacts cause significant concerns for Europeans. Addressing **anthropogenic climate change** is at the top of the EU's agenda, with the European Climate Law (European Union 2021) setting the target of achieving climate neutrality by the year 2050. The EU has also been active for decades to improve **air quality** by controlling emissions of harmful substances into the atmosphere, improving fuel quality, and integrating environmental protection requirements into energy production, industry and transport (González Ortiz et al. 2020). As part of the European Green Deal (European Commission 2019), the European Commission adopted a Zero Pollution Action Plan for air, water and soil (European Commission 2021e), which sets out a 2050 vision where pollution is reduced to levels that are no longer harmful to human health and ecosystems. Despite these efforts and ensuing emission reductions, air quality remains poor in many areas. A significant share of EU urban population lives in areas that exceed air quality standards. This has led the European Commission to launch infringement procedures against several Member States that are in breach of air quality standards (González Ortiz et al. 2020).

Many studies have investigated avoided air pollutions as a result of policies. Among air pollution effects, human health is mostly studied and effects are rarely monetized, but rather expressed in other indicators (e.g. disease burden, years of life lost, working days lost). Only a handful of studies deal with the **effects of building retrofits** and other end-use energy efficiency measures in the building sector on air pollution

[10] Worldwide, air pollution is responsible for 4.9 million deaths and 147 million years of health life lost each year. In comparison, pollution kills three times more people than HIV-AIDS, tuberculosis, and malaria combined (Sovacool et al. 2021).

emissions. Impacts are monetized only in few cases (Mzavanadze 2015). Also, to date, there seem to be no studies investigating the implications for air pollution impacts associated with different pathways that reach net-zero GHG emissions by 2050 and the cumulative emissions involved in these pathways.

The three **scenarios** in this analysis (LOWEFF, MEDIUMEFF, HIGHEFF) investigate different ambition levels for end-use energy efficiency in both residential and non-residential buildings. The underlying measures reduce air pollution impacts at different scales. Local air quality improves in response to better performing building envelopes and less polluting heating systems. At the energy system level, reduced energy demand lowers the need of power plants, boilers and other combustion facilities. In this chapter, we estimate the impacts of air pollution on four receptors: human health (mortality and morbidity); biodiversity (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:

(i) **Assessment of energy consumption by energy carrier** [kWh_{th}] | Based on the scenario outputs (ENEFIRST 2022), we have detailed data on primary/final energy consumption by energy carrier (e.g. natural gas), emission source (e.g. power plant), EU country, and scenario for the period 2020–2050.
(ii) **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). Our focus is on direct emissions, i.e. those arising in the conversion from primary, secondary and final energy to useful energy. Upstream or indirect emissions – e.g. from production of energy technologies – are beyond the scope of this analysis and would have required a detailed life-cycle assessment of all relevant technology options. **Table 5** shows the emission factors used.
(iii) **Estimation of total emissions** [$t_{emission}$] | Energy consumption by energy carrier is multiplied with the respective emission factors to yield the total emissions by pollutant. Note that the emission factors for electricity and district heating supply are expressed in primary energy terms [g/kWh_{PE}] and those for fuels used onsite in buildings in final energy terms [g/kWh_{FE}].
(iv) **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.[11] We apply these cost rates to the remaining EU countries by taking into account that the willingness to pay for avoiding health damage increases with income. Therefore, cost rates for health damages were corrected for differences in gross domestic product per capita (Eurostat 2022b), using an elasticity value of 0.85 (Matthey and Bünger 2019). The resulting cost rates are expressed as real prices for the year 2016 and are converted to 2018 prices levels (EUR_{2018}) using consumer price indices by EU country (Eurostat 2022a). **Table 6** provides the resulting cost rates.
(v) **Estimation of total damage cost** [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 to help assess whether society is better off as a result of the comprehensive and ambitious building efficiency measures in the scenarios LOWEFF, MEDIUMEFF and HIGHEFF.

[11] Matthey and Bünger (2019) used the EcoSenseWeb model air quality and exposure. Health effects are assessed on basis of current WHO data and monetary valuation rates are adjusted to the greatest possible extent to current EU standards. Crop failure is assessed on basis of a response function. The resulting cost rates differ depending on different release heights for power generation (>100 m), industrial processes (20-100 m), and small-scale combustion facilities (0-20 m). Also, a distinction is made between emissions in large metropolitan and urban areas.

Table 5. Emission factors by energy carrier

Source: EEA (2019), Lauf et al. (2021)

Energy carrier	Unit	CO_2-eq.	CO_2	CH_4	N_2O	SO_2-eq.	SO_2	NO_X	PM	CO	NMVOC
Biomass	g/kWh$_{th}$	0.39	0.00	0.00	0.00	0.23	0.02	0.31	0.07	0.53	0.01
Hard coal	g/kWh$_{th}$	338.61	337.23	0.00	0.00	0.27	0.13	0.20	0.01	0.02	0.01
Lignite	g/kWh$_{th}$	397.20	393.38	0.00	0.01	0.38	0.19	0.28	0.01	0.12	0.01
Natural gas	g/kWh$_{th}$	207.86	200.70	0.23	0.01	0.09	0.00	0.13	0.00	0.04	0.00
Oil	g/kWh$_{th}$	268.77	266.47	0.02	0.01	0.67	0.18	0.70	0.01	0.19	0.01
Waste	g/kWh$_{th}$	1.45	0.00	0.01	0.00	0.13	0.01	0.18	0.00	0.02	0.00

Table 6. Cost rates by emission source, type and receptor

Source: Matthey and Bünger (2019) | Corrected for differences in GDP per capita (Eurostat 2022b) | Ranges (min, max) indicate differences among EU countries

Emission source	Emission type	Receptor	Min [2020]	Max [2020]	Min [2050]	Max [2050]
				[EUR$_{2018}$/t]		
Energy supply (electricity, district heating)	**CO_2-eq.**	Climate damage	181.8	192.9	242.4	257.3
	SO_2	Health damage	5,897.5	28,287.2	5,897.5	28,287.2
		Biodiversity losses	1,010.0	1,071.9	1,010.0	1,071.9
		Crop damage	-214.4	-202.0	-214.4	-202.0
		Material damage	278.6	1,336.4	278.6	1,336.4
	NO_X	Health damage	5,154.5	24,723.5	5,154.5	24,723.5
		Biodiversity losses	2,626.1	2,787.0	2,626.1	2,787.0
		Crop damage	808.0	857.5	808.0	857.5
		Material damage	46.4	222.7	46.4	222.7
	PM	Health damage	10,262.7	49,224.2	10,262.7	49,224.2
	NMVOC	Health damage	557.2	2,672.8	557.2	2,672.8
		Crop damage	1,010.0	1,071.9	1,010.0	1,071.9
Direct combustion in buildings, industry, transport	**CO_2-eq.**	Climate damage	181.8	192.9	242.4	257.3
	SO_2	Health damage	6,826.3	32,741.9	6,826.3	32,741.9
		Biodiversity losses	1,010.0	1,071.9	1,010.0	1,071.9
		Crop damage	-214.4	-202.0	-214.4	-202.0
		Material damage	278.6	1,336.4	278.6	1,336.4
	NO_X	Health damage	7,337.1	35,192.0	7,337.1	35,192.0
		Biodiversity losses	2,626.1	2,787.0	2,626.1	2,787.0
		Crop damage	808.0	857.5	808.0	857.5
		Material damage	46.4	222.7	46.4	222.7
	PM	Health damage	20,200.3	96,889.3	20,200.3	96,889.3
	NMVOC	Health damage	557.2	2,672.8	557.2	2,672.8
		Crop damage	1,010.0	1,071.9	1,010.0	1,071.9

To assess whether end-use energy efficiency in buildings involves air pollution- and climate change-related benefits in transitioning to the single-year target of net-zero greenhouse gas emissions by 2050, the three scenarios (LowEff, MediumEff, HighEff) were compared for emission levels and associated damage cost.

