Deliverable 2.2

Cost-Benefit Analysis and aggregation methodology

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Multiple Impacts Calculation Tool

Executive summary

Improvements in energy efficiency lead to numerous impacts additional to energy savings and greenhouse gas reductions. The monetary value of the multiple impacts (MI) of energy efficiency can be of substantial size and thus can significantly change the results of Cost-Benefit Analyses (CBA). Neglecting MI in CBA would thus reduce the cost-effectiveness of Energy Efficiency Improvement (EEI) actions. This can bias policy decisions, leading to sub-optimal levels of energy efficiency for the economy and society. Policymakers and regulators therefore need to know the "whole picture" of MI of energy efficiency, i.e. an aggregated overview of the various impacts is needed. This report presents the methodological framework for the aggregation of monetary values of the multiple impacts assessed in MICAT and for conducting a comprehensive CBA, and serves to operationalise the CBA in the MICATool. The document is structured in four main sections:

1. Consideration of multiple impacts of energy efficiency in Cost-Benefit Analysis
2. Impact monetisation and aggregation
3. Operationalisation of the Cost-Benefit Analysis in MICAT
4. Summary of key features of the Cost-Benefit Analysis in the MICAT online tool

Consideration of multiple impacts of energy efficiency in Cost-Benefit Analysis

CBA is a standard evaluation approach in welfare economics to support policy-related decisions. When evaluating energy efficiency interventions, a CBA typically refers to the comparison of investments with (discounted) lifetime energy cost savings and MI. Due to the high relevance of MI, the online tool developed in MICAT will include the option for users to perform

a Cost-Benefit Analysis (CBA) that allows to consider the MI as comprehensively as possible. As the primary target groups of the tool are evaluators, policy makers and regulators at European, national and local levels, the CBA is conducted taking on a societal perspective as the most relevant to policy-making. This differs from an evaluation from an end-user/investor point of view with regard to the discount rate used in the CBA and the specific benefit and cost components considered. The specific costs and benefits taken into account in MICAT are presented in this section.

Impact monetisation and aggregation

This section presents the methodologies applied for the monetisation of MICAT indicators in the categories social, economic and environmental impacts. Due to the different types of impacts quantified in MICAT, also different monetisation methodologies are applied. The monetisation is either based on market prices or on proxies to market values estimated as avoided costs or damages, willingness-to-pay or willingness-to-accept.

This part of the report also analyses possibilities for the aggregation of monetary values of the impacts quantified in MICAT. In order to avoid double-counting of impacts in the CBA, overlaps and interactions between indicators are identified and discussed, and a decision is made which indicators can be aggregated. The section concludes with a selection of impacts monetised in MICAT that can be included in the CBA without double counting any effects. It is expected that 8-13 indicators can be considered in the CBA.

Operationalisation of the Cost-Benefit Analysis in MICAT

This section of the report elaborates how the CBA will be operationalised in the MICAT online tool. First, framework data needed for the calculation of a CBA is discussed and values to be used in MICAT are proposed. This in particular includes data inputs for discounting future benefits (discount rates and lifetimes of EEI actions) and basic energy-related benefits and costs. A social discount rate is used that is lower than a market discount rate. Lifetime assumptions depend on the type of EEI actions evaluated. The lifetimes used in MICAT are based on EU standard values established by the European Committee for Standardization (CEN 2007) and the European Commission EC (2019). For EEI actions with a mix of various technologies with varying lifetimes, an average lifetime is specified.

The section also presents a series of indicators operationalising a CBA. These include net present value and annuity, benefit-cost ratios and levelised cost of energy (€/kWh) and GHG emissions saved (€/tCO_2). The last two indicators can also be used to construct marginal cost curves. For the evaluation of policy measures that promote energy efficiency technologies via financial incentives, additional indicators that measure the effectiveness of subsidies are proposed (funding efficiency and leverage effect).

Summary of key features of the Cost-Benefit Analysis in the MICAT online tool

Finally, the last section of the report summarises the key features that characterise the CBA carried out in MICAT. First, the CBA is conducted from a societal perspective. Second, in the MICATool, a limited number of impact indicators can be selected for inclusion into the CBA. Namely, only those that are a) quantifiable in monetary terms and b) not affected by double-counting to avoid an overestimation. As pointed out above, 8-13 of the indicators are likely suitable to be included for the CBA. Third, MICAT offers users of the online tool various indicators (see above) for executing and presenting the CBA. Visualisation of results in the online tool via marginal cost curves (with and without multiple impacts) is also planned. Finally, the MICATool offers various options to run sensitivity tests of the CBA results, e.g., by adjusting discount rates, lifetimes of energy efficiency improvement actions, energy price levels and monetisation factors, and by selecting different multiple impacts to be included into the CBA.

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Summary of MICAT

The Horizon 2020 Research and Innovation project, "MICAT – Multiple Impacts Calculation Tool", aims to develop a comprehensive approach and user-friendly online tool to estimate the Multiple Impacts of energy efficiency measures. There is still significant potential to improve energy efficiency in all sectors and levels where efficiency measures can be applied. Facing the often cited “energy efficiency gap”, even the economic potentials are not fully exploited. Highlighting and quantifying the additional values of energy efficiency measures and linked investments considering the multiple non-energy impacts (economic, social and environmental impacts) could help to close this gap and facilitate energy-relevant decisions and policy-making.

MICAT will enable analyses at three different governance levels (local, national and EU) to address a broad target group of decision makers and other interested actors. This allows simplified analyses to be carried out on the basis of different data and policy scenarios in order to compare and assess the relevance of the Multiple Impacts for different measures / policy options. The project will establish a sound scientific empirical basis for monitoring Multiple Impacts and provide a publicly available and user-friendly online tool (MICATool), which shall be developed in a co-creational manner with stakeholders from the different governance levels. The national and local cases for monitoring Multiple Impacts of Energy Efficiency will be developed further in a broad stakeholder and dissemination approach to set a standard for future reporting on Multiple Impacts of Energy Efficiency.

Summary of MICAT's objectives

The main objective of the MICAT project is to link science, policy and stakeholders in the field of Multiple Impacts of energy efficiency. MICAT shall:

- improve scientific knowledge and provide a set of methods to analyse Multiple Impacts of energy efficiency measures;
- develop a comprehensive approach and online tool for estimating Multiple Impacts of energy efficiency;
- allow facilitated assessments of core policy scenarios and specific policies at EU, national and local levels estimating the outcomes of Multiple Impacts;

- establish a culture of underlining the importance and assessment of Multiple Impacts in connection with scenario approaches and policy evaluations on EU, national and local level.

MICAT Consortium Partners

Organisation	Type	Country
Fraunhofer ISI	Research institute	Germany
IEECP	Research institute	The Netherlands
Wuppertal Institute for Climate, Environment and Energy	Research institute	Germany
WiseEuropa	Think-tank	Poland
E3M	Private consulting company	Greece
IIASA	Research institute	Austria
ICLEI European Secretariat	Association of local governments in Europe	Germany

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1. Introduction and overview

1.1 General overview of activities in MICAT

The MICAT project aims to develop a comprehensive approach to estimate Multiple Impacts of energy efficiency (MI) by providing a publicly available, easy to use and scientifically sound online tool (MICATool), to enable holistic analyses of MI at the European, national and local level. It builds on the work of previous projects with a comparable scope of MI: COMBI and ODYSSEE-MURE's MB:EE.

- **COMBI** (Calculating and Operationalising the Multiple Benefits of Energy Efficiency) quantified five key types of multiple benefits (health, resource, social welfare, macroeconomic impacts, and energy security) of energy efficiency in Europe. This project has comprehensive data on direct costs and direct and indirect benefits of energy efficiency improvement actions in the residential, commercial, industry and transport sectors.
- The **ODYSSEE-MURE** (MB:EE) - Tool was developed as part of the ODYSSEE-MURE project and represents a quantitative indicator approach to measure multiple benefits of energy efficiency (MB-EE). These are classified into three groups: environmental, economic, and social-related MBs.

TABLE 1: MAIN FEATURES OF THE COMBI AND ODYSSEE-MURE (MB:EE) PROJECTS

Term	COMBI	MB:EE
Country coverage	28 EU member states	28 EU member states (some indicators only partially covered)
Level of analysis	National	National
Evaluation horizon	Ex-ante (2030 impacts)	Ex-post
Input data	Bottom-up model	Bottom-up/top-down
Quantification approach and reliability	Specialised model runs on input data > reliable results, but only for defined scenarios	Impact factor approach (for some impacts backed by modelling) > less reliable results but scalability and replicability. Rapidly adaptable to progress in data availability
Monetisation	For majority of impacts	For selected impacts
Aggregation & CBA	Inclusion of majority of impacts in CBA	–
Online tool	Complex Physical, monetary, aggregated impacts Country & impact selection Sensitivities	User-friendly, transparent Only quantified impacts

The results to be obtained within the MICAT project rely on efficient data collection from several sources, which allows to assess the relevance of the MI in order to:

- compare and assess the relevance of the MI;
- set a sound scientific empirical basis for monitoring MI;
- provide a publicly available and easy to use online tool (MICATool);
- set a standard for future reporting on MI of energy efficiency.

The online tool developed in MICAT will go beyond the approaches of the COMBI and MB:EE projects by combining their findings into one tool that covers an even wider range of MI and also both ex-ante and ex-post calculations. It will also take advantage of other related specialised modelling, like GAINS (IIASA), PRIMES and GEM-E3 (E3M).

Furthermore, MICAT will carry out robust analyses based on different policy scenarios in order to compare and assess the relevance of the MI at the three governance levels (EU, national, local). A meaningful, repeated involvement of stakeholders at different stages of the tool's development and on each of the three levels shall ensure the quality as well as the transferability and applicability of the tool across the EU. The aim is to establish the MICATool as a semi-standard tool for evaluating energy efficiency policies with respect to their non-energy impacts. Figure 1 illustrates the conceptual approach of the MICAT project.

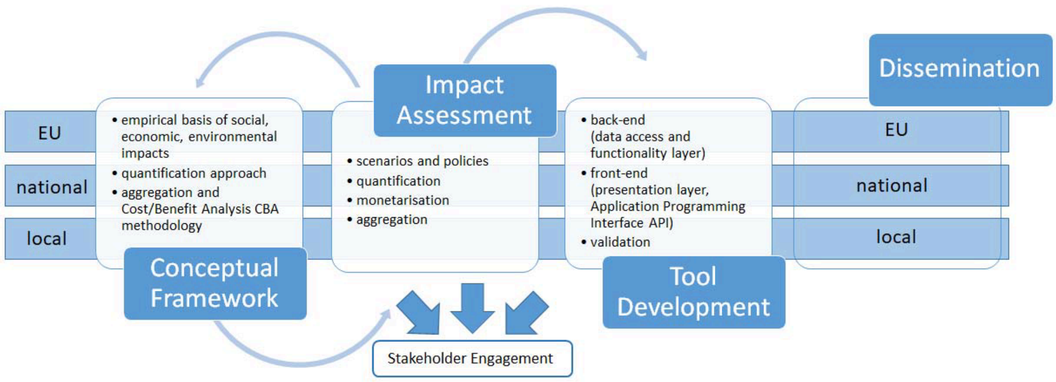


FIGURE 1: CONCEPTUAL APPROACH OF THE MICAT PROJECT

1.2 Important terms used in MICAT

TABLE 2: IMPORTANT TERMS USED IN MICAT

Term	Abbreviation	Definition/Description	Source
Energy efficiency	EE	"a ratio between an output of performance, service, goods or energy, and an input of energy"	EED
Energy efficiency improvement	EEI	"an increase in energy end-use efficiency as a result of technological, behavioural and/or economic changes"	EED
Policy measure	PM	"a regulatory, financial, fiscal, voluntary or information provision instrument formally established and implemented in a Member State to create a supportive framework, requirement or incentive for market actors to provide and purchase energy services and to undertake other energy efficiency improvement measures."	EED
Multiple Impacts	MI	All energy efficiency impacts (benefits and costs) except direct energy savings and energy cost savings	MICAT
Ex-post	EP	Evaluation of an already achieved impact in the past	MICAT
Ex-ante	EA	Evaluation of an expected impact in the future	MICAT
Top-down	TD	• Focus on the overall picture of an impact on the macro level • Takes into account overarching influences (fuel prices, CO_2 price, economic growth) • Based on savings derived from statistics/modelling • Includes autonomous savings	MICAT
Bottom-up	BU	• Focus on the impacts of individual policy measures • Direct impact relationship between policy measure and impact • Only limited consideration of policy interactions possible • Based on energy savings (and investments) derived from e.g., policy evaluations	MICAT
Impact factor/function	IF	• Impact factors or functions will be developed for each MI indicator and applied to input data from scenarios and PM as well as external data sources in order to quantify the MI	MICAT

Source: Most definitions of terms are taken from the EU Energy Efficiency Directive (EED, 2012/27/EU), others specified by MICAT project partners.

