Multiple Impacts Calculation Tool

Environmental Impacts

D2.5 Empirical basis of Environmental Impacts. Quantification/monetisation methodology and derived impact factors

Lead partner for Deliverable: IIASA

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Authors: Fabian Wagner, Gregor Kiesewetter (IIASA), Jens Teubler, Severin Hackspiel (WI), Frederic Berger (Fraunhofer ISI)

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MICAT
Multiple Impacts Calculation Tool

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1 INTRODUCTION

In the MICAT project Multiple Impacts (MI) of energy efficiency have been grouped into three overarching categories in line with the three pillars of sustainability (Purvis et al. 2019):

- Social impacts
- Economic impacts
- Environmental impacts

This deliverable contains the different indicators that will be analysed within MICAT in the category of **Environmental Impacts** (EnI) (see Table 1 below) and presents the indicator-specific quantification and monetisation methods used. Moreover, the report presents the impact factors/functions that are implemented within the MICATool in order to calculate the indicators in the environmental impact category and the respective data requirements.[1]

Environmental Impacts (EnI) covered in Task 2.5 involve two main impact categories:

Energy and Resource management

This category includes energy savings which, will be quantified by energy carrier and monetised as energy cost savings under the responsibility of Fraunhofer ISI. Energy savings are derived from scenario analysis or bottom-up evaluation of policies and are partly based on PRIMES.

Furthermore, this impact category contains material resource savings which are quantified by WI. This involves material flow accounting for abiotic and biotic materials that can be directly linked to the investments in energy efficiency technologies (production phase) as well as their usage (e.g., reduction of burned fossil fuels). Impacts (sum of all materials required to provide a service) are disaggregated along abiotic and biotic materials and include the consideration of primary materials (e.g., ores) and materials that were not put to an economic use (e.g., overburden from mining). The method material input per unit of service (MIPS) is used for this purpose which in turn is closely aligned with life-cycle assessment methods (in particular in terms of life-cycle inventories and the definition of functional units). Two types of monetisation approaches can be applied: Embodied costs can be based on market prices for processed raw materials and linked to the raw material demand (metals and fossil fuels), indirect material costs, which are externalised costs to society, monetised via future cost estimates provided by the eco-cost model.

Finally, the impacts of energy efficiency on (partial) achievement of renewables targets due to the reduction of gross final energy consumption, replacement of RES capacity and reduced need for interconnectors are assessed by Fraunhofer ISI. This impact is relevant since energy savings allow to reach RES targets more easily.

Global & Local Pollutants

This category involves on the one hand impacts directly linked to the input data as direct GHG/CO_2 emission reductions. The calculation of direct greenhouse gas emission reductions is based on emission factors for different fuel types listed in CO_2 equivalents per unit of energy.

It further groups impacts related to various outdoor air pollutants emissions from fuel combustion, transportation and other economic activities and their impacts on ecosystems. The impacts are quantified by applying the Greenhouse gas – Air pollution INteractions and Synergies (GAINS) model by IIASA. Monetisation of the benefit of reduced air pollution is performed via the human health indicators air pollution-related mortality and morbidity.

[1] The quantification of MI in MICAT is based on impacts factors or functions (IF) instead of single model runs due to the high flexibility required. The use of IF will allow to calculate the indicators for various dimensions, at different levels of disaggregation and an assessment of MI based on input data entered by tool users (open data entry in MICATool).