Table 7 presents the **emission levels** (tons of emissions) by emission type. Compared to 2020 levels, end-use energy efficiency in buildings significantly reduces emissions in many respects. As described in ENEFIRST (2022), all three scenarios can be said to reach the 2050 target of net-zero greenhouse gas emissions (see CO_2-eq.). Note that carbon sinks, leading to negative greenhouse gas emissions, are not factored in here. As a side effect from decarbonisation, most air pollutants are also significantly reduced by 2050. One notable exception is particulate matter (PM), which remains present in the decarbonised 2050 systems due to biomass combustion. Another observation from this table relates to the cumulative emissions. While the three scenarios result in net-zero greenhouse gas emissions *by* 2050, they involve different levels of *cumulative* emissions over the period 2020–2050. For example, cumulative emissions of CO2-eq. in HIGHEFF are -6.3% lower than in LOWEFF. The results are similar for most of the air pollutants.

Table 7. Emission levels by emission type

Middle column: emission levels in the year 2050, relative difference to 2020 in brackets | Right column: Cumulative emissions over the period 2020–2050

		LOWEFF	MEDIUMEFF	HIGHEFF	LOWEFF	MEDIUMEFF	HIGHEFF
Emission type	2020	2050 (% vs. 2020)			Σ2020–2050		
CO	1.85 t	0.16 t (-91.5%)	0.16 t (-91.4%)	0.17 t (-91.0%)	30.20 t	30.20 t	30.25 t
CO_2	1,074.16 t	19.59 t (-98.2%)	12.88 t (-98.8%)	7.44 t (-99.3%)	12,325.79 t	11,966.05 t	11,546.08 t
CO_2-eq.	1,090.32 t	19.75 t (-98.2%)	13.03 t (-98.8%)	7.58 t (-99.3%)	12,539.53 t	12,171.64 t	11,740.77 t
CH_4	0.37 t	0.00 t (-99.6%)	0.00 t (-99.6%)	0.00 t (-99.6%)	5.41 t	5.16 t	4.81 t
NO_X	0.88 t	0.10 t (-88.1%)	0.10 t (-88.4%)	0.10 t (-88.3%)	11.74 t	11.55 t	11.35 t
N_2O	0.02 t	0.00 t (-97.9%)	0.00 t (-98.2%)	0.00 t (-98.3%)	0.28 t	0.27 t	0.26 t
PM	0.05 t	0.02 t (-61.3%)	0.02 t (-60.2%)	0.02 t (-58.4%)	1.00 t	1.01 t	1.02 t
SO_2	0.35 t	0.01 t (-98.3%)	0.01 t (-98.4%)	0.01 t (-98.3%)	3.87 t	3.86 t	3.86 t
SO_2-eq.	0.96 t	0.08 t (-91.8%)	0.08 t (-92.0%)	0.08 t (-92.0%)	12.03 t	11.90 t	11.76 t
NMVOC	0.05 t	0.00 t (-95.5%)	0.00 t (-95.7%)	0.00 t (-95.8%)	0.71 t	0.70 t	0.69 t

As a consequence of the differences in cumulative emissions over the period 2020–2050, the scenarios result in different levels of **damage cost from air pollution and climate change**. **Figure 4** shows the breakdown of cumulative cost (2020–2050) for (a) air pollution and (b) anthropogenic climate change impacts. End-use energy efficiency measures in buildings clearly lead to damage cost reduction compared to LOWEFF. Most significant are the reductions in **climate change damage** of -143.0 bn EUR (HIGHEFF) and -66.3 bn EUR (MEDIUMEFF) versus LOWEFF.Even though all three scenarios reach roughly the same outcome of net-zero greenhouse gas emissions by 2050, there are significant differences in the emissions accumulating in the pathway between 2020–2050.

Another finding from **Figure 4** is that, in monetary terms, **air pollution impacts** are less significant than climate change damage, with reductions compared to LOWEFF amounting to -1.7 bn EUR (MEDIUMEFF) and -3.5 bn EUR (HIGHEFF) over the period 2020–2050. Among the receptors, health damage is most critical (-1.2 to -2.5 bn EUR), followed by biodiversity losses (-0.4 to -0.8 bn EUR), crop damage (-0.1 to -0.3 bn EUR), and material damage (-0.01 to -0.03 bn EUR). End-use energy efficiency in buildings thus brings a variety of air pollution benefits over the period 2020–2050, even if all pathways end up with net-zero greenhouse gas emission levels by 2050.