1.3 Overarching quantification concept of the MICAT project

Overarching quantification concept

The overarching quantification concept lays the foundation for the actual quantification and monetisation of Multiple Impacts (MI) and for the online tool. More specifically, it defines the quantification chain from input data to outputs in the form of quantified and monetised MI. The concept is illustrated in Figure 2.

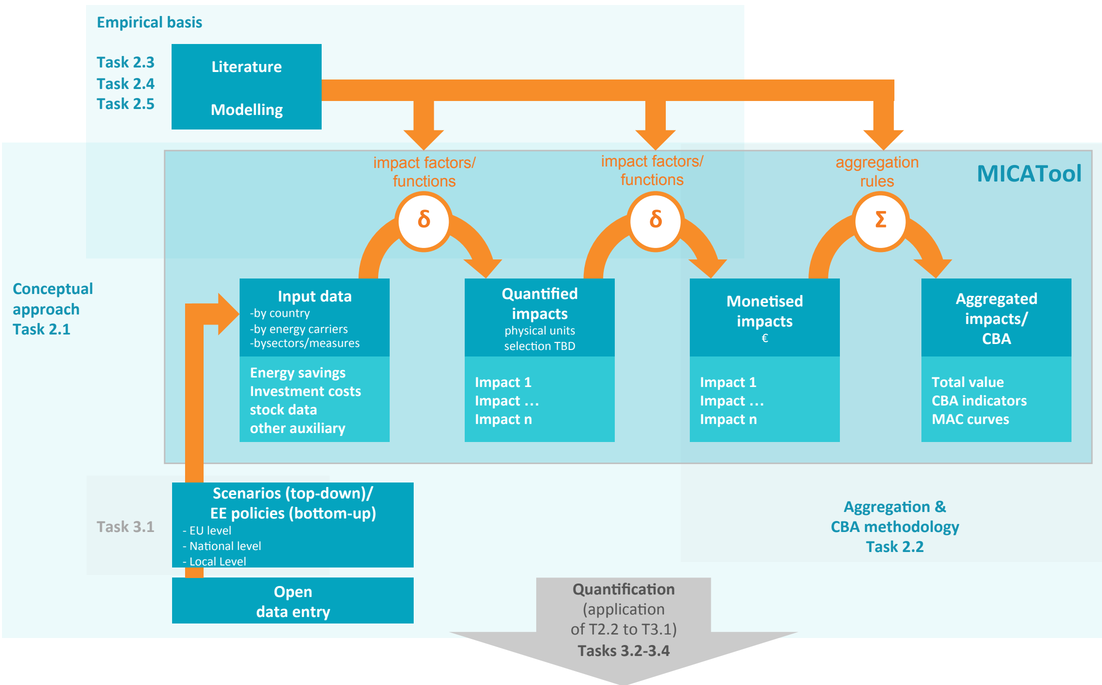


FIGURE 2: METHODOLOGICAL CONCEPT FOR A QUANTIFICATION CHAIN FOR MI FROM THE INPUT DATA TO IMPACT QUANTIFICATION, MONETISATION AND THE AGGREGATION AND/OR COST-BENEFIT ANALYSIS

The approach will allow for (I) an *ex-ante* quantification of future MI for various scenarios at the three governance levels (e.g., EU-level with the PRIMES model, national projections used in the framework of National Energy and Climate Plans (NECPs), local level scenarios); (II) an *ex-post* evaluation of already achieved MI; and (III) the assessment of MI for input data entered by tool users (open data entry into the tool).

Due to the high flexibility required in MICAT, MI will be quantified based on impacts factors/functions that are directly linked to specific input parameters (such as energy savings, investments costs, or stock data of technologies) of the respective scenarios or policy evaluations. Input data will be obtained from scenarios and policy measures at different levels of disaggregation, e.g., by country, energy carrier, sector, end-use and/or energy efficiency improvement (EEI) action.

In a first step, the MI will be derived in physical units (e.g., tons of GHG emissions reduced or number of additional job years). In order to aggregate impacts with different units, compare their magnitude, and integrate them into the CBA, physical units have to be converted into monetary values.[1] The specific monetisation method will be separately developed for each indicator. The objective is to monetise as many MI as possible in MICAT. The final step is an aggregation of monetised impacts and performing a CBA in the MICATool by including the MI in monetary values. This step is challenging since interactions/overlaps of different impacts will have to be accounted for to avoid a double-counting of impacts.

The results of quantification and monetisation of MI are generated in the back end (i.e. the data access and functionality layer), where the Application Programming Interface (API)) is also located. The CBA will be implemented

[1] For some impacts such as health-related benefits monetisation is controversial (e.g., valuation of life-years) or methods have flaws, why monetisation is be challenging for some impacts.

in the front end (i.e. the presentation layer), making it more responsive, pacy and adjustable.

1.4 Purpose and scope of this document

The aim of the report is to present the conceptual framework for a CBA in MICAT. This serves to operationalise the CBA in the MICATool. The report is structured as follows:

Chapter 2 starts with a general introduction of the relevance of MI in CBA by looking at results of other studies having assessed and monetised MI of energy efficiency. Furthermore, the chapter defines the target group of the CBA in MICAT and shows for which use cases it is suitable. Subsequent to that, Chapter 2.3 discusses differences between CBA from a societal or end-user/investor point of view and provides a categorisation from which perspectives the specific MI analysed within MICAT are relevant.

Chapters 3.1 introduces the topic of impact monetisation and aggregation and points out how double counting of impacts can generally be avoided in a CBA. Afterwards, Chapter 3.2 presents the different methodologies applied for the monetisation of MICAT indicators in the categories social, economic and environmental impacts. Possible strategies to avoid double counting of impacts in CBA are pointed out in Chapter 3.3. Chapter 3.4 qualitatively discusses potential interactions and overlaps of the impacts monetised in MICAT and where a potential danger of double counting exists. On this basis, Chapter 3.5 concludes with a selection of the indicators that can be included in the CBA of MICAT without double counting any effects to avoid that the outcome will be overestimated.

Chapters 4.1, 4.2 and 4.3 cover basic framework data that is needed for the calculation of any CBA and propose values to use in MICAT. This includes calculation inputs for discounting future benefits (discount rates and lifetimes of EEI actions) and basic energy-related benefits and costs such as energy savings, energy prices, energy cost savings and investment costs of EEI actions. Finally, Chapter 4.4 presents the calculation methods of a range of cost-benefit indicators that may be calculated in the online tool including net present value, annuity, benefit-cost ratios, levelised cost of energy and GHG emissions saved and marginal cost curves. For the evaluation of policy measures that promote energy efficiency technologies via financial incentives, additional indicators that measure the effectiveness of subsidies are proposed.

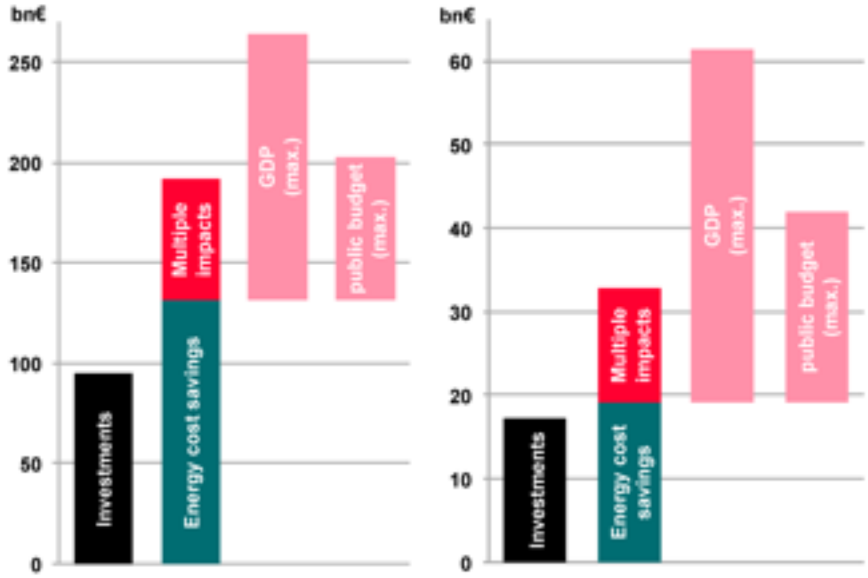
Chapter 5 summarises the key features on how the CBA is planned to be operationalised in the MICAT online tool. This includes the definition of the evaluation perspective, the impacts to be considered in the CBA, appropriate indicators for operationalising a CBA by aggregating multiple impacts and comparing them with costs, and conducting a sensitivity analysis.

2. Consideration of multiple impacts of energy efficiency in Cost-Benefit Analyses

2.1 Relevance of multiple impacts

Improvements in energy efficiency lead to numerous impacts additional to energy savings and greenhouse gas reductions. The monetised value of these wider impacts can be of substantial size in CBA. A meta-analysis of Ürge-Vorsatz et al. (2016), which reviewed 52 case studies on wider impacts of energy efficiency measures, has found that in 63% of the cases analysed, the value of the MI was equal or greater than the energy cost savings. In 30% of the cases studied, the monetised value of MI were three times higher than the energy costs savings, and in around 25% of the cases, MI were more than four times the size of the energy cost savings. Lazar and Colburn (2013) also conclude that the non-energy benefits of energy efficiency measures are large and that the value is between 50% and 100% or more of the direct energy benefits according to assessments of Neme and Kushler (2010) and Skumatz (2006).

The COMBI project also corroborated these findings. With a conservative estimate taken in COMBI, monetised MI sum up to a size of at least 50–70% of energy cost savings, with substantial impacts coming from e.g., air pollution and energy poverty related health impacts and economic impacts (see Figure 3). As the assessment excluded several MI that could either not be quantified or monetised or where any double counting was detected, actual benefits may in reality be much larger (Thema et al. 2019).



Note: left figure shows multiple impacts for all COMBI EEI actions (excl. modal shift and trucks), right figure specific results for the example of residential building refurbishment

Source: Thema et al. (2019)

FIGURE 3: INVESTMENTS, ENERGY COST SAVINGS AND MULTIPLE IMPACTS (BN€ ANNUAL IN 2030)

The COMBI results illustrate that the inclusion of MI can significantly change CBA results. In turn, neglecting MI in CBA (implicitly valuing MI at zero) reduces the cost-effectiveness of EEI actions below their actual societal value. This can bias regulatory and policy decisions against cost-effective energy efficiency investments leading to suboptimal levels of energy efficiency for the economy and society (Lazar and Colburn 2013). A more comprehensive quantification and monetisation of MI may thus help to allocate public funding to policy measures that provide the largest net benefit to society.