TABLE 1: MICAT INDICATORS IN CATEGORY ENVIRONMENTAL IMPACTS

EnI	Environmental impact indicators	Lead	Quantification methodology / unit
		Energy & Resource Management	
EnI-1	Energy (cost) savings	Fraunhofer, E3M	Energy savings derived from scenario analysis or bottom-up evaluation of policies Partly based on PRIMES Unit: MWh, ktoe
EnI-2	Savings on material resources	WI	Material Flow Accounting: Bottom-up modelling (cradle-to-gate) of material and energy flows; characterisation by intensity of primary materials Unit: tons, tons/GDP
EnI-2.1	*Reduction in overall material footprint*	WI	Sum of extracted abiotic (fossil fuels, metal ores, minerals) and biotic raw materials from nature, including the extraction of economic unused materials. Unit: tons, tons/GDP
EnI-2.2	*Life-Cycle wide fossil fuel consumption*	WI	Accounting of all raw materials from nature, that can be classified as fossil fuels and are put to an economic use. Unit: tons
EnI-2.3	*Metal ores*	WI	Accounting of all raw materials from nature that can be classified as metal ores and are put to an economic use. Unit: tons
EnI-2.4	*Minerals*	WI	Accounting of all raw materials from nature that can be classified as minerals and are put to an economic use. Unit: tons
EnI-2.5	*Biotic raw materials*	WI	Accounting of all raw materials from nature that can be classified as biotic raw materials and are put to an economic use. Unit: tons
EnI-2.6	*Unused extraction*	WI	Accounting of materials that are extracted from nature that are not translocated from site or put to an economic use. This includes overburden and by-catch as well as waste on site. Unit: tons
		Global & Local Pollutants	
EnI-3	Impacts on RES targets	Fraunhofer	Partial achievement of RES targets due to the reduction of gross final energy consumption; replacement of RES capacity; reduced need for interconnectors Unit: %
EnI-4	GHG savings (savings of direct carbon emissions)	Fraunhofer	Direct carbon emissions are based on emission factors for different fuel types. Values are listed in CO_2 equivalents per unit of energy. Unit: Mt CO2eq
EnI-5	Reduction in air pollution emissions	IIASA	GAINS model Outdoor air pollutants emissions from fuel combustion, transportation and other economic activities (SO2, PM2.5, NOx, NH3, NMVOC) Unit: tons

2 ENERGY (COST) SAVINGS

Author: Frederic Berger (Fraunhofer ISI)

Reviewer: Felix Suerkemper (Wuppertal Institute)

Executive Summary

This indicator describes the energy saved with the proposed measures. This is done for final and primary energy consumption, the latter taking the conversion processes necessary for the generation of hydrogen and synthetic fuels, electricity, and heat into account. In the course of the monetisation, the value of the saved fuels is assessed.

While the characterisation as a multiple impact rather than as the main impact can be debated, it is highly relevant to quantify it for a meaningful cost-benefit analysis.

This indicator has a high relevance at all governance levels, since the energy and accompanying cost savings are accruing at the implementation level. Thus, this results in low energy bills for their constituents, a major interest of all involved government levels.

This impact has several possible overlaps with other indicators, such as import dependency, material resources, avoided investments in grid and capacity expansion, and alleviation of energy poverty and equality. However, since it is the central indicator of energy efficiency, it will be the one to be monetised and the avoidance of double counting will be done in the course of monetising the other conflicting MI.

It is calculated by multiplying the savings from the different improvement actions with their respective fuel split allocation vector, resulting in the savings disaggregated by final energy carrier:

$$\Delta E_{c,ss,u,e,y} = \Delta E_{c,ss,u,y} \cdot \lambda_{c,ss,u,e,y} = \Delta E_{c,ss,u,y} \cdot \lambda_{c,ss,e,y} \cdot \chi_{c,ss,u,e}$$

In this equation, $\Delta E_{c,ss,u,y}$ describes the generated energy savings, $\lambda_{c,ss,u,e,y}$ the assumed relevant improvement action fuel mix, $\lambda_{c,ss,e,y}$ the (sub-)sectoral fuel mix, and $\chi_{c,ss,u,e}$ the assumed ratio between improvement action and (sub-)sectoral fuel mix vectors, issued from models, in this case PRIMES.

The indicator will be monetised using energy price data from Enerdata. These include taxes and differ between sectors. The energy cost savings $\xi\Delta E_{c,e,ss,u,y}$ are calculated using the following formula ($EP_{c,e,s,y}$ being the energy prices):

$$\xi\Delta E_{c,e,ss,u,y} = \Delta E_{c,e,ss,u,y} \cdot EP_{c,e,s,y}$$

This indicator can be aggregated with any monetised multiple impact representing a profit and not merely a turnover.

2.1 Scope of MI indicator

2.1.1 Definition

This indicator describes the energy saved with the proposed measures. This is done for final and primary energy consumption, the latter taking the conversion processes necessary for the generation of hydrogen and synthetic fuels, electricity, and heat into account. In the course of the monetisation, the value of the saved fuels is assessed.