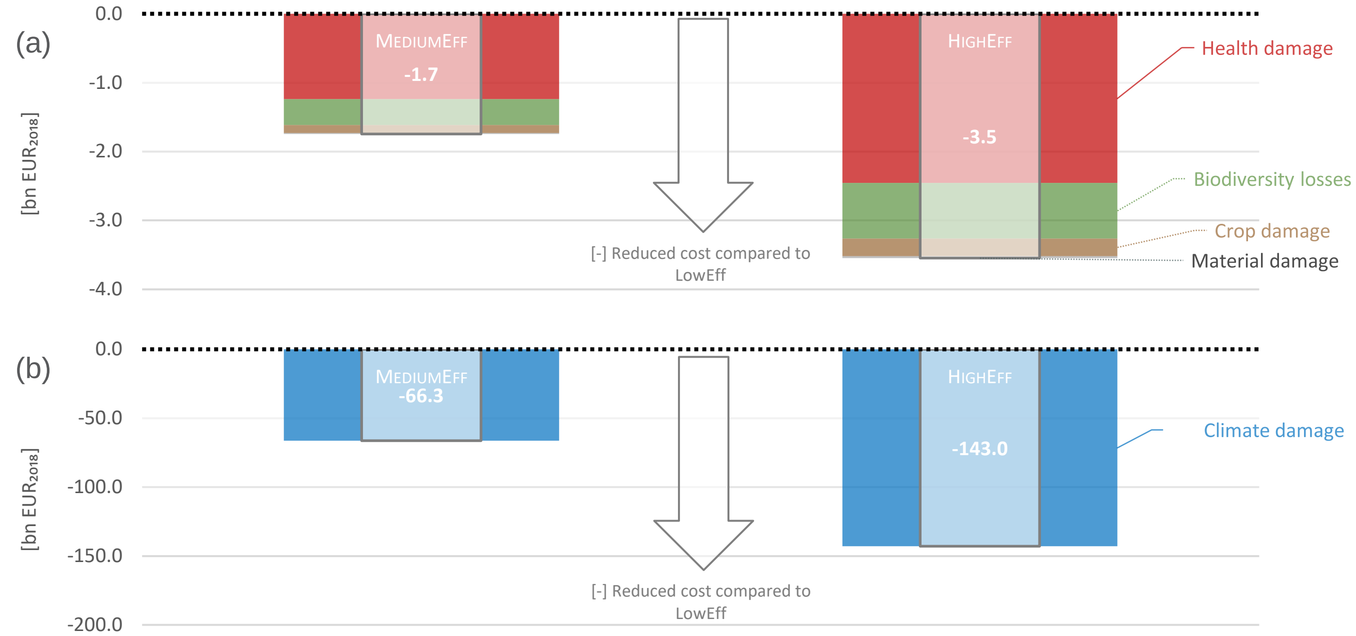

Figure 4. Cumulative differential cost compared to LowEff scenario for EU-27 (2020–2050) by receptor
(a) Damages from air pollution, (b) damage from anthropogenic climate change

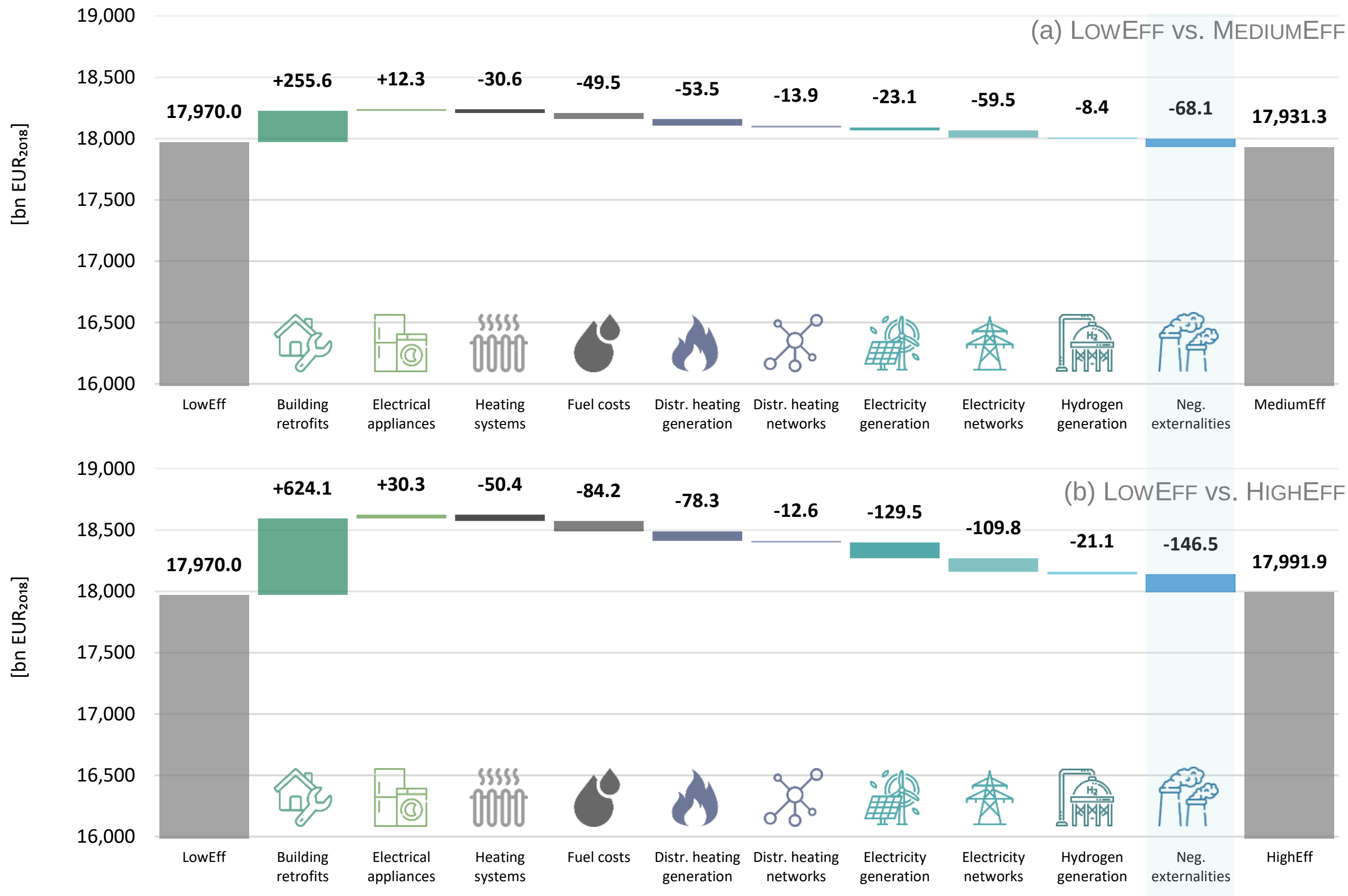

Figure 5. Decomposition of cumulative differential costs compared to LowEff for EU-27 (2020–2050)
Neg. externalities including air pollution and climate change damage | See ENEFIRST (2022) for discussion of other cost items

How these damage costs affect the societal **trade-off between saving energy and supplying energy** is displayed in **Figure 5**. These charts have already been used in the techno-economic assessment of the EU scenarios (ENEFIRST 2022). They show individual items of energy system cost accruing over the period 2020–2050 from the LowEff scenario to MediumEff and HighEff, respectively. The additional cost for end-use energy efficiency (building renovation, electrical appliances) relative to the LowEff scenario amounts to EUR +255.6 billion (MediumEff) and EUR +624.1 billion (HighEff). This cost is partly offset by reduced cost for electricity, gas and heat supply. Without factoring in negative externalities from air pollution and climate change, the energy efficiency measures for the building sector in MediumEff are not cost-effective (+6.0 bn EUR). In turn, when including negative externalities, MediumEff turns out as cost-effective (-38.6 bn EUR) compared to LowEff. The **measures in HighEff are not cost-effective**, even when including air pollution (+21.9 bn EUR). Highly ambitious levels of building retrofits and appliance efficiency as exemplified in HighEff can thus not be justified on the grounds of monetary energy system cost and negative externalities from air pollution and climate change damage. In sum, these numbers suggest that the inclusion of damage cost from air pollution and climate change in a cost-benefit analysis framework can enhance the attractiveness or cost-effectiveness of some building efficiency measures from a societal perspective.

However, as pointed out in **Chapter 2.2**, monetization of MIs involves considerable **uncertainty**, with different methods yielding different results on how pollutants are transported and in the atmosphere, how the chemical composition of atmosphere changes over time and how pollutants affect health and other receptors (González Ortiz et al. 2020; Kamal et al. 2019). In this chapter, we used cost rates, also known as marginal co-benefit estimates, that can be readily integrated in CBA frameworks. More sophisticated modelling would have required dedicated models for specific sectors, recipients and types of emissions (e.g. TREMOVE) as well as whole-economy models (e.g. GAINS) to estimate their monetary impacts (Thema et al. 2019).