2.2 Objective and use cases of the Cost-Benefit Analysis

CBA is a standard evaluation approach applied in environmental and welfare economics to support policy-related decisions. Basically, in a CBA all costs and benefits that arise due to a policy measure or investment are evaluated in monetary units and compared with each other.[2] When evaluating energy efficiency interventions, a CBA typically refers to the comparison of investments with (discounted) lifetime energy cost savings and various multiple impacts. Due to the high relevance of MI described above, the online tool developed in MICAT will include the option for users to perform a Cost-Benefit Analysis (CBA) that allows to consider the MI as comprehensively as possible. The CBA will be the final step in the online tool after MI have been quantified and presented in physical and monetary values. The objective is to consider in the CBA as many of the MI as possible, while at the same time avoiding double counting of impacts.

Target groups and use-cases

As the primary target groups of the tool are evaluators, policy makers and regulators at European, national and local levels, the CBA is conducted taking on a societal perspective as the most relevant to policy-making.

The CBA is not designed for a specific use case in the MICAT online tool, but to provide users with an intuitive online tool option for a CBA that can be adapted to different use cases. It can be carried out both ex-post and ex-ante, and be applied to different sectors and energy efficiency improvement (EEI) actions and at different governance levels (local, national, EU). The

[2] Boardman et al (1996) and Pearce et al. (2006) contain a detailed description of the CBA concept and strengths and weaknesses of different assessment methodologies.

evaluation results of the CBA can be useful for the planning and (re-)design, implementation and comparison of a wide range of policy measures to improve end-use energy efficiency. It allows to assess and compare the cost-effectiveness with and without including all or specific MI and to rank different measures according to their cost-effectiveness. The CBA thus helps to identify the most cost-effective energy-efficiency solutions. The policy intervention to be evaluated can be the promotion of a certain EEI action (e.g., energy refurbishment of residential buildings), a specific policy instrument (e.g., white certificate scheme or energy efficiency fund), or scenario (e.g., PRIMES, NECPs or SECAPs). The visualisation of results can also be used to communicate policy outcomes to the public.

Energy Efficiency First principle

The outcomes of the CBA can in principle also be used to assess whether demand-side measures should be prioritised over supply-side options (e.g., investments in energy supply infrastructure) by comparing their cost-effectiveness.[3] The CBA may thus also be useful for decision makers to operationalise the Energy Efficiency First (EE1st) principle[4]. Taking into

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[3] However, since MICAT focusses on energy efficiency, supply-side measures would have to be assessed independently, i.e., based on other studies and data sources.

[4] The EE1st principle is embedded in the Regulation on the Governance of the Energy Union and Climate Action (Regulation (EU) 2018/1999) and in the Energy Efficiency Directive ((EU) 2018/2002) (EED). The 2018 amendment of the EED (EC 2018) includes the following explanation of how the EE1st principle should be taken into account: *"Directive 2012/27/EU of the European Parliament and of the Council is an element to progress towards the Energy Union, under which energy efficiency is to be treated as an energy source in its own right. The energy efficiency first principle should be taken into account when setting new rules for the supply side and other policy areas. The Commission should ensure that energy efficiency and demand-side response can compete on equal terms with generation capacity.*

account the MI of energy efficiency from the societal perspective is an important aspect to be considered when implementing the EE1st principle according to the ANNEX to the Commission Recommendation on Energy Efficiency First (EC 2021a).

2.3 Evaluation perspectives

For any evaluation of MI, the perspective of the assessment needs to be defined, i.e. whether benefits and costs are evaluated from a societal or end-user/investor point of view.[5] The two evaluation perspectives differ with regard to the discount rate used in the CBA and the specific benefit and cost components considered. The central evaluation perspective in MICAT is the societal perspective as the most relevant to policy making. Several impacts studied in MICAT (e.g., energy cost savings, investment costs and several wider benefits) are however also relevant from an investor/end-user point of view since they affect also the individual utility (see the following section).

Energy efficiency needs to be considered whenever decisions relating to planning the energy system or to financing are taken. Energy efficiency improvements need to be made whenever they are more cost-effective than equivalent supply-side solutions. This ought to help exploit the multiple benefits of energy efficiency for the Union, in particular for citizens and businesses."

[5] In the US, even five different evaluation perspectives are distinguished and respective cost-effectiveness tests conducted. These tests are developed by the California Public Utilities Commission (CPUC) in particular for the evaluation of utility-funded energy efficiency programmes. These cost-effectiveness tests consider the different cost and benefit components relevant for each evaluation perspective (society, state, utility, programme participants, ratepayers) and thereby provide different information for utilities and regulators (cf. NAPEE 2008). This approach is, however, less relevant to the liberalised energy market in the EU where most energy efficiency programmes and policies are implemented and funded by the state, i.e., not by vertically integrated utilities that pass on the costs of the programmes to their customers (Mandel et al. 2020).

Societal perspective

In CBA, societal costs and benefits are equal to the sum of all individual costs and benefits. Where a measure imposes costs on one group of individuals and results in a corresponding and equal benefit to another group, then from a societal perspective, these costs and benefits cancel out and are considered a transfer between different groups without an impact on overall social welfare. For this reason, impacts are quantified net of taxes and other transfers from a societal perspective, i.e., only those costs and benefits count, which are not simple transfers but have an impact on the overall social welfare.

The cost components to be considered are primarily the (incremental) investment costs of the EEI actions and, if policy measures are evaluated, the administration costs of the programme and transaction costs for market actors (if quantifiable).

The primary benefits of energy efficiency investments are energy cost savings (net of taxes) (cf. Chapter 4.3) during the lifetime of EEI actions. Additional benefits that can be considered in a CBA from a societal perspective include reduced external environmental costs resulting from GHG emissions, air pollution, noise and soil contamination (cf. Sartori et al. 2015), health improvements, increased competitiveness, productivity gains, increased energy security, and possibly macroeconomic effects. The latter should, however, only be included in the CBA if a double counting of impacts can be avoided (Ürge-Vorsatz et al. 2016; Santori et al. 2015; Mandel et al. 2020). A "social" discount rate is applied in CBA to discount the impacts, which is lower than market discount rates (cf. Chapter 4.1).

End-user/investor perspective:[6]

The private evaluation perspective analyses the cost-effectiveness of an investment in energy efficiency for the end-user/investor. For this reason, taxes, subsidies and other potential financial transfers are taken into account as they directly impact the cash flows of end-users/investors (Mandel et al. 2020).

(Additional) costs of the energy efficient investments are considered in the assessment on the cost side, while the energy cost savings (energy bill savings) over the action lifetime are counted as direct benefits. Non-energy benefits (or costs if relevant) for the end-user/investor to be considered include for example increased building value, comfort and health gains, noise reduction and increased productivity. Taxes and financial incentives (subsidies, low-interest loans etc.) provided by policy and hidden costs such as transaction costs should also be taken into account from this evaluation perspective if available / quantifiable. Higher benefits than costs indicate that investors/end-users have economic incentives for investing in the respective EEI action provided that there are no other barriers. A discount rate from the end-user/investor perspective is usually oriented on alternative investment opportunities. Therefore, a market discount rate is used in the analysis representing the opportunity costs of invested capital.

Categorisation of multiple impacts analysed in MICAT by evaluation perspective

Table 3 shows the multiple energy efficiency impacts analysed within MICAT and provides a categorisation from which perspectives they are relevant. The quantification/monetisation approaches of the MI may however differ by evaluation perspective. The categorisation shows that all

[6] This can also be called private perspective (Shnapp et al. 2020).

MI analysed are relevant from the societal perspective, and some impacts also from an investor/end-user point of view.

TABLE 3: MICAT MULTIPLE IMPACTS BY PERSPECTIVE

		Relevance for evaluation perspective	
Indicator code	**Impact**	**Investor/ end-user**	**Society**
SoI-1	Energy poverty alleviation	(x)	x
SoI-2	Alleviation of inequality		x
SoI-3	Workforce performance in tertiary buildings	x	x
SoI-4	Human health due to improved indoor climate	x	x
SoI-5	Human health due to reduced air pollution	x	x
EcI-1	Impact on GDP, and other macroeconomic indicators (investment, consumption)	(x)	x
EcI-2	Employment effects (by sector, country) and also capturing skill requirements		x
EcI-3	Impact on public budget		x
EcI-4	Energy price effects	x	x
EcI-5	ETS effect**	x	x
EcI-6	Terms of Trade effect by sector		x
EcI-7	Energy intensity		x
EcI-8	Industrial productivity	x	x
EcI-9	Asset value of commercial buildings (with possible extension to households)	x	x
EcI-10	Investments	x	x
EcI-11	Turnover of energy efficiency goods	x	x
EcI-12	Competitiveness by sector		x
EcI-13	Innovation impacts	(x)	x
EcI-14	Import dependency		x
EcI-15	Aggregated energy security (supplier diversity)		x
EcI-16	Impact on integration of renewables		x
EcI-17	Avoided invest. in grid and capacity expansion due to lower energy demand		x
EnI-1	Energy (cost) savings	x	x
EnI-2	Savings on material resources		x
EnI-3	Impacts on RES targets		x
EnI-4	GHG savings (Savings of direct carbon emissions)		x
EnI-5	Reduction in air pollution		x

**to be defined at what level It will be quantified

In MICAT, the CBA is conducted from a societal perspective, as this is most relevant for policy makers, regulators, and stakeholders who influence political/public decisions affecting social welfare. Various participants in the national and EU workshops of MICAT also pointed out that the CBA implemented in MICAT can also be useful for the operationalisation of the energy efficiency first principle. The principle should be implemented primarily from a societal perspective (i.e., not just from an end-user/investor perspective) and requires taking into account the MI of energy efficiency for the society. The Guidelines for implementation of Energy Efficiency First (European Commission 2021a) explicitly state that "*Under the EE1st principle, it is important that a CBA is done whenever possible from the societal perspective when evaluating the costs and benefits […].*"

3. Impact monetisation and aggregation

3.1 General approach and challenges

In order to aggregate outcomes of impacts with different physical units, compare their magnitude, and integrate them into a CBA, a conversion into one common metric is necessary. For this reason, physical impacts will be converted into a monetary value applying an appropriate monetisation methodology if feasible.[7] The specific monetisation method is separately developed for each indicator (cf. MICAT Tasks 2.3-2.5). The objective is to monetise as many MI as possible since the first pre-condition for MI to enter a CBA is that that they can be monetised (Thema et al. 2019). The final step is an aggregation of monetised impacts and performing a CBA in the MICATool. This step is challenging since interactions/overlaps of different impacts need to be accounted for and double counting of impacts has to be avoided. Otherwise, the aggregate outcome will be overestimated.

3.2 Monetisation methodologies for multiple impacts in MICAT

The step of monetisation usually follows the assessment of physical impacts with a suitable method such as Life Cycle Assessment, Environmental Impact Assessment or Health Impact Assessment. The monetisation can in principle be based on the market price of a good when available. Since markets are often missing for public goods such as health, well-being or ecosystems, an alternative is to value a good by a proxy to market prices

[7] For some impacts such as health-related benefits monetisation is controversial (e.g., valuation of life-years) or methods have flaws, why monetisation might be challenging for some impacts.

(e.g., avoided costs or damages), by willingness-to-pay (WTP) or willingness-to-accept (WTA) (Ürge-Vorsatz et al. 2015). There is a variety of methods that can be used in CBA to estimate the monetary value if market prices are not available such as revealed or stated preference methods. A comprehensive summary of these valuation techniques for monetisation of impacts is provided in Ürge-Vorsatz et al. (2015) and Atkinson et al. (2018).