While the characterisation as a multiple impact rather than as the main impact can be debated, it is highly relevant to quantify it for a meaningful cost-benefit analysis.

2.1.2 Relevance on EU, national and/or local level

This indicator has a high relevance at all governance levels, since the energy and accompanying cost savings are accruing at the implementation level. Thus, this results in low energy bills for their constituents, a major interest of all involved government levels.

2.1.3 Impact pathway figure

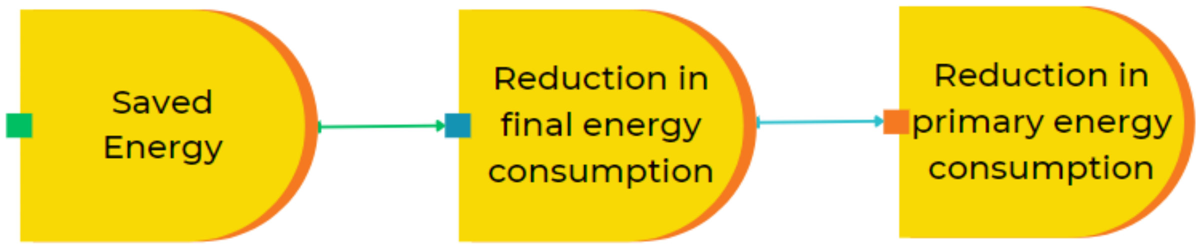

FIGURE 1: IMPACT PATHWAY FIGURE OF THE INDICATOR ENERGY (COST) SAVINGS

2.1.4 Overlaps with other MI indicators and potential risk of double-counting

This impact has several possible overlaps with other indicators, such as import depend-ency, material resources, avoided investments in grid and capacity expansion, and alle-viation of energy poverty and equality. However, since it is the central indicator of ener-gy efficiency, it will be the one to be monetised and the avoidance of double counting will be done in the course of monetising the other conflicting MI.

2.2 Quantification method

2.2.1 Description

The quantification of final energy savings is straightforward and merely involves the allocation of a fuel mix to every improvement action and make it possible to generate it from the relevant (sub-)sector's energy mix. Thus, for every improvement action, a vector describing the ratio of a given energy carrier's prevalence in the energy savings compared to the prevalence in the whole (sub-)sector's consumption is calculated. This vector can be multiplied with any new (sub-)sectoral fuel mix, then normalised, resulting in an improvement action-level fuel split. Multiplying the savings from the different improvement actions with their respective fuel split allocation vector results in the savings disaggregated by final energy carrier:

$$\Delta E_{c,ss,u,e,y} = \Delta E_{c,ss,u,y} \cdot \lambda_{c,ss,u,e,y} = \Delta E_{c,ss,u,y} \cdot \lambda_{c,ss,e,y} \cdot \chi_{c,ss,u,e}$$

In this equation, $\Delta E_{c,ss,u,y}$ describes the generated energy savings, $\lambda_{c,ss,u,e,y}$ the assumed relevant improvement action fuel mix, $\lambda_{c,ss,e,y}$ the (sub-)sectoral fuel mix, and $\chi_{c,ss,u,e}$ the assumed ratio between improvement action and (sub-)sectoral fuel mix vectors, issued from models, in this case PRIMES. The underlying assumption is that, in case the user does not specify which energy carriers are saved, the proportion of energy carriers among the savings are identical to their share of the energy mix typical for the relevant improvement action.

In order to calculate the primary energy savings, the final energy consumption is translated into primary energy consumption (the lists of final and primary energy carriers are shown in Table 2). This is done by remapping hardly transformed energy carriers (oil, coal, gas, and biomass and waste) to the list of primary energy carriers and calculate the conversion of transformed energy carriers (electricity, heat, and H2 and e-fuels). The formula for this is shown below:

$$\Delta E_{P,e,ss,u,y} = \Delta E_{P_{con},e,ss,u,y} + \Delta E_{P_{map}e,ss,u,y}$$

$\Delta E_{P_{con},e,ss,u,y}$ = Converted primary energy saving from electricity and heat generation

$\Delta E_{P_{map}e,ss,u,y}$ = mapping of $\Delta E_{e,ss,u,y}$ to primary energy carriers