Besides uncertainties, another monetization-related issue pointed out above are **overlaps** and interactions between air pollution and other MIs. For example, reduced air pollution is strongly correlated with **labour productivity**. In response to building retrofits, the infiltration of outdoor pollutants reduces. The ensuing reduction in indoor air pollution can improve labour productivity by improving labour input efficiency in terms of workdays, performance, and by improving the quality of output. In turn, poor indoor environments can affect mental well-being, health and consequently work performance (Chatterjee and Ürge-Vorsatz 2021). As pointed out by Ürge-Vorsatz et al. (2015), double counting of air pollution and labour productivity impacts would occur if a monetary value is placed on lost productivity due to premature death, and additionally life years are used as measure of health because both essentially value the same effect: the loss in health time. To avoid this overlap, only life years lost due to indoor air pollution would be accounted in CBA for productivity and outdoor pollution-related health impact would be accounted under air pollution (Mzavanadze 2015).

In sum, the study of air pollution and climate change impacts as a dedicated MIs in this chapter demonstrates that **end-use energy efficiency in the building sector reduces the overall damage cost incurred by society**. This includes health benefits from reduced pollution exposure, but also improvements in biodiversity, as well as higher crop yields and durability of buildings. More significant in monetary terms than air pollution impacts, however, are reduced climate change damages. This is an interesting finding because the three scenarios LowEff, MediumEff and HighEff are all set to reach net-zero greenhouse gas emissions *by* the year 2050. Yet what differs in these scenarios are the *cumulative* emissions over the period 2020–2050, with significant implications for societal costs incurred in this transition. As exemplified particularly by the MediumEff scenario, the inclusion or omission of these costs can **significantly affect the outcome** when using a CBA as a decision-support framework. This has important implications with regard to the definition decision objectives in the scope of the EE1st principle: ideally, targets – such as greenhouse gas reductions – should be formulated in cumulative terms in the sense of a carbon budget, rather than a single-year target.

3.3 Impact 2: Comfort and possible follow-up impacts

As shown in the literature discussed above (**Chapter 2.1.1**), the **increase in comfort and related follow-up impacts** (health, productivity, well-being) is mentioned as one of the essential MIs of building retrofitting. Thus, when it comes to making the EE1st principle operational, it needs approaches to consider these MIs. In particular, when comparing scenarios with different energy efficiency improvements in terms of energy savings, greenhouse gas emissions and system cost, a quantification of this co-benefit seems required. In this chapter, we propose a method how to provide a quantitative estimation of the MIs associated with different scenarios of building retrofitting. This method is applied to selected countries modelled in the frame of the ENEFIRST scenarios (ENEFIRST 2022).

Existing research has indicated that **building occupants' behaviour** such as indoor temperature settings, ventilation behaviour, household size or use of different type of electric appliances with their corresponding internal gains, significantly impacts actual energy use. Referring to the views of Holzmann et al. (2013), it is revealed that the rising comfort needs outrank the significant technical energy efficiency improvements observed for the period of 1993 to 2009. As could be shown, real, final energy consumption for space heating typically is lower than theoretically calculated demand, in particular in older, not yet refurbished buildings. However, this effect, caused by consumer behaviour in Austria declined from 1993 to 2009: While the consumer behaviour reduced final energy use compared to theoretically calculated demand by 49% in 1993, this effect was only 40% in 2009. They also infer that omitting the consumer behaviour effect can substantially bias estimating the effects of energy efficiency measures.

The **literature on behavioural aspects** in the context of space heating energy consumption and the role of buildings' energy performance lists different possible reasons for behaviour-induced consumption differences (Moeller et al. 2020) 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). All these studies provide evidence that behavioural aspects have a significant impact on energy demand in buildings. Still, **energy demand modelling** in buildings at a national level does not necessarily need to consider these effects explicitly on a high resolution, as long as the related research question does not ask for corresponding detailed results. An example of the latter is Müller et al. (2019) who modelled the uptake of smart thermostats and the possible impacts on energy demand and indoor comfort.

The broad literature on **rebound effects** discusses strongly resulting lower energy savings followed by behavioural changes. These are commonly interpreted as a loss of efficiency gains, which might have been expected. At the same time, it has to be acknowledged that these behavioural changes often are associated with an increase in comfort, health and well-being. This aspect is also discussed in IEA (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 – as an average over the heating season and the floor area of the building, which has an impact on the energy consumption. For these reasons, in order to analyse the MIs of comfort increase, we decided to consider the **effective indoor temperature** in the residential sector as calculated in the Invert/EE-Lab model as a proxy indicator.

In the following, we first describe the approach, how different behavioural aspects and their impact on energy demand due to modified effective indoor temperature are implemented in the building stock model Invert/EE-Lab and how energy performance of the building envelope (heat transfer coefficient) may impact the resulting behaviour and thus effective indoor temperature. Subsequently, we present selected, exemplary results for the three **ENEFIRST scenarios** (ENEFIRST 2022). This section is mainly based on the concept developed by Müller (2015). As can be seen from the cited references, the data for calibrating the approach was derived from measured buildings in Germany around the year 2000. As we discuss below, it would be important to recalibrate the approach based on more recent data and across other regions in Europe, which however, was not possible in the frame of this project. Thus, there are limitations due to the regional and historical evidence. Still, the authors believe that (1) the underlying basic behavioural patterns are quite persistent and do not change quickly and that (2) the value of this chapter is also to show how such a method can be used to quantify this co-benefit of building renovation in foresight studies.

The energy calculation approach of the Invert/EE-Lab model considers various behavioural aspects observed for space heating. For instance, the heating degree days approach, using a variable heating limit temperature, reproduces the energy demand according to the monthly energy balance approach has applied, as (Loga 2004). Based on this basic estimation of demand, in addition to the influence factors as defined by Loga et al., a correction factor f_{hs} for the heating system type is introduced (Biermayr 1998) equation (1).

$$\theta_{i,h} = \theta_e + f_t f_a f_{use} f_{hs}\left(\theta_{i,h,set} - \theta_e\right)[°C]. \quad (1)$$

where

$\theta_{i,h}$ ... Average indoor temperature, heating(°C)

θ_e ... Average outdoor temperature (°C)

$\theta_{i,h,set}$ ... Desired nominal indoor set temperature, heating (°C)

f_t ... Correction factor for temporal temperature reductions (night mode)

f_a ... Correction factor for non − directly heated areas

f_{use} ... Correction factor for user behavior

f_{hs} ... Correction factor for heating system

$\theta_{i,h,min}$ ... Lower boundary for indoor temperature, heating(°C)

$\theta_{i,h,max}$ ... Upper boundary for indoor temperature, heating(°C)

$\theta_{i,h} \in \{\theta_{i,h,min}, \theta_{i,h,max}\}$

In the user behaviour model represented by Loga, two parameters affect the scale of the user behaviour: the surface coefficient of heat transfer h, and the heated gross floor area per apartment $A_{gfa,dw}$.