Due to the different types of MIs quantified in MICAT, also different monetisation methodologies are applied. The following section describes the methods used to monetise the (physical) indicators in the categories social, economic and environmental impacts. Details on the monetisation methodologies for the different impact quantifications are presented in the respective indicator factsheets.

Social impacts

Table 4 contains the indicators that are planned to be quantified in MICAT in the category social impacts. These are subdivided into *energy poverty*, *quality of life* and *health*. The table shows the primary quantification units of the indicators and whether they are monetised.[8]

TABLE 4: LIST OF INDICATORS IN THE CATEGORY SOCIAL IMPACTS

SoI	Social impact indicators	Lead	Unit	Monetisation possible
		Energy Poverty		
SoI-1	Alleviation of energy poverty	WI/E3M	Number of households / persons lifted from energy poverty	Yes (monetised as energy cost savings)
		Quality of Life		
SoI-2	Alleviation of inequality	E3M	S80/S20, Income/Consumption by income decile	Yes (monetised as income loss/gain)

[8] The extent to which these impacts can in the end be included in the MICAT tool depends on data and resource availabilities.

SoI-3	Workforce performance in tertiary buildings[9]	(WI)	Working days gained	Yes
Health				
SoI-4	Human health due to improved indoor climate	WI	-	-
SoI-4.1	*Reduced or avoided excess cold weather mortality*	WI	Number of deaths avoided	Yes
SoI-4.2	*Avoided asthma cases due to the reduced exposure to indoor dampness*	WI	DALY	Yes
SoI-5	Human health due to reduced air pollution	IIASA		Yes
SoI-5.1	*Air pollution-related mortality*	IIASA	Number of deaths avoided	Yes
SoI-5.2	*Air pollution-related morbidity*	IIASA	DALY OR Restricted activity days (RAD)	Yes
SoI-5.3	*Working days lost (impact related to health)*	IIASA	Number of days gained	Yes

Valuation of *health impacts*, such as excess mortality reduction potential, can be estimated based on a) market values (e.g., average costs associated with treatment of an illness by the health care system, costs of medication, lost productivity in sick days) and/or; b) non-market values, based on surveys estimating the value of a statistical life (VSL) or value of a life year (VOLY). The market value approach requires a systematic inquiry into the health care systems of EU member states. Thus, MICAT will apply the non-market values approach to monetise the health impacts.

The indicator *reduced or avoided excess cold weather mortality* is monetised based on the value of a life year (VOLY) estimates per (avoided) deaths, assuming that the elderly population affected would have lived at least one more year (Mzavanadze 2018). The non-market values approach is also used for the monetisation of the indicator *avoided asthma cases due to the reduced exposure to indoor dampness*. Each disease case, such as

[9] Whether this indicator (SoI-3) will be quantified in MICAT is not yet decided and depends on stakeholder interest, data availability and available resources.

asthma, or every person with asthma is assigned a disability weight, which represents the magnitude of health loss associated with specific disease (GHDx 2020).

Air pollution-related mortality and morbidity cannot be directly monetised with the GAINS model that is used for quantifying these impacts in MICAT. This is because, while all other parts of the above impact assessment are based on a combination of methods that allow for an objective assessment, a monetisation using the concept of the value of statistical life (VSL) introduces an element of value judgement that is fraught with methodological and conceptual difficulties (cf. OECD 2016). The VSL is derived from aggregating individuals' willingness-to-pay to secure a marginal reduction in the risk of premature death over a given timespan and can potentially bias a CBA in one way or another. However, since the VSL will be used for other indicators as well in this project, it might be considered as a parameter that the user of the tool will need to choose prior to the analysis. Alternatively, mortality and morbidity effects could be recorded without monetisation and fed into a Computable General Equilibrium (CGE) analysis as reduced labour or foregone consumption. In this way, the issues with the VSL could be circumvented.

Working days lost (impact related to health) are quantified using the methodology described in (OECD 2016) and as implemented in Spadaro, Kendrovski and Sanchez Martinez (2018). Working days lost are quantified using country-specific concentration response functions and are then monetised by taking a cost-of-illness approach and estimating the reduced productivity due to reduced working time.

Economic impacts

Table 5 contains the indicators that are planned to be quantified in MICAT in the category economic impacts. These are subdivided into *economy (macro), economy (micro), innovation & competitiveness and energy security & energy delivery*. The table shows the primary quantification units of the indicators and whether they are monetised.[10]

TABLE 5: LIST OF INDICATORS IN THE CATEGORY ECONOMIC IMPACTS

EcI	Economic impact indicators	Lead	Unit	Monetisation possible
		Economy (Macro)		
EcI-1	Impact on GDP, and other macro-economic indicators (investment, consumption)	E3M/Fraunhofer	€ (or % change from a baseline)	Yes
EcI-2	Employment effects (by sector, country) and also capturing skill requirements	E3M/Fraunhofer	thousand persons (or % change from a baseline)	Yes (equivalent salary)
EcI-3	Impact on public budget	E3M/Fraunhofer	€	Yes
EcI-4	Energy price effects	E3M	% change (range)	Depending on perspective
EcI-5	ETS effect	E3M		Yes (at what level will be defined at later stage)
EcI-6	Terms of Trade effect by sector	E3M	change from a baseline/ baseyear	Not explicitly, implicitly only by assessing the impacts on net trade
EcI-7	Energy intensity	Fraunhofer	ktoe/1000€	No, rather an indicator than a direct benefit
		Economy (Micro)		
EcI-8	Industrial productivity	Fraunhofer	% change	No, indicator & double counting with EnI-1
EcI-9	Asset value of commercial buildings (with poss. extension to private households)	IEECP	€, % change	Yes
		Innovation & Competitiveness		
EcI-10	Investments	E3M	€	Yes
EcI-11	Turnover of energy efficiency goods	IEECP	€	Yes

[10] The extent to which these impacts can in the end be included in the MICAT tool depends on data and resource availabilities.

EcI-12	Competitiveness	Fraunhofer/E3M	RCA	No
EcI-13	Innovation impacts	Fraunhofer	RPA	No
Energy Security & Energy Delivery				
EcI-14	Import dependency	Fraunhofer	%	Currently researching monetisation approach
EcI-15	Aggregated energy security (supplier diversity)	Fraunhofer	Herfindahl-Hirschman-Index (HHI)	Together with EcI-15, currently researching monetisation approach. Potential double counting with EnI-1 due to internalisation
EcI-16	Impact on integration of renewables (Demand-response potentials)	Fraunhofer	MW / %	Yes
EcI-17	Avoided investments in grid and capacity expansion due to lower energy demand	Fraunhofer	€	Yes, however double-counting with EnI-1 due to internalisation of costs

To quantify macroeconomic impacts, dedicated models such as Input-Output analysis, macro-econometric models or partial equilibrium and Computable General Equilibrium (CGE) models are generally used (Ürge-Vorsatz et al. 2016). The model outcomes for several macroeconomic impacts are already in monetary terms. For some of these impacts, a separate monetisation approach is thus not required. Yet, not all quantifications in monetary terms are equivalent to a monetisation, since some may constitute turnover and not benefit values (i.e. GDP, investments, and turnover of energy efficiency goods) as well as some representing indicators without directly resulting benefits (i.e. industrial productivity and energy intensity). Other economic indicators are not expressed in monetary terms and thus require a separate monetisation methodology. The monetisation methodologies applied in MICAT for those economic indicators, not initially calculated in monetary units, are outlined in the following.

The impact on public budgets indicator monetises the fiscal benefits arising from additional economic turnover as represented by the GDP and from employment effects. Therefore, relevant tax rates (mainly sales and income taxes) within member states are researched and applied. Potentially, the costs of relevant subsidy programmes will also be included, although this is still in discussion.

The monetisation of energy security indicators, namely import dependency and supplier diversity, is still under research. As both aspects are paramount for it, a combined approach is used, multiplying both indicators. The calculation is based on three price-defining components: the difference between domestic and foreign resource exploitation costs, infrastructure expenses to transport and store the resource, and the revenue and security premium collected by companies along the supply chain to insure themselves against the risk of price and supply volatilities.

For the impact on demand-response potentials, the value is assessed by considering the pricing of companies' voluntary flexibility at peak load times and the alternative costs to ensure the flexibility centrally with additional short-term generation capacity or large-scale batteries.

Environmental impacts

Table 6 contains the indicators that are planned to be quantified in MICAT in the category environmental impacts. These are subdivided into *energy & resource management* and *global & local pollutants*. The table shows the primary quantification units of the indicators and whether they are monetised.[11]

TABLE 6: LIST OF INDICATORS IN THE CATEGORY ENVIRONMENTAL IMPACTS

SoI	**Environmental impact indicators**	**Lead**	**Unit**	**Monetisation possible**
		Energy & Resource Management		
EnI-1	Energy (cost) savings	Fraunhofer (E3M based on PRIMES)	MWh, ktoe	Yes
EnI-2	Savings on material resources	WI	tons, tons/GDP	
EnI-2.1	*Reduction in overall material footprint*	WI	tons, tons/GDP	Only partially monetised
EnI-2.2	*Life-Cycle wide fossil fuel consumption*	WI	tons	Yes
EnI-2.3	*Metal ores*	WI	tons	No
EnI-2.4	*Minerals*	WI	tons	No
EnI-2.5	*Biotic raw materials*	WI	tons	No
EnI-2.6	*Unused extraction*	WI	tons	No
EnI-3	Impacts on RES targets	Fraunhofer	%	No, merely an indicator
		Global & Local Pollutants		
EnI-4	GHG savings (Savings of direct carbon emissions)	Fraunhofer	Mt CO2eq	Yes
EnI-5	Reduction in air pollution emissions	IIASA	tons	No, however via health impacts resulting from reduced outdoor air pollution

GHG emissions reductions in tons of carbon dioxide equivalent are typically valued in monetary terms using a shadow price of carbon (in Euro per ton of CO_{2eq}) (Santori et al. 2021). European Commission (2021c) and Santori et al. (2021) recommend the use of shadow cost of carbon values established by the European Investment Bank (EIB), which are regarded therein as the

[11] The extent to which these impacts can in the end be included in the MICAT tool depends on data and resource availabilities.

best available evidence on the cost of meeting the 1.5 ⁰C temperature goal of the Paris agreement. The recommended shadow cost of carbon values is shown for the timeframe 2020–2050 in Santori et al. (2021, Table 4).

For *savings on material resources* two types of monetisation approaches can be applied: embodied or direct costs and indirect or external costs (Teubler et al. 2018).[12] The embodied costs can be based on market prices for processed raw materials and linked to the raw material demand. This is particularly feasible for metals and fossil fuels. These costs may be already included in the monetary investment cost as these embodied costs are based on the market price. The indirect material costs are externalised costs of societies that occur if raw materials deplete in the future and additional investments are necessary to provide them in the same quality. The eco-cost model provides such future costs for metals by using historic data and assuming fixed developments for scarce metal prices as well as the growth of population and economies.

The *reduction in air pollution* due to energy efficiency interventions is calculated with the GAINS model (Greenhouse Gas – Air Pollution Interactions and Synergies model). Monetisation of the benefit of reduced air pollution is performed via the human health indicators *air pollution-related mortality and morbidity* in MICAT (see above).

[12] See also the D4.4 quantification report of the COMBI project for further details and monetisation factors.

3.3 Strategies to avoid double counting of impacts in the Cost-Benefit Analysis

Some of the MI quantified in MICAT may overlap and interact with each other, which would lead to a double counting of impacts. Double counting of impacts is particularly relevant when they are converted into a monetary value and aggregated or incorporated into a CBA (cf. Ürge-Vorsatz et al. 2014).