$$h = \frac{H}{A_{nfa,build}} = \frac{H_{tr} + H_{ve}}{A_{nfa,build}}\left[\frac{W}{m^2K}\right]. \quad (2)$$

where

$H_{tr} + H_{ve}$ … Heat transfer coefficient by transmission and ventilation conductivity [W/K]

$A_{nfa,build}$ … Heated net floor area (0.7-0.8$A_{gfa,build}$) $[m^2]$

$A_{gfa,build}$ … Heated gross floor area $[m^2]$

h … Surface coefficient of heat transfer [W/(m^2K)]

Our model, developed on user behaviour's effects, calculates a surface coefficient of heat transfer h_{corr}, corrected by effects that impact the economic variable "energy-consumption-dependent running costs against the household income".

$$h_{corr} = \left(\frac{c_{run,hs}}{c_{run,ref}}\right)^{\alpha_{c,run}} * \left(\frac{Y_{household}}{Y_{household,ref}}\right)^{\alpha_{Income}} * \left(\frac{HDD_{building\ side}}{3240}\right)^{\alpha_{hdd}} * h \left[\frac{W}{m^2K}\right]. \qquad (3)$$

where

h_{corr} … Surface coefficient of heat transfer used in the user model, corrected by running energy costs, household income, and heating degree days [W/(m^2K)]

$HDD_{building\ site}$ … Heating degree days at the specific building site conditions [Kd]

3240 … Average long term heating degree days in Germany 1980-2004 (estimated HDD Loga used to calibrate their model)

$c_{run,ref}$ … Reference running energy costs (estimated reference marginal heating costs on which Loga et al. calibrated their model; standard natural gas boiler, energy prices of 2000:$c_{run,ref}$=60€/MWh)

$c_{run,hs}$ … Marginal (running) heating costs based on the actual efficiency of the heating system and the price of the energy carrier

$Y_{household,(ref)}$ … (Reference) Household income

$\alpha_{c,run}$, α_{hdd}, α_{Income} =1 for Households

Further, in our model, the correction factor that depicts user behaviour is implemented according to (Loga et al. 2003) but is extended by the heating degree days, energy price, and income adjusted heat transfer coefficient h_{corr}. This extension is defined in equation 4 below.

$$f_{use} = 0.5 + \frac{2}{3 + 0.6 * h_{corr}}. \qquad (4)$$

As illustrated in **Figure 6**, in the building stock model Invert/EE-Lab the correction factor representing user behaviour depends on the surface coefficient of heat transfer h. Since the user factor is related to a certain effective indoor temperature level, for each ENEFIRST scenario, we can identify the **distribution of effective indoor temperature levels in the building stock**. However, it should also be remembered that this approach is derived from a German source and should be validated by other regions' analysis.

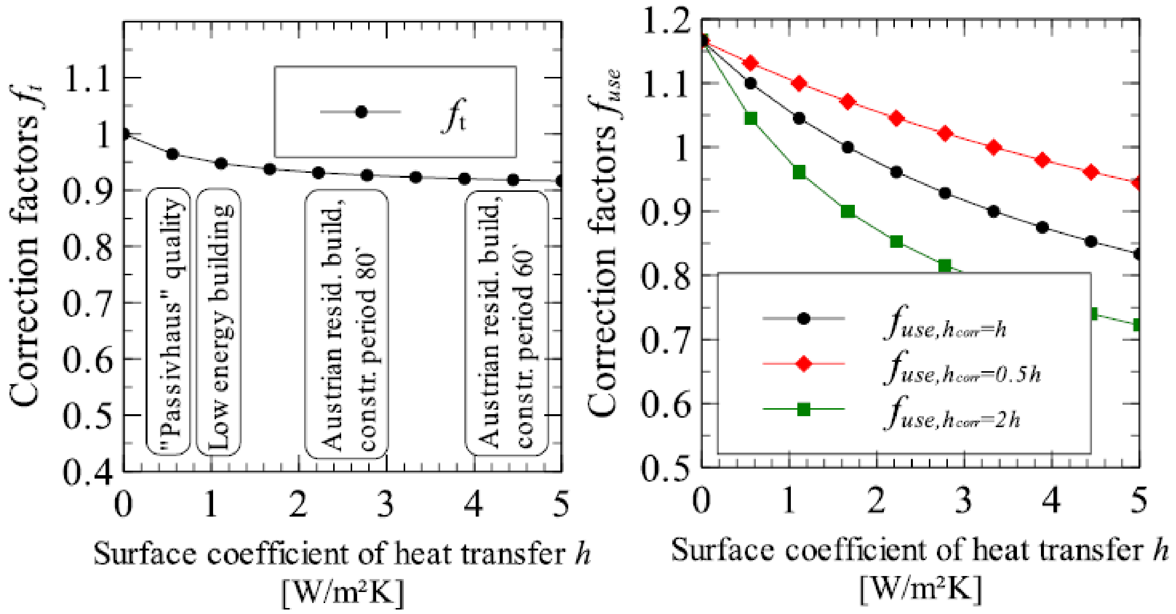

Figure 6. Correction factors for night-setback and user behaviour as implemented in the Invert/EE-Lab Model

Source: Müller (2015), based on the concept described in Loga et al. (2003)

From the following equation the link to the average, effective indoor temperature can be drawn (Müller et al 2015).

$$\theta_{i,h} = \theta_e + f_t f_a f_{use} f_{hs} \left(\theta_{i,h,set} - \theta_e\right) \quad [°C]$$

where

$\theta_{i,h}$ ... Average indoor temperature, heating(°C)

θ_e ... Average outdoor temperature (°C)

$\theta_{i,h,set}$ ... Desired nominal indoor set temperature, heating (°C)

f_t ... Correction factor for temporal temperature reductions (night mode)

f_a ... Correction factor for non − directly heated areas

f_{use} ... Correction factor for user behavior

f_{hs} ... Correction factor for heating system

$\theta_{i,h,min}$ ... Lower boundary for indoor temperature, heating(°C)

$\theta_{i,h,max}$ ... Upper boundary for indoor temperature, heating(°C)

$\theta_{i,h} \in \{\theta_{i,h,min}, \theta_{i,h,max}\}$

Above, the user behavioural aspects of the Invert/EE-Lab model were mentioned. Then, three different scenarios were created with energy efficiency levels high, medium and low. Accordingly, **heated floor area-weighted effective indoor temperatures** of residential buildings during the heating season have been computed for each scenario. Thereafter, the share of floor areas heated between 13°C-25°C for each country was calculated cumulatively. Numerical results calculated for all EU member states are reported for Germany, Greece, France, Poland, Romania, and Sweden, which represent distinct climates. In the following, the results are presented in detail. In **Figure 7** below, the grey line represents the status quo for each country in 2017; green, yellow, and blue lines illustrate high, medium, and low-efficiency scenarios, respectively in the simulation year 2050. It is possible to interpret the graphs from two different directions, horizontal and vertical. Starting with the horizontal perspective, 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 in Germany (2050). The situation is also similar in France, about 2°C for Greece and Poland and even 3.5 °C for Romania. Moreover, it should be noted that for all countries there is a significant improvement compared to the base year of the model run.

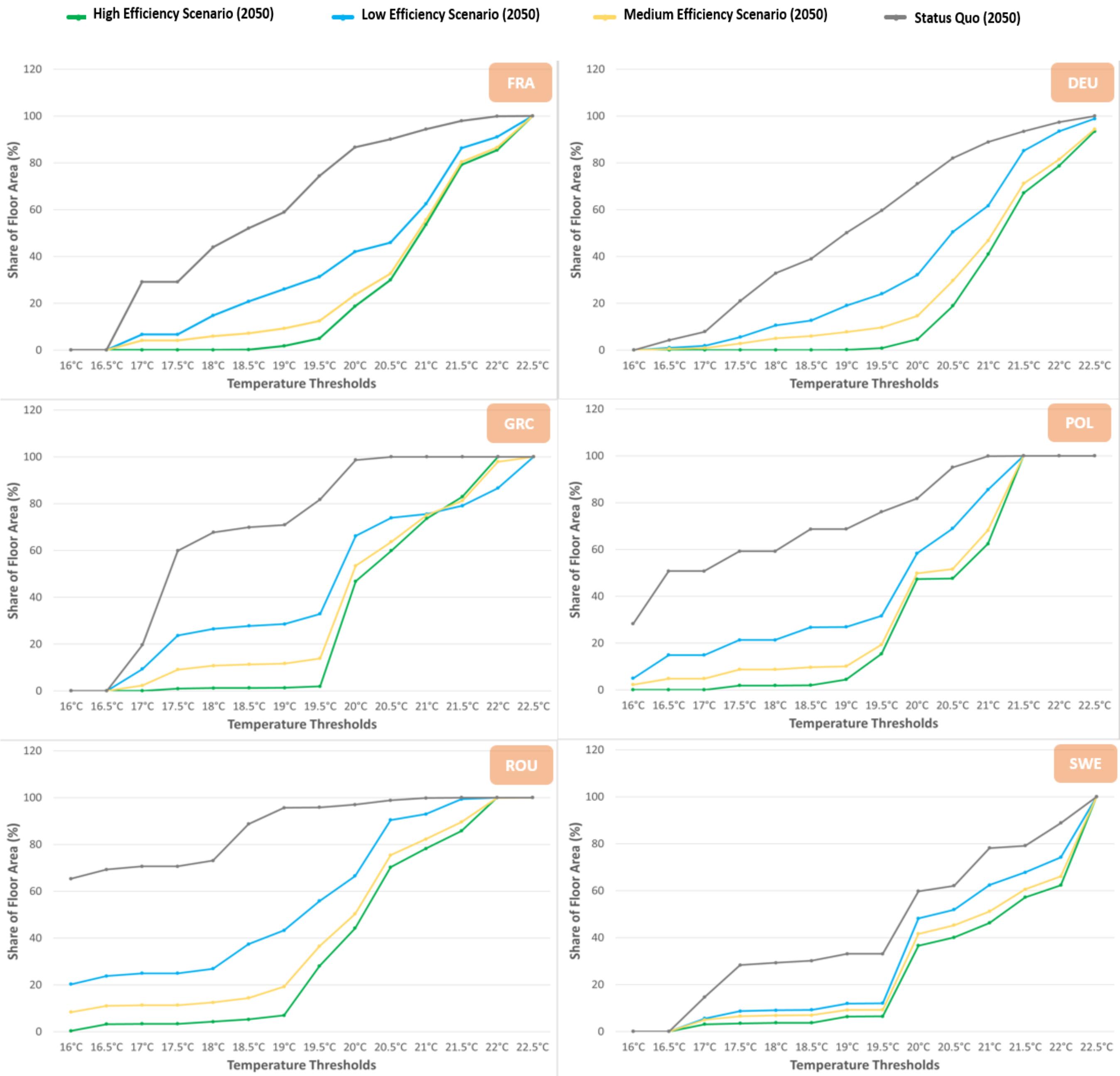

Figure 7. Floor Area Weighted Average of Effective Indoor Temperature for Residential Sector

What are the reasons for the differences between the countries? In PL, GR and RO, we can observe a flat plateau of the low-efficiency curve (blue curve) between 20% and 30% of the floor area. This is not so much the case for FR, SE and DE. This can mainly be explained by the different **share of single-family houses** (SFH) which are not well insulated (both due to different share of SFHs, but also due to different mix of vintage classes and their renovation status). In the high-efficiency scenario, these differences are less pronounced between the countries, i.e. these buildings (mainly SFHs) which were not so well insulated in the low-efficiency scenario become renovated, thus being moved to a higher effective indoor temperature level and related comfort. The shape of the curves and their differences in the end are the reason for the exact result of the “lower 20% of the floor area” indicator: due to the flat plateau between 20% and 30% (at least for some of the countries), a slight shift of this plateau can have a strong effect on the result.

When we check the results from the **vertical perspective**, it is shown that the share of floor area with an effective indoor temperature of 18.5 or lower is 20 ppt lower in the High-Efficiency scenario than in the Low-Efficiency scenario in France (2050). The situation is again similar for Germany, Greece, Poland, and Romania. However, we can still notice that the difference between the two scenarios in Sweden is not as significant as in previous countries. Reasons for the low difference of the three scenarios in the case of SE are (1) the colder climate, which makes building retrofitting more profitable, at least with some more stringent policy measures in place, which is assumed even in the low-efficiency scenario and (2) the significant share of SFHs with moderate energy performance in the base year, which are cost-effective to be renovated also in the low-efficiency scenario.

In this respect, as mentioned above, the limitation of the model's approach based on Germany in its application to other countries needs to be considered. As a summary, **Figure 8** shows the difference achieved in the high and the low efficiency scenario in the analysed countries in terms of two indicators: (i) the decrease of the floor area with an effective indoor temperature of 18°C or lower and the increase of the effective indoor temperature for the lower 20% of the floor area. It can be seen, that the approach delivers the **highest comfort gains** for Romania, Greece and Poland and the lowest impact for Sweden. The **results are strongly driven by** (1) the difference of the ambition levels of energy savings in the different scenarios, (2) the efficiency of the building stock in the start year 2017, (3) climatic conditions and (4) the structure of the building stock in terms of the share of SFH and MFH from different vintage classes.