In order to yield reliable and credible results, impacts could either be adjusted for double-counting or, if not possible, only impacts included in a CBA, where no risk of double-counting exists. The latter, i.e., excluding specific overlapping impacts completely from the CBA, has been the approach applied in the COMBI project (cf. Chatterjee et al. 2018). Out of the 31 quantified and 17 monetised impacts in the COMBI project 11 could finally be included in the CBA (Thema et al 2019). Among the excluded impacts from the CBA were resource impacts (at least partially covered by investment costs and energy cost savings), aggregate demand and employment effects (fraction already counted with investment costs) and public budget effect (partially overlapping with investment costs, other economic and health impacts) (cf. Thema et al. 2019).

The advantage of this approach, i.e. of excluding overlapping impacts from the CBA, is that it can easily be implemented after interactions of impacts have been identified, it is transparent, easy to understand and leads to a conservative estimate of the cost-effectiveness.

The drawback of this approach on the other hand is that it may lead to an underestimation of the total MI and cost-effectiveness. An adjustment for double counting would however only be possible if the fractions of the impacts that are additional to others can be determined, e.g., applying reliable adjustment factors, in order to include them in the CBA.

In the next sections, the interactions between indicators quantified in MICAT will be discussed based on the information given on interactions/overlaps in the methodological factsheets (MICAT Tasks 2.3-2.5).

3.4 Interactions between MICAT impacts and risk of double counting

There are a number of indicators that are quantified in MICAT but may not be included in the CBA, although they are monetised and relevant from a societal perspective. This concerns impacts that overlap with other indicators and thus would be double counted in the CBA.

Interactions between social and economic impacts

Improved indoor thermal comfort as well as air quality and reduced indoor dampness due to energy efficiency refurbishments both affect (positively) health and thus productivity, which ultimately result in economic impacts such as on public budget (partial overlap between health, productivity and economic impacts) (Chatterjee et al. 2018).

Indoor dampness and mould increase the risk of asthma. Decreased indoor dampness due to energy efficiency renovation may thus reduce public budget spent on public health service for asthma. However, whether and to which extent it reduces public budget spending in this regard varies, depending on the health insurance system types of the specific countries, financing sources of public health system, etc.

Benefits on mortality and morbidity associated with reduced air pollution resulting from improved energy efficiency arise for whole populations, not just for those groups of persons directly or indirectly implementing energy efficiency measures. As such the benefits are less concentrated and need to be estimated at the level of cities, countries or the EU as a whole. Since air pollution knows no borders, efficiency improvements and associated emission reductions also generate benefits in neighbouring regions. Depending on the specific efficiency measure and the geographical distribution, these transboundary benefits can be substantial. While in subnational and national accounting schemes they are often neglected, at the EU level they should be included in order not to systematically underestimate the benefits.

The effects of indoor dampness and outdoor air pollution may interact for specific health conditions. However, since the assessment of air pollution benefits takes into account not only asthma but many other pathways the risk of double counting is small.

The alleviation of energy poverty results from reduced financial burden on household budgets due to decreased energy costs. These savings are however already captured in the monetised energy savings indicator and should not be double counted. Furthermore, there can be an overlapping effect on public budgets if transfer payments or spending on energy subsidies are reduced. However, similar to the positive health impacts, whether and to what extent public budget spending is reduced depends on the respective existence and setup of welfare state institutions.

Interactions between environmental and economic impacts

Savings on material resources: The monetised value of materials required for producing energy efficient technologies are part of the market prices of these technologies (production phase), i.e. they fully overlap with investment costs. Furthermore, the monetised material savings in the use phase (avoided resources due to energy saved) of technologies are part of the energy cost savings. In order to avoid a double counting with investment costs and energy cost savings, monetised savings on material resources will thus not feed into the CBA. However, external costs to society related to material resources (not captured in market prices) are independent from the other impacts quantified in MICAT and may be considered in the CBA if quantifiable. The indirect material costs are externalised costs of societies that occur if raw materials deplete in the future and additional investments are necessary to provide them in the same quality. The eco-cost model provides such future costs for metals by using historic data and assuming fixed developments for scarce metal prices as well as the growth of population and economies. In addition, costs related to the disposal and recycling of materials that are not included in market prices could be taken into account.

In general, several indicators are merely specifications of energy cost savings. As a result, a monetisation of these indicators would lead to double counting, since the related costs are internalised in the energy price. Inter alia, this is the case for the indicators industrial productivity, and avoided investments in grid and capacity expansion.

Furthermore, double counting concerns were discussed with regard to the monetisation of ETS / Effort Sharing Regulation (ESR) certificates and environmental damage costs. However, the revenues from the ETS do not instigate additional measures or cover damages to the environment but merely feed into the planned national climate mitigation budgets. As the total number of certificates is predetermined, the price of the certificates does not regulate the extent of pollution but merely the emitters. In addition, the costs and revenues from the acquisition or sale of ESR certificates always happen across borders, thus these sums do not cover environmental damages in underperforming countries. Therefore, no risk of double counting was detected in either case.

Interactions among macroeconomic effects

Macroeconomic effects, such as the impact of energy efficiency improvements on the public budget as well as on GDP, are probably the largest impacts in monetary terms. This, at least, is the result of the analyses carried out in the COMBI project (Thema et al. 2019). The impact on GDP, for example, is an indirect result of many effects also quantified in other indicators such as employment effects, innovation, increased competitiveness, and productivity as well as health improvements. A strong interaction and overlaps between individual impacts and GDP thus exist. Yet, since only the related corporate, value-added, and income taxes as well as reduced social welfare expenses are considered within the scope of the impact on public budgets, the risk of double counting is averted[13]. Further effects on public budget include

[13] To determine the net effect on the public budget, costs must also be taken into account. For policy measures to increase energy efficiency that are financed from the public budget, these typically consist of programme costs including financial incentives as well as administrative and labour costs. In addition, the assessment of the net impact on the public budget must take into account the lower energy

reduced public health spending and decreasing external costs for environmental degradation (e.g., soil, climate change adaptation), yet these effects are not considered within this indicator to avoid double counting and since it is unclear whether these costs would always be covered by the state.

3.5 Inclusion of MICAT indicators in the Cost-Benefit Analysis

Table 7 includes all impacts monetised in MICAT and shows which of them can be taken into account in the CBA without double counting any effects. It is expected that 8-13 indicators can be included in total in the CBA performed in the MICATool.

TABLE 7: MONETISED INDICATORS IN MICAT AND POSSIBILITY TO INCLUDE INTO CBA

Indicator code	Monetised Impact indicator	Inclusion in CBA?	Reason
SoI-1	Alleviation of energy poverty	No	Overlaps with energy savings and public budget indicator → double counting
SoI-4.1	Reduced or avoided excess cold weather mortality	Yes	No risk of double counting with other MI indicators since macroeconomic impacts will not be included in CBA
SoI-4.2	Avoided asthma cases due to the reduced exposure to indoor dampness	Yes	No risk of double counting with other MI indicators since macroeconomic impacts will not be included in CBA
SoI-5.1	Air pollution-related mortality	Yes	No risk of double counting with other MI indicators since macroeconomic impacts will not be included in CBA
SoI-5.2	Air pollution-related morbidity	Yes	No risk of double counting with other MI indicators since macroeconomic impacts will not be included in CBA
EcI-1	Impact on GDP, and other macro-economic indicators (investment, consumption)	No	Overlaps with several other MI indicators (e.g., energy cost savings, investment, productivity, competitiveness, health) → stand-alone indicator not included into CBA
EcI-3	Impact on public budget	No	Merely covering additional taxation effects, not revenue or turnover. Financial transfers not considered in CBA from societal perspective (see Ch. 2.3) → stand-alone indicator not included in CBA

tax revenues for the government due to declining energy sales and the higher tax revenues from technology sales (cf. Suerkemper et al. 2016).

EcI-5	ETS effect	Possibly	No risk of double-counting, since ETS and ESR do not relate in any way to the coverage of environmental damages caused by pollution, as does EnI-4. A carbon price/value can be used in the CBA to evaluate, Tbd whether it will be the ETS carbon price.
EcI-9	Asset value of commercial buildings (with possible extension to private households)	Yes	No risk of double counting with other MI indicators since macroeconomic impacts will not be included in CBA
EcI-11	Turnover of energy efficiency goods	No	Double counting due to overlaps with investment cost (EcI-10)
EcI-14	Import dependency	Possibly	Can be included in CBA if possible to monetise. However, no risk of double-counting.
EcI-15	Aggregated energy security (supplier diversity)	Possibly	Risk of double counting with EnI-1 due to internalisation in energy costs
EcI-16	Impact on integration of renewables (demand-response potentials	Yes	No risk of double-counting
EcI-17	Avoided investments in grid and capacity expansion due to lower energy demand	Possibly	Risk of double counting due to partial overlaps with avoided energy costs from societal perspective → inclusion in CBA only if EnI-1 will not be included
EnI-1	Energy (cost) savings	Yes	Primary benefit of investment into energy efficiency → included in CBA
EnI-2	Savings on material resources (and sub-indicators)	Possibly partially	Double counting due to overlaps with investment cost (production phase) and energy cost savings (use phase) → direct benefits not included into CBA; external costs to society and/or end-of-life costs (disposal and recycling costs) may be included if quantifiable and not captured in market prices
EnI-4	GHG savings (savings of direct carbon emissions)	Yes	No risk of double counting → included in CBA

4. Operationalisation of the Cost-Benefit Analysis in MICAT

This chapter presents the methodological framework for performing a comprehensive Cost-Benefit Analysis (CBA) in MICAT and serves to operationalise the CBA in the MICATool. First, basic framework data needed for the calculation of a CBA is discussed and values to be used in MICAT are proposed. This includes data inputs for discounting future benefits (discount rates and lifetimes of EEI actions) and basic energy-related benefits and costs. Second, the calculation methods of a range of cost-benefit indicators are presented that may be calculated in the online tool.

4.1 Discount rates and their use in MICAT

Theoretical background

The level of discount rates used in CBA has a strong impact on the evaluation outcome. The higher the discount rate used, the lower the value assigned to future impacts, thereby reducing the net present value of energy-efficiency interventions (eceee & Ecofys 2015). In other words, a positive discount rate assigns a preference for current over future impacts (Sartori et al. 2015). The discount rate also has an effect of the quantification of costs if the CBA is calculated on annual basis (if costs and benefits stay constant over time in real terms). In this case annualised investment costs are compared with annual benefits, where the discount rate takes the role of discounting future payments by converting upfront investment into equal annual instalments over the lifetime.

Basically, two types of discount rates can be distinguished: social and private (end-user/investor) discount rates.[14] Depending on the evaluation perspective assessed, the respective discount rate will have to be used.

A discount rate from the end-user/investor perspective is oriented on private returns/alternative investment opportunities. The discount rate should reflect the opportunity costs of invested capital for the individuum or company doing the investment. From the end-user/investor perspective a market discount rate is therefore typically used in CBA reflecting the (weighted average) cost of capital (EC 2021).

In contrast, in CBA from the societal perspective (assessing costs and benefits of policies for the society rather than for individuals), as carried out in MICAT, a "social" discount rate should be applied, which is lower than private lending rates. This results in a higher net present value, i.e. energy efficiency investments become more cost-effective. As a proxy for the societal discount rate, the interest rate on long-term (e.g., 10 year) public bonds may be used. For short- and medium-term periods up to 20 years the real market discount rate for risk-averse investments may for example be suitable for societal evaluations (UBA 2007).

Which values to use in MICAT?

Within the MICAT project, the consortium will need to find reasonable assumptions on social discount rates. The objective of MICAT is not to model decision making of investors on different technology options. For this

[14] Assuming a perfectly competitive economy and under equilibrium, the social discount rate would be the same as the financial discount rate, i.e., both would correspond to the interest rate of the financial market. However, in practice this assumption does not hold since capital markets are distorted (Sartori et al. 2015).

reason, discount rates do not and need not reflect time preferences of investors, any (non-economic) barriers and bounded rationality of decision making[15], as is often the approach for the use of implicit/subjective discount rates, which are thus much higher (e.g., discount rates used in PRIMES or the BRISKEE project[16]).