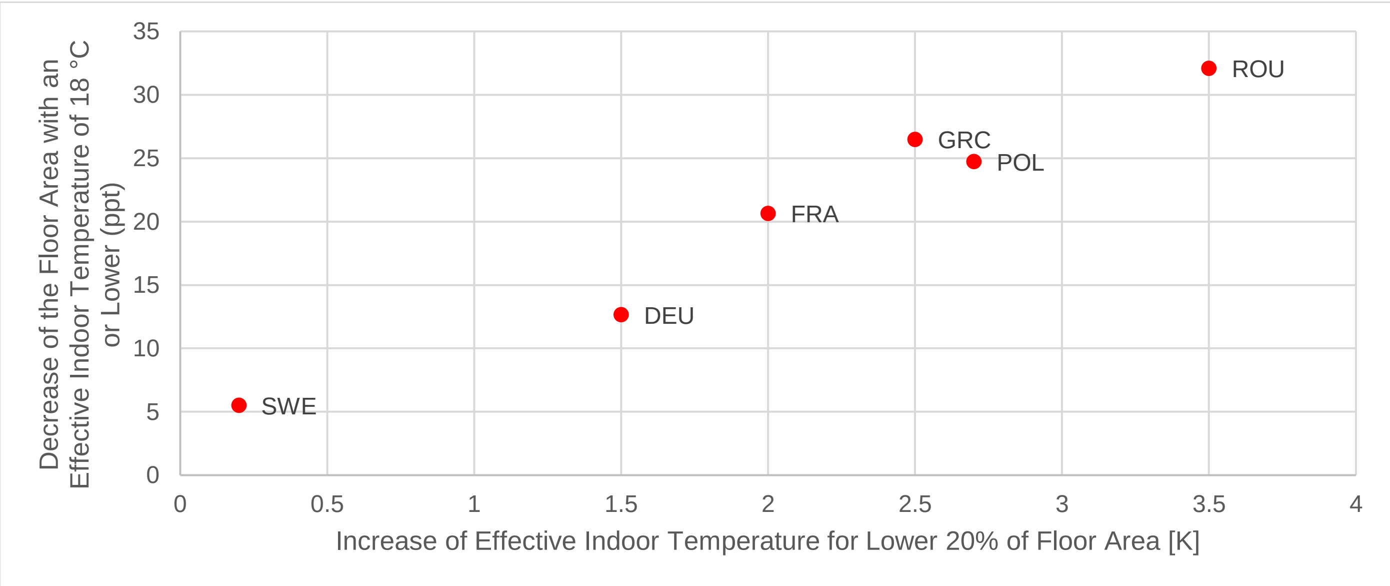

Figure 8. Cross-Country Comparison of High Efficiency and Low-Efficiency Scenarios

The proposed approach does not include **monetization** of these multiple impacts, although obviously there are monetary implications. These include effects like improved health and resulting lower sick-leave periods or – in case of non-residential buildings – productivity gains or even impact on cold weather mortality. Also, the real estate value may be impacted by indoor environmental quality and comfort (see e.g. Chegut et al. 2016). Mzavanadze (2018) discussed and developed methods for energy poverty related health impacts of lacking energy efficiency. They address effects like excess cold-weather deaths or health impacts. However, besides the limitations and uncertainties connected to this approach, they do not provide a method how to assess **efficiency improvements in future scenarios**, in particular comparing different scenarios of different efficiency enhancement.

Thus, we conclude that the monetary assessment of these impacts is associated with a large number of uncertainties and subjective weightings which makes monetization either impossible or would require much higher research efforts than foreseen in this study. Overall, we conclude that the **effective indoor temperature can be a reasonable proxy for the comfort gains as MIs of building renovation**. However, additional research is needed regarding the possibly required parameterisation of the approach in other countries than Germany. This involves questions as to which extent cultural habits and the structure of the building stock would impact the parameterization of the approach and related results.

Summary | Chapter 3 | Practice: Multiple impacts in model-based assessment for EU-27

This chapter began with the premise that the techno-economic assessment of energy system cost in ENEFIRST (2022) certainly undervalues the societal benefits of end-use energy efficiency in buildings because its monetary estimates are limited to capital costs, fuel costs, and other tangible financial metrics. Against this background, this chapter set out to substantiate the three ENEFIRST scenarios (LOWEFF, MEDIUMEFF, HIGHEFF) with robust estimates of selected MIs in a so-called socio-environmental assessment.

The first type of MIs investigated are air pollution and climate change impacts. A comprehensive set of emission types was quantified in physical terms, monetized using cost rates, and finally integrated in the existing indicator of energy system cost in a CBA-type framework. The key finding is that even though all three scenarios are set to reach the common objective of net-zero greenhouse gas emissions by the year 2050, there are significant differences in cumulative emissions and ensuing costs accumulating over the period 2020–2050. Ambitious levels of energy efficiency in buildings can reduce cumulative damage cost by up to 146.5 bn EUR compared to less ambitious standards. The inclusion of these cost estimates has a strong impact on the cost-effectiveness of energy efficiency measures from a societal viewpoint.

The second MIs considered are indoor comfort improvements. A new method was developed to quantify comfort gains as a result of building retrofits for the entire building stocks of individual Member States. The approach is based on the effective indoor temperature as a proxy for comfort and was integrated in the building stock model Invert/EE-Lab. The results indicate significant comfort gains for countries with poor efficiency of the building stock in the base year. As a result of the modelled retrofit measures, the share of poorly heated floor space below 18°C can be reduced by more than 30 percentage points, with ensuing benefits for health, well-being and workforce productivity. While the method does not involve monetization of comfort gains and thus the possibility to integrate it with the CBA for the three scenarios, it demonstrates that the effective indoor temperature can be a reasonable metric for indoor comfort in future research. This metric, in turn, can be used in MCA, composite and scoreboard approaches, and other decision-support frameworks.

In conclusion, any scenarios developed in the scope of the EE1st principle should be substantiated with quantitative and qualitative estimates of different MIs to ensure a fair comparison of demand- and supply-side resources and thus to enable informed decisions on technology investment.

4. CONCLUSION

This report set out to integrate the state of knowledge on the concepts of **Energy Efficiency First** (EE1st) and **Multiple Impacts** (MIs). In the theoretical part (**Chapter 2**), it described the **conceptual interlinkages between the two concepts**. MIs are an integral element of EE1st as the principle aims to prioritize demand side (e.g. building retrofit) 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. Levelling the playing field 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 MIs.

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 MIs. 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. Questions of what decision-support framework are most suitable to a given decision-making context (e.g. network planning) will have to be deliberated on a case-by-case basis.

Besides the conceptual interlinkages between EE1st and MIs and the role of different decision-support frameworks, this report also discussed the relation between the **evaluation perspective** (societal, private, public budget) on the **scope of MIs** that should ideally be considered was discussed. The **societal perspective** factors in all economic, social and environmental impacts and is the lens through which public sector decision makers should analyse alternative options for meeting policy objectives in the scope of the EE1st principle. In a CBA, costs and benefits should be weighted using a social discount rate, to ensure that future impacts are accounted for appropriately. The **private perspective** considers only those impacts experienced by the private actors making their assessments. It is important to be aware of the private perspective, particularly when the achievement of policy objectives is dependent upon the actions of regulated utilities. Multiple private benefits may arise from energy efficiency investments, some of which will not be captured in the societal perspective, as they are transfers between elements of society (e.g. increases in asset values). Public sector decision makers wishing to optimise their policy packages from a **public budget perspective** may wish to devote resources to raising awareness of the private impacts if this could leverage private sector investment in energy efficiency. Improving the value for money to the state (representing society) may be an important objective for policy makers. As such, the public budget perspective may be an important consideration for public sector decision makers. Understanding the broader impacts of MIs on public budgets (e.g. on public sector health systems and finance departments) could be important in building a cross-governmental consensus for supporting energy efficiency.