Discount rates used in MICAT should, however, reflect opportunity costs. Since the selection of a suitable discount rate will depend on specific use cases and framework conditions (scenario or policy assessed, country, sector, etc.), considering a range of discount rates is in general recommended in MICAT. This will help the tool user to assess the sensitivity and robustness of the results to the assumed discount rate[17]. In the MICATool this could either be implemented by allowing the user to freely enter a discount rate value when performing a CBA or by providing a set of different default discount rates the user can select.

Table 8 compares the level of social discount rates suggested in different energy studies. The findings of these studies help to set a default discount rate value (e.g., of 2 or 3%) and possibly define upper and lower limits in the MICAT tool.

[15] E.g., split incentives between landlords and tenants, risk aversion, short time horizons in decision-making, information asymmetries.

[16] https://www.briskee-cheetah.eu/briskee/

[17] The better regulation toolbox of the European Commission also stresses the need for sensitivity by applying alternative higher and lower discount rates (up to +/-1% at least) than the proposed central value to assess the robustness of the results and for assuring transparency (European Commission 2021a).

TABLE 8: REVIEW OF SOCIAL DISCOUNT RATES IN ENERGY ASSESSMENTS

Source	Social discount rate
Steinbach, Jan; Staniaszek, Dan (2015). Discount rates in energy systems analysis. Diskussion Paper. Fraunhofer ISI and Buildings Performance Institute Europe (BPIE).	1% – 7%
eceee & Ecofys (2015): Evaluating our future. The crucial role of discount rates in European Commission energy system modelling.	4%
Agora Energiewende (2019). Building sector Efficiency: A crucial Component of the Energy Transition Final report on a study conducted by Institut für Energie- und Umweltforschung Heidelberg (Ifeu), Fraunhofer IEE and Consentec.	1.5%
Santori et al. (2015): Guide to Cost-Benefit Analysis of Investment Projects. Economic appraisal tool for Cohesion Policy 2014-2020, European Commission.	5% (Cohesion countries) 3% (other EU Member States)
Santori et al. (2021): Economic Appraisal Vademecum 2021-2027, General Principles and Sector Applications, DG REGIO, European Commission.	Projects 2021–2027: Member States are free to establish and use their own country-specific social discount rate; 3% can be used in the absence of a national approach
European Commission (2021b): Better Regulation Toolbox – November 2021 edition	3%

4.2 Lifetimes of energy efficiency improvement actions and their use in MICAT

In order to discount future benefits and costs in a CBA, it is necessary to define lifetimes of EEI actions. The period of time, in which energy savings occur, has a major effect on the cost-effectiveness. If a longer (shorter) saving period of an energy efficiency technology than in reality was used, the calculated cost-effectiveness would increase (decrease). With respect to the quantification of MI typically the assumption is taken in CBA that the MI accrue over the full lifetime of EEI actions.

In 2007, the European Committee for Standardization (CEN) established a methodology for the definition of average lifetimes for several common EEI actions and derived harmonised lifetime values (CEN 2007). The saving period of EEI actions lasts from the first year of implementation until the year when the EEI action stops to perform. In cases where it has not been possible to agree on an EU standard value, CEN provided conservative estimates for EEI actions instead (default saving lifetimes).

In 2019, the European Commission published an ANNEX to Commission Recommendation on transposing the energy savings obligations under the Energy Efficiency Directive (EED). This ANNEX to the EED contains in APPENDIX VIII also a list with indicative energy savings lifetimes for the most relevant energy efficiency measures in buildings, services, transport and industry that can be used by Member States for their reporting requirements (EC 2019).[18] The indicative lifetime values in the list are based on the previous work of CEN (2007) and EC (2019).

The lifetime values developed by CEN (2007) and (EC 2019) are depicted in Table 12 in the ANNEX. The two lists partly differ with respect to the EEI actions considered, the length of the lifetimes and the level of detail of EEI actions. For example, the list of EC (2019) differentiates air-to-air, air-to-water and geothermal heat pumps in regard to their lifetimes, whereas CEN (2007) includes only one average lifetime value for heat pumps. Outdated technologies are replaced by more up-to-date measures in the European Commission's list (EC 2019), e.g., in the case of efficient light bulbs, lifetimes are provided for LEDs instead of CFLs.

In MICAT end-uses are assessed that bundle different EEI actions. Since these are a mix of various technologies with varying lifetimes, an average lifetime must therefore be determined for the CBA. Based on the lifetimes

[18] https://ec.europa.eu/energy/sites/ener/files/documents/c_2019_6621_-_annex_com_recom_energy_savings.pdf

of CEN (2007) and EC (2019), plausible lifetimes values are derived for the specific EEI actions analysed in MICAT. The lifetimes will be set as default in the MICATool to carry out the CBA. However, they can be adapted (up or down) by the users according to their needs. The provisional list of EEI actions specified for MICAT and the proposed (default) saving lifetimes specified are shown in Table 9.

TABLE 9: ENERGY SAVING LIFETIMES FOR EEI ACTIONS EVALUATED IN MICAT

EEI actions defined for MICAT		
EEI action		**Default saving lifetime [years]**
Households		
Construction of new EE dwellings and building retrofitting (windows, insulation, etc)		25
Heating fuel switch (including the change to district heating)		20
Energy-efficient heating (Boilers, pipe insulation, heaters)		20
Electric appliances (wet & cold appliances, electric AC, lighting, consumer electronics)		15
Lighting		15
Behavioural changes (temperature changes)		2
Commercial / Public / Industrial buildings		
Construction of new EE buildings and building retrofitting (windows, insulation, etc)		25
Heating fuel switch (including the change to district heating)		20
Energy-efficient heating (Boilers, DH, pipe insulation, heaters)		20
Electric appliances (wet & cold appliances, electric AC, lighting, consumer electronics)		10
Lighting		12
Organisational / behavioural changes (temperature changes)		2
Agriculture		
Process-specific savings (incl. waste-heat recovery)		To be specified
Fuel switch in existing processes (change in machinery, not in process)		To be specified
Transport		
Consumption reduction of vehicles (low-resistance tyres, side-boards on trucks, etc)		Trucks: 100,000 km (5 years) Cars: 50,000 km (5 years)
Modal shift (Freight/passenger)		2
Behavioural / driving changes (e.g., due to speed limits)		2
Efficient vehicles		100,000 km (10 years)
Fuel additives		2
Industry		
Energy-efficient electric cross-cutting technologies		8
• Iron & steel • Chemical & petrochemical • Non-ferrous metals • Non-metallic minerals	Process change (fundamental changes to processes, e.g., blast furnaces, gas to hydrogen)	To be specified

• Transport equipment • Machinery • Mining & quarrying • Food, beverages & tobacco • Paper, pulp & printing • Wood & wood products • Construction • Textile & leather • Not elsewhere specified (industry)	Fuel switch in existing processes (change in machinery, not in process)	To be specified
	Process-specific savings (incl. waste-heat recovery)	To be specified

4.3 Operationalisation of direct energy benefits and costs in the MICAT CBA

Basic energy-related benefits and costs are essential inputs to a CBA. These are shown in Table 10 and include energy savings, energy prices, energy cost savings and (incremental) investment costs of EEI actions. Their operationalisation and use partly differs depending on the evaluation perspective. From a societal perspective, in particular, taxes and levies need to be deducted from final consumer energy prices and investment costs of EEI actions since they represent transfer payments that are not relevant for overall social welfare.

Energy savings will have to be calculated both in annual and lifetime values to be able to perform a CBA. Therefore, EEI action-specific lifetimes need to be derived (cf. Chapter 4.2). In addition, in ex-ante evaluations energy cost savings resulting from energy savings and prices need to be based on energy price forecasts.

The disaggregation level shown in Table 10 is probably necessary for the quantification of the range of MI in MICAT. All (disaggregated) values of the benefit and cost items will be inputs for the quantification of MI and have to be included in the final consolidated data base for use in the online tool.

TABLE 10: MICAT ENERGY BENEFITS AND COSTS

Benefit/cost component	disaggregation level	Differentiation by evaluation perspective	
		end-user/investor	**society** (→ MICAT approach)
Input: energy savings	by EEI action, energy carrier, country, sector	-	**-**
Input: energy prices	by energy carrier, country, sector	gross (incl. taxes, final consumer prices)	**net (final consumer prices excl. taxes)**
Energy cost savings = energy savings * energy prices	by EEI action, energy carrier, country, sector	gross (incl. taxes, energy cost savings for final consumer)	**net (energy cost savings excl. taxes)**
(Incremental) investment costs of EEI actions	by EEI action, country	gross (incl. taxes, final consumer prices)	**net (excl. taxes)**

4.4 CBA indicator options

A variety of cost-benefit indicators can be calculated in the online tool, including net present value (lifetime and annualised), cost-benefit and benefit-cost ratios and levelised cost of energy and GHG emissions saved. The latter indicator can also be used to construct marginal cost curves. A prerequisite for the calculation is that only monetisable and summable impacts can be included in the below-discussed CBA indicators. Otherwise, they cannot be aggregated and compared to the investment costs. They have also in common that suitable discount rates and lifetimes of EEI actions have to be specified. Each CBA indicator option is not perfect, i.e., has different shortcomings, advantages and challenges in its calculation.

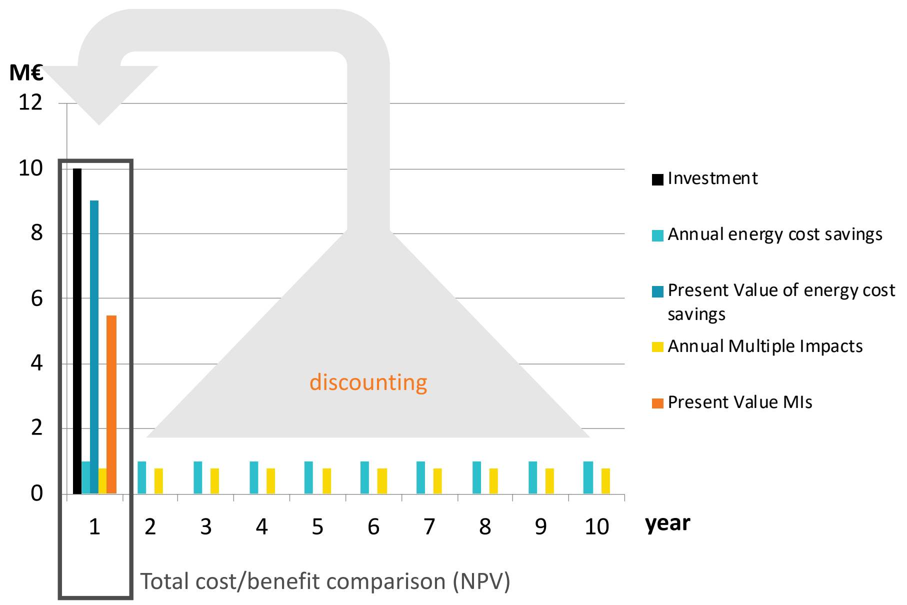
There are two principal approaches of how a CBA of energy efficiency interventions is calculated: Either to calculate the net present value (NPV) over the lifetime of EEI actions or to compare annualised values of investment with annual energy (cost) savings and annual MIs. Both indicators consider the lifetime of EEI actions and calculate discounted cash flows. Table 11 lists the variables and indices used in the following CBA formulas.