In the practical part (**Chapter 3**), the report provided evidence on the selected MIs in the scope of the model-based scenarios developed in ENEFIRST (2022). The starting premise was that the techno-economic assessment of EU scenarios certainly undervalues the societal benefits of end-use energy efficiency in buildings because its monetary estimates are limited to capital costs, fuel costs, and other tangible financial metrics. Against this background, this chapter set out to substantiate the three **ENEFIRST scenarios** (LOWEFF, MEDIUMEFF, HIGHEFF) with robust estimates of selected MIs in a so-called **socio-environmental assessment**. The goal was not to achieve an exhaustive account of MIs in the scenarios, but to investigate how the outcomes of the assessment – otherwise centred on financial metrics – change in response to the inclusion of selected MIs. Two types of MIs were analysed in detail.

The first type of MIs investigated are **air pollution and climate change impacts**. A comprehensive set of emission types was quantified in physical terms, monetized using cost rates, and finally integrated in the existing indicator of energy system cost in a CBA-type framework. The key finding is that even though all three scenarios are set to reach the common objective of net-zero greenhouse gas emissions by the year 2050, there are significant differences in cumulative emissions and ensuing costs accumulating to individuals and society over the period 2020–2050. Climate damage is the predominant cost item, reflecting the adverse impacts on human livelihoods and well-being resulting from greenhouse gas emissions. Smaller in size but still significant are human health damage, biodiversity losses, crop and material damage resulting from air pollution emissions – most notably nitrogen oxides (NO_X), sulphur dioxide (SO_2) and particulate matter (PM). Ambitious levels of energy efficiency in buildings can reduce cumulative damage cost from greenhouse gas emissions and air pollutants by up to 146.5 bn EUR (HIGHEFF) compared to less ambitious standards (LOWEFF). The inclusion of these cost estimates has a strong impact on the cost-effectiveness of energy efficiency measures from a societal viewpoint.

The second MIs considered are **indoor comfort improvements**. A new method was developed to quantify comfort gains as a result of building retrofits for the entire building stocks of individual Member States. The approach is based on the effective indoor temperature as a proxy for comfort and was integrated in the building stock model Invert/EE-Lab that was also used for the scenarios of the building sector in ENEFIRST (2022). The results indicate significant comfort gains for countries with poor efficiency of the building stock in the base year. As a result of the modelled retrofit measures, the share of poorly heated floor space below 18°C can be reduced by more than 30 percentage points, with ensuing benefits for health, well-being and workforce productivity. While the method does not involve monetization of comfort gains and thus the possibility to integrate it with the CBA for the three ENEFIRST scenarios, it demonstrates that the effective indoor temperature can be a reasonable metric for indoor comfort in future research. This metric, in turn, can be used in MCA, composite and scoreboard approaches, and other decision-support frameworks.

Overall, any quantitative assessments or scenarios developed in the scope of the EE1st principle should be substantiated with quantitative and qualitative estimates of different MIs to ensure **a fair comparison of demand- and supply-side resources** and thus to enable informed decisions on technology investment and operation. Meanwhile, the MIs framing of energy efficiency is under development as an area of research and practice in the context of the EE1st principle, but important changes are becoming apparent. For example, the European Commission’s legislative proposal (2021f) to revise and recast the Energy Efficiency Directive (European Union 2012, 2018a), would provide for Member State to “promote and, where cost-benefit assessments are required, ensure the application of cost-benefit methodologies that allow proper assessment of wider benefits of energy efficiency solutions from the societal perspective” (Art. 3.3a). As demonstrated in the report, developing such methodologies and using CBA in particular is certainly challenging and requires dedicated guidance to ensure the proper inclusion of MIs.

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ACRONYMS AND ABBREVIATIONS

CAPEX	Capital expenditures
CBA	Cost-benefit analysis
EE1st	Energy Efficiency First
EED	Energy Efficiency Directive
EPBD	Energy Performance of Buildings Directive
EU	European Union
GHG	Greenhouse gas
MCA	Multi-criteria analysis
MI	Multiple impact
OPEX	Operating expenses
SDG	Sustainable Development Goals
TEN-E	Trans-European Networks for Energy

ANNEX: WORKSHOP INFORMATION

Multiple Impacts and Energy Efficiency First: Uniting two complementary frameworks for decision-making in the EU energy system

Expert Online Workshop │ Friday 3 December 2021, 10 to 12 am CET

Acknowledgements

We wish to express our gratitude to the 10 guest experts who took part in the workshop and provided important and valuable insights. Note that the information and views set out in this report are those of the authors and do not necessarily reflect the opinion of the experts.

List of participants

Guest experts:

Name	First name	Organisation	Country
Atanasiu	Bogdan	European Commission, DG ENER	EU organisation
Botzler	Sebastian	TUM - Technical University of Munich	Germany
Chatterjee	Souran	CEU - Central Europe University	Hungary
Keyaerts	Nico	ACER - Agency for the Cooperation of Energy Regulators	EU organisation
Killip	Gavin	Oxford University	UK
Mzavanadze	Nora	Independent researcher and consultant	Lithuania
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Eichhammer	Wolfgang	Fraunhofer ISI	Germany
Mandel	Tim	Fraunhofer ISI	Germany
Rogulj	Ivana	IEECP	Croatia
Thomas	Samuel	RAP	UK/France

Objectives and agenda

This workshop aimed to discuss:

- the approaches used to incorporate multiple impacts in decision-making following the EE1st principle, and especially the relevance of cost-benefit analysis (CBA) as a possible framework for incorporating the concept of Multiple Impacts into Energy Efficiency First;
- theoretical and methodological issues between the concepts of Multiple Impacts and Energy Efficiency First;
- methodological issues in using a CBA framework for decision-making.

<table>
<tr><th colspan="2">10:00 – 10:50 am: Part 1
Cost-benefit analysis and multi-criteria analysis: Two frameworks for decision-support in the context of Multiple Impacts and Energy Efficiency First</th></tr>
<tr><td>Input presentation</td><td>Relevance of cost-benefit analysis (CBA) and multi-criteria analysis (MCA) as possible decision-support frameworks for incorporating the concept of Multiple Impacts into Energy Efficiency First</td></tr>
<tr><td>Open discussion</td><td>• Which of the two frameworks do you generally consider more appropriate for decision-support in energy investment and policymaking?
• Does the decision-making level matter concerning which framework is more appropriate (e.g. policymaking at EU level vs. local investment planning)?</td></tr>
<tr><th colspan="2">10:50 – 11:40 am: Part 2
A deep dive into cost-benefit analysis. Ongoing issues in the context of Multiple Impacts and Energy Efficiency First</th></tr>
<tr><td>Input presentation</td><td>Issue A | Perspective matters: Suggestion of a categorisation as to what MIs should be accounted from a private perspective, societal perspective, or from a state perspective
Issue B | Not all MIs fit into cost-benefit analysis: Suggestion of a standard set of MIs that can be meaningfully incorporated into a CBA framework under consideration of overlaps.</td></tr>
<tr><td>Open discussion</td><td>• Do you agree with the categorisation of MIs?
• Do you agree with the standard set of MIs for CBA? What MIs are missing? What MIs are irrelevant? What MIs are too small in size and given too much attention?</td></tr>
<tr><th colspan="2">Wrap-up and conclusion</th></tr>
</table>