TABLE 11: VARIABLES AND INDICES IN CBA FORMULA

Variables and Indices	description
a	action (energy efficiency improvement action)
A	annuity [€]
BCR / CBR	benefit-cost ratio (BCR) / cost-benefit ratio (CBR)
C_a	annual costs (e.g., operation and maintenance (O&M) costs) [€]
CR_a	GHG emission reductions (per action) (t CO2eq)
CRF_a	Capital Recovery Factor (per action)
E_a	energy savings (per action) [MWh]
FE	funding efficiency [MWh/€ or t CO2eq/€]
FI	financial incentives [€]
i	discount rate [%]
I_a	investment cost (per EEI action) [€]
LCSE	levelised costs of saved energy [€/kWh]
LE	leverage effect
MI_a	(monetised) multiple impacts (per action) [€]
NPV	net present value [€]
PC	programme costs (financial incentives and administration costs) [€]
PVF_a	Present Value Factor (per action) (for calculating the present value of a stream of impacts, based on EEI action lifetime and discount rate)
S_a	energy cost savings (per action) [€]
t_a	lifetime (per action) [years]

Net Present Value (NPV)

When calculating the net present value (NPV) the upfront investment cost is compared to the future benefits (and possibly costs) that are discounted to today. In other words, all negative and positive values (the costs and benefits) are discounted and then aggregated in order to calculate the net total effect. The NPV corresponds to the difference of discounted total costs and benefits and is expressed in monetary terms. The basic calculation approach is illustrated in Figure 4.



Source: adapted from Thema and Suerkemper (2018)

FIGURE 4: SCHEMATIC ILLUSTRATION OF AN EXPANDED CBA INCLUDING MULTIPLE IMPACTS

Discounting is necessary as energy efficiency investments involve substantial upfront costs but the energy cost savings and wider benefits accrue in future years and less value is typically assigned to impacts occurring in the future. The value of the applied discount rate and the choice of the lifetimes of the EEI actions thus have a significant impact on the NPV of the intervention analysed (Sartori et al. 2015).

A NPV larger than 0 indicates that the intervention generates a net benefit to society or the end-user/investor (depending on the evaluation perspective analysed) as the future benefits outweigh the costs of the interventions. The NPV is expressed in absolute monetary terms (€) and is thus a suitable indicator to compare and rank different options in absolute terms[19] and to select the most cost-effective alternative (Sartori et al. 2015). The NPV can be expressed in the following formula where I_a are initial (incremental) investments for the EEI action, $EC_{a,t}$, $MI_{a,t}$ and $C_{a,t}$ are the energy cost savings, aggregated multiple impacts and (potential) annual costs[20] for a specific EEI action in a given year t over the lifetime of n years (starting in year 0), and i is the discount rate:[21]

$$NPV_a = -I_a + \sum_{t=0}^{n} \frac{EC_{a,t} + MI_{a,t} - C_{a,t}}{(1+i)^{t_a}}$$

When impacts EC_a, MI_a and C_a are assumed to be constant annual values during the action lifetime, the NPV can be calculated in a more simplified manner. Then, annual values can simply be multiplied with a present value factor (PVF) and compared to the upfront investment cost. The simplified version of the NPV formula can be written as:

$$NPV_a = -I_a + (EC_a + MI_a - C_a) \times PVF_a$$

where $PVF_a = \frac{(1+i)^{t_a} - 1}{i(1+i)^{t_a}}$

[19] The larger the difference between the present value of the benefits and costs, the better.

[20] Annual costs are typically operation and maintenance (O&M) costs of the respective EEI action. They are however often neglected in the NPV calculation, since the cost-effectiveness is assessed in comparison to a reference situation, and thus only incremental (additional) costs have to be taken into account. Since O&M costs of the EEI action and the reference technology in many cases do not differ substantially, it is reasonable to assume that they cancel-out and neglect them in the NPV calculation.

[21] Benefits that occur only in one specific year (e.g., as a direct result of the investment made in t=0) can be distributed over the lifetime by calculating the equivalent constant annuity (one-time impact multiplied by a capital recovery factor (CRF)).

Annuity

A variant of the NPV is to calculate annuities. The calculation is based on the same input parameters (discount rates and lifetimes) as the NPV. The upfront investment cost of EEI actions is transformed (taking into account lifetime and discount rate) into equal annual instalments ("annuities") over the lifetime of EEI actions. This is done by multiplying the upfront investment with a capital recovery factor (CRF). The cost-effectiveness is determined by comparing the annuity of upfront investment with the sum of average annual energy cost savings and MI (net of potential annual costs). The calculation of annuities is particularly suitable when the energy cost savings and benefits are available in constant annual values. In this case the calculation and results are mathematically identical with the NPV calculation. If annual cost savings and wider benefits vary however over the lifetime, the NPV needs to be calculated. The annuity formula can be written as:

$$A_a = -I_a \times CRF_a + (EC_a + MI_a - C_a)$$

where $CRF_a = \frac{i(1+i)^{ta}}{(1+i)^{ta}-1}$

Benefit-Cost Ratio & Cost-Benefit Ratio (BCR & CBR)

Other indicator options are benefit-cost ratio (BCR) or cost-benefit Ratio (CBR). The BCR corresponds to the ratio of the stream of discounted benefits and discounted costs. The calculation can either be based on lifetime present values or annuities (formula below for lifetime present value). A BCR larger than one indicates that an investment in energy efficiency is cost-effective, i.e. that benefits outweigh costs.

$$BCR_a = [(EC_a + MI_a) \times PVF_a] \div [C_a \times PVF_a + I_a]$$

$$CBR_a = (BCR_a)^{-1}$$

A disadvantage is that the BCR is sensitive to the classification of the impacts as benefits rather than costs. This is problematic for impacts that can either be treated as benefits or as avoided costs and the converse. Treating a benefit as a cost reduction rather than a positive effect would result in only an artificial improvement of the BCR as the indicator rewards projects with low costs (Santori et al. 2015).

Levelised cost of saved energy (LCSE)

An alternative to the indicators above (NPV and annuity) in absolute monetary terms (€) is to express the results per unit energy (in €/kWh) or CO_2 (in €/tCO_2) saved or per other X indicators. This indicator is called levelised cost of saved energy (LCSE) or levelised cost of conserved energy (LCCE). The calculation of LCSE can either be based on NPV or annuities (below shown for annuity) and divides this quantity by the annual or lifetime energy savings E. Both calculation approaches lead to exactly the same values in terms of €/kWh if the annual energy cost savings and benefits included are constant values (equivalent from a mathematical point of view) (eceee & Ecofys 2015).

$$LCSE_a = \frac{A_a}{E_a}$$

where $A_a = -I_a \times CRF_a + (EC_a + MI_a - C_a)$

Alternative: instead of per saved energy, also per other X indicators:

$$LCSE_a = \frac{A_a}{x_a}$$

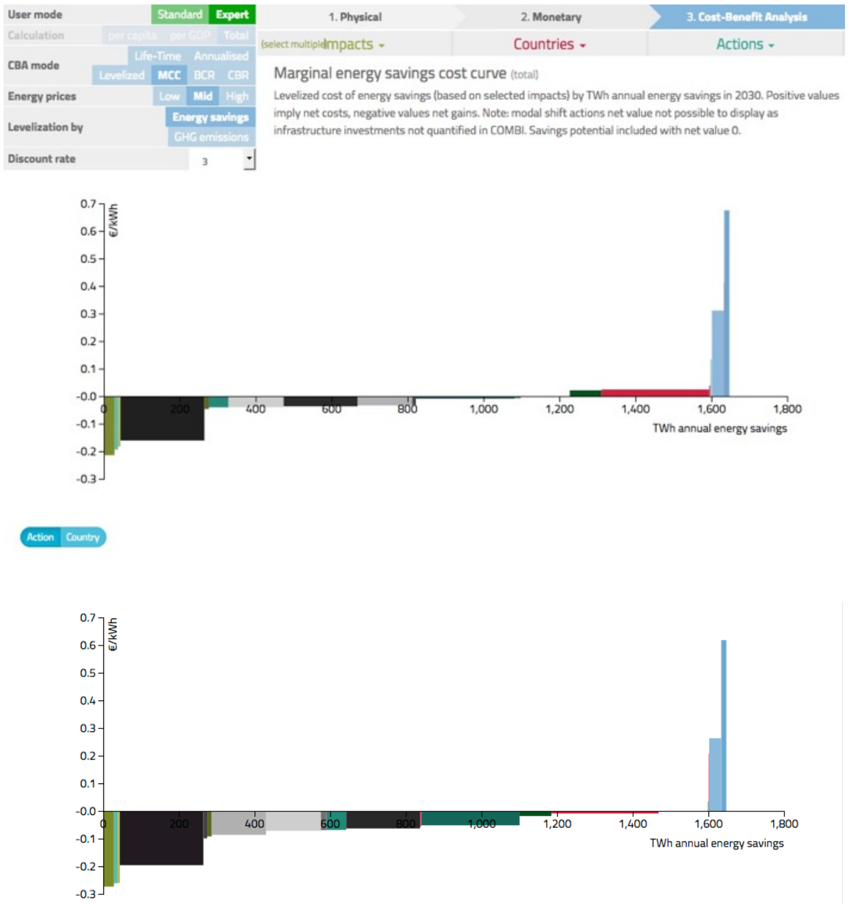
with x being an indicator out of x = 1, … , X indicators like CO_2 reduction, PM emissions, NOx emissions, t material footprint

The concept of LCSE is particularly useful to compare the cost-effectiveness of different EEI actions or for comparing the cost of a unit of energy saved due to energy efficiency investments with the costs of different energy supply options per kWh. The concept is also typically used to operationalise the EE1st principle. LCSE is also the metric that is used for the calculation of marginal cost curves (see next section).

Marginal cost curves

LCSE are the basis for the construction of marginal cost curves. These are usually presented as marginal energy savings cost curve or marginal greenhouse gas abatement cost curve. Marginal cost curves are a combination of LCSE (levelized by total kWh or tCO2eq) for the height of bars and the total energy/GHG savings of the individual EEI actions for the width of bars. By ranking EEI actions by net marginal cost, a marginal cost curve can be derived. The most cost-effective values (highest net benefits) are shown at the left side, the least cost-effective values at the right side. The width of the bars shows the amount of energy or GHG savings of EEI actions assessed (Thema 2018).

Figure 5 shows the marginal cost curves derived in the COMBI project excluding (upper curve) and including the MI. It shows that almost all EEI actions included become cost-effective if MI are considered (except for cold appliances in residential buildings and two wheelers in passenger transport) (Thema et al. n.d.).



Source: *Thema et al. (n.d.)*

FIGURE 5: COMBI MARGINAL ENERGY COST CURVES BY EEI ACTION FOR EU28 IN 2030 (EXCLUDING AND INCLUDING MULTIPLE IMPACTS)

4.5 Indicators to analyse funding efficiency of policy measures

The objective of MICAT is to evaluate the MI of (1) scenarios and (2) policy measures promoting EEI actions. The latter include funding programmes that aim at incentivising energy efficiency investments by providing financial incentives to end-users/investors. The incentive payment is usually linked to the achievement of a certain (certified) level of energy efficiency and serves the primary purpose of improving the cost-effectiveness of the measure from the end-user's/investor's point of view. The end-user/investor typically receives a subsidy – either in the form of a direct financial grant or soft loan, i.e. with a subsidised interest rate[22].

The cost-effectiveness of funding programmes can be assessed with different performance indicators measuring the effectiveness of subsidies provided. Since financial incentives are not included in a CBA from a societal perspective (cf. Section 2.3), these indicators provide relevant, additional information in MICAT. The results may allow for a comparison of the effectiveness of different funding programmes and can support economical housekeeping on the federal budget (Reineck et al. 2020). A prerequisite for calculating these indicators in the MICAT online tool is that the costs of the programme to be evaluated (volume of the public funding provided and administration costs) are known to the tool user (i.e. costs are quantifiable on the basis of real data or at least approximately estimable) and can be entered in the input mask of the online tool.

Funding efficiency

The indicator *funding efficiency* (FE) represents the relationship between the energy savings or the CO_2 emission reductions achieved and the programme costs. The programme costs typically include both the subsidies provided for grants and low-interest loans to end-users / investors and the administrative costs of the policy measure (cf. Fraunhofer ISI et al. 2020). If the latter are not available and cannot be estimated, only the subsidies

[22] A subsidised interest rate can be translated into a monetary benefit in the sense of a grant to consider it in the indicator quantification.

can be considered. This should be presented transparently. In general, the adjusted (net) energy and GHG savings over the lifetime are used to calculate the funding efficiency. The criterium answers the questions “How much public funding was provided (ex-post) or is needed (ex-ante) to save one MWh of final energy or one tonne of GHG emissions?”. The indicators to operationalise funding efficiency are energy savings per Euro spent (MWh/€) and GHG emissions reductions per Euro spent (t CO2eq/€). The formulas for these indicators can be written as

$FE_E = \frac{\sum_{t=0}^{n} E}{PC}$ and $FE_{\text{CO2eq}} = \frac{\sum_{t=0}^{n} CR}{PC}$

where FE is funding efficiency, E annual energy savings in a given year t, CR annual CO2eq emission reduction in a given year t and PC the total programme costs (financial incentives and administration costs) of the policy measure.

When savings E and CR are assumed to be constant annual values during the lifetime of EEI actions promoted by the policy measure, the funding efficiency can be calculated in a more simplified manner. Then, annual values E and CR can be multiplied with the lifetime t of the EEI actions and compared to the programme costs. The simplified version can be written as:

$$FE_E = \frac{t \times E}{PC}$$

$$FE_{\text{CO2eq}} = \frac{t \times CR}{PC}$$

Leverage effect

The *leverage effect* (LE) puts the financial incentives and the investments in relation to each other. Administrative costs of the policy measure are not included in this indicator. The leverage effect indicates how many euros of investments were triggered per Euro (public) funding provided (total Euros invested per Euro provided by public funding). The indicator therefore has no unit (€/€). It is important to note that only those investments are taken into account in the leverage effect that were actually funded (Fraunhofer ISI et al. 2020). The financial leverage effect can be calculated as follows, where LE is the leverage effect, I the induced investments funded and FI the total financial incentives (public funding) provided to beneficiaries.

$$LE = \frac{I}{FI}$$

5. Summary of key features of the Cost-Benefit Analysis in the MICAT online tool

5.1 Cost-Benefit Analysis from societal perspective

In MICAT, the CBA is performed from a societal perspective, as this evaluation perspective is most relevant for the main target groups of MICAT: policy makers, regulators and other decision makers from public institutions. A CBA from a societal perspective is also in line with the MI quantified in MICAT (all impacts analysed are relevant to society). The CBA implemented in MICAT can also be useful for the operationalisation of the energy efficiency first principle, which should be implemented primarily from a societal perspective (i.e. not just from an end-user/investor perspective) and requires taking into account the MI of energy efficiency for society (European Commission 2021a).

The societal perspective has implications for the discount rate to be applied in the CBA. A social discount rate has to be used in the CBA that is typically lower than a market discount rate applied from a private perspective and lower than (implicit/subjective) discount rates, which are used in modelling of individual investment decisions (European Commission 2021a). A social discount rate is thus suggested in the MICAT online tool as a default. The rate can be adjusted (up or down) by the user of the tool according to the purpose of the evaluation. The level of the social discount rate to be applied will depend on specific use cases and framework conditions (scenario or policy assessed, country, sector, etc.).

Furthermore, the implementation of a CBA from a societal perspective has implications in terms of the choice of cost and benefit components included in the analysis. While all MI quantified in MICAT are relevant from a societal perspective, taxes and other financial transfers (including subsidies/ incentive payments to programme beneficiaries) are not taken into account in the CBA. These represent transfer payments between different societal groups without an effect on overall social welfare.

5.2 Inclusion of MICAT indicators into CBA

The impact indicators quantified in MICAT must fulfil two conditions in order to be considered in the CBA: Firstly, they must be available in monetary values and secondly, they must not overlap with other impacts considered in the CBA, so that no double counting takes place and thus the result is not overestimated. The following indicators are expected to fulfil these two conditions:

- Reduced or avoided excess cold weather mortality
- Avoided asthma cases due to the reduced exposure to indoor dampness
- Air pollution-related mortality
- Air pollution-related morbidity
- ETS price effect (possibly)
- Asset value of commercial buildings (with possible extension to private households)
- Import dependency (possibly)
- Aggregated energy security (supplier diversity) (possibly)
- Impact on integration of renewables (demand-response potentials)

- Avoided investments in grid and capacity expansion due to lower energy demand (possibly)
- Energy (cost) savings
- Savings on material resources (and sub-indicators) (possibly partially)
- GHG savings (savings of direct carbon emissions)

Users of the online tool are able to select either all or only some of these indicators for the CBA, depending on their interest and the policy measure being assessed. Indicators that are available in monetary values, but do not fulfil the second condition, are presented as stand-alone indicators (e.g., macroeconomic indicators such as GDP and public budget). In the monetary mode of the tool, where no aggregation takes place, all impacts monetised by MICAT can be displayed.

5.3 Cost-benefit indicators

MICAT online tool users will have the opportunity to calculate a range of cost-benefit indicators such as net present value and annuities (expressed in €), cost-benefit and benefit-cost ratios (no unit) and levelised cost of energy (€/kWh) and GHG emissions saved (€/tCO_2). These CBA indicators have in common that suitable discount rates and lifetimes of EEI actions have to be specified in order to calculate discounted lifetime present values of future energy cost savings and multiple benefits and compare them with initial investment costs. At present, it is also planned to calculate and visualise marginal cost curves (with and without MI in the online tool. The prerequisite for the calculation of marginal cost curves is that a bundle of different EEI actions is assessed for which individual savings potentials and investment costs are available.

For the evaluation of policy measures that incentivise energy efficiency investments through the provision of public funds, it is planned that users of the online tool can calculate additional indicators that measure the effectiveness of subsidies. The indicator *funding efficiency* shows how much public funding was provided or is needed to save one MWh of final energy or one tonne of GHG emissions. The *leverage effect* indicates how many euros of investments were induced per Euro (public) funds provided.

5.4 Sensitivity analysis in CBA

MICAT quantification results of individual impacts are generally point estimates resulting from impact factors or functions derived mostly from modelling exercises. Monetisation of physical values is done for the majority of indicators by applying monetisation factors. By nature, numerous assumptions are taken in such impact quantifications, most of them are laid down in the respective indicator factsheets (D2.3-2.5). MICAT includes different options for users of the online tool to directly test CBA results for sensitivity:

- A default social discount rate is given in the online tool, which can be adjusted by the users for the purpose of sensitivity testing.
- Users of the online tool can adjust the energy price levels proposed as default, directly entering the calculation of energy cost savings.
- Default saving lifetimes for EEI actions are provided in the online tool, which can be adjusted by the users according to their needs.
- Monetisation factors of some impacts can be adjusted by the tool users. Default monetisation values are, however, proposed in the tool.

- Tool users can select the impacts to be included in the CBA, provided that they are a) expressed in monetary terms and b) not affected from potential double-counting in order to avoid overestimations.

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ANNEX

TABLE 12: ENERGY SAVING LIFETIMES FOR COMMONLY APPLIED EEI ACTIONS

CEN (2007			EC (2019)	
EEI action	Harmonised saving lifetime (years)	Default saving lifetime (years)	EEI action	Indicative lifetimes (years)
Households			**Buildings (residential sector)**	
Insulation: building envelope	>25		Energy-efficient construction	>25
Draught proofing		5	Insulation of building envelope (cavity wall, solid wall, loft, roof, floor)	>25
Windows/glazing	24		Windows/glazing	>25
Replace of hot water storage tank	15		Insulation of hot-water pipes	20
Insulation of hot water pipes	>25		New/upgraded district heating	20
Heat reflecting radiator panels	18		Heat-reflecting radiator panels (insulation material installed between radiators and the wall to reflect heat back into the room)	18
Small boilers	17		High-efficiency boilers (< 30 kW) 20	20
Large boilers		17	Heat-recovery systems	17
Heating control		5	Heat pump	air-to-air: 10 air-to-water: 15 geothermal: 25
Heat recovery systems	17		Circulating pump (heat distribution)	10
Hot water saving faucets	15		Efficient lightbulb (LED)	15
Heat pump (household)	17		Luminaire with ballast systems (lighting units with dedicated efficient lamp fittings)	15
Efficient chiller or room air conditioner	10		Efficient cold appliances	15
New/upgraded district heating	20		Efficient wet appliances	12
Solar water heating	19		Hot-water-saving taps with flow restrictors	15
Efficient cold appliances	15		Hot-water tank with insulation	15
Efficient wet appliances	12		Efficient chiller or room air-conditioner	10
Consumer electronic goods	3		Hydraulic balancing of heating distribution (for central heating systems)	10
Efficient bulbs CFL		(6000h)	Heating control	5
Luminaire with ballast systems	15		Draughtproofing (material to fill gaps around doors, windows, etc. to increase	5

			the airtightness of buildings)	
Energy efficient architecture	>25		Consumer electronic goods	3
Micro-CHP		8		
PV-panels	23			
Hydraulic balancing of heating	10			
Electricity saving		2		
Heat saving		2		
Feedback on use from smart meters		2		
Commercial / Public sector			**Services**	
Windows/glazing	24		Energy-efficient construction	>25
Insulation: building envelope	>25		Insulation of building envelope (cavity wall, solid wall, loft, roof, floor)	>25
Heat recovery systems	17		Windows/glazing	>25
Energy efficient architecture	>25		Boilers (> 30 kW)	25
Heat pumps (commercial sector)	20		Heat pumps	air-to-air: 10 air-to-water: 15 geothermal: 25
Efficient chillers in AC	17		Heat-recovery systems	17
Efficient ventilation systems	15		Efficient central air-conditioning and chillers	17
Commercial refrigeration		8	Efficient ventilation systems	15
Energy efficient office appliances		3	Public/street lighting systems	13
Combined heat and power		8	New/renovated office lighting	12
Motion detection light controls	10		Commercial refrigeration	8
New/renovated office lighting	12		Motion-detection light controls	10
Public lighting systems	13		Energy-efficient office appliances	3
EMS (monitoring, ISO)		2	Energy management systems (cf. ISO 50001)	2
Transport			**Transport**	
Efficient vehicles		100,000 km	Efficient vehicles	100,000 km
Low resistance tyres for cars		50,000 km	Low-resistance tyres for cars	50,000 km
Low resistance tyres for trucks		100,000 km	Low-resistance tyres for trucks	100,000 km
Side boards on trucks		500,000 km	Side-boards on trucks (aerodynamic additions for heavy goods vehicles)	50,000 km
Tyre pressure control on trucks		500,000 km	Tyre-pressure control on trucks (automatic tyre-pressure monitoring devices)	50,000 km
Fuel additives		2	Fuel additives	2
Modal shift		2	Modal shift	2
Econometer		2		
Optimal tyre pressure		1		

Efficient driving style		2		
Industry (not part of emission trading)			**Industry**	
Combined heat and power		8	Combined heat and power (CHP)	10
Waste heat recovery		8	Waste-heat recovery	10
Efficient compressed air systems		8	Efficient compressed-air systems	10
Efficient electric motors/variable speed drives		8	Efficient electric motors/variable-speed drives	8
Efficient pumping systems		8	Efficient pumping systems	10
Good energy management and monitoring		2	Efficient ventilation system	10
			Energy management systems (cf. ISO 50001)	2

Sources: CEN (2007) and EC (2019)