$\Delta E_{e,ss,u,y}$ = Additional primary energy savings from final energy savings without conversion

TABLE 2: LIST OF MICAT FINAL AND PRIMARY ENERGY CARRIERS

id	Final energy carriers	Primary energy carriers
1	Electricity	Oil
2	Oil	Coal
3	Coal	Gas
4	Gas	Biomass and renewable waste
5	Biomass and waste	Renewable energy sources
6	Heat	Others
7	H2 and e-fuels	

The conversion is using data from Eurostat to assess the energy carriers that flow into the generation of electricity and heat. In a first stage, hydrogen and e-fuels are defined to be generated from electricity (such as electrolysis). This results in the following formula:

$$\Delta E_{P_{con},e,ss,u,y} = k_{heat,e,y} \cdot \Delta E_{heat,ss,u,y} + k_{elec,e,y} \cdot (\Delta E_{elec,ss,u,y} + k_{h2,y} \cdot \Delta E_{H2,ss,u,y})$$

$\Delta E_{P_{con},e,ss,u,y}$: Conventional primary energy saving for energy carrier e and year y for heat and electricity

$k_{heat,e,y}$: Coefficient for heat (=> new id_parameter 20)

$k_{elec,e,y}$: Coefficient for electricity (=> new id_parameter 21)

$k_{H2,e,y}$: Coefficient for electricity (=> new id_parameter 22)

$\Delta E_{elec,ss,u,y}$ = Final energy saving for electricity (= $\Delta E_{e,ss,u,y}$ for e=1)

$\Delta E_{heat,ss,u,y}$ = Final energy saving for heat (= $\Delta E_{e,ss,u,y}$ for e=7)

$\Delta E_{H2,ss,u,y}$ = Final energy saving for hydrogen and synthetic carburants (= $\Delta E_{e,ss,u,y}$ for e=8)

The calculation of the coefficients for electricity and heat takes cogeneration into account. This requires to decide for an accounting method, to allocate the energy consumption of the cogeneration plant to the outputs electricity and heat. For MICAT, an equivalent number approach has been selected, assuming the ratio of efficiency between electricity and heat efficiency is the same in a cogeneration plant as it is between two standalone electricity and heat plants.

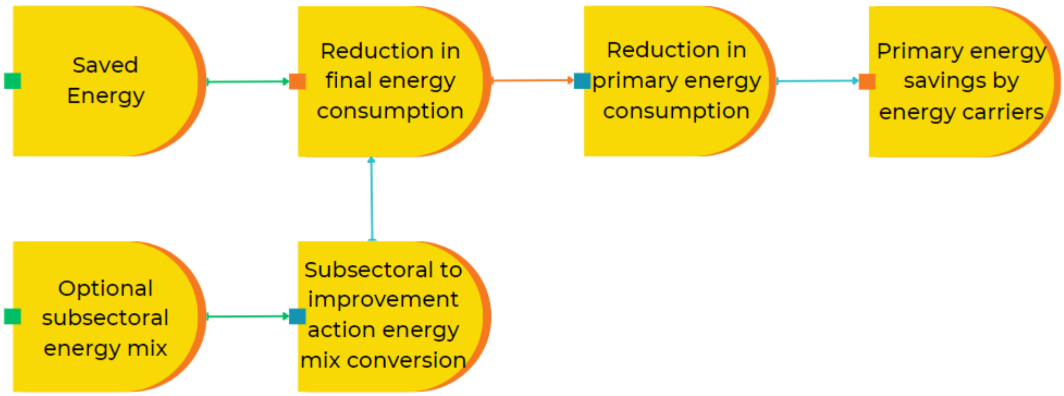

FIGURE 2: QUANTIFICATION APPROACH

2.2.2 Methodological challenges

Some countries do not have dedicated heat plants, which are needed to calculate the efficiency of a country's heat generation, which in turn is necessary for the calculation of the equivalent number approach for cogeneration. To circumvent the issue, the average efficiency of heat plants is used for those countries.

2.2.3 Data requirements

- Eurostat and PRIMES energy balances (ex-post and ex-ante, respectively)
- A reference scenario to calculate the subsectoral-to-improvement-action-energy-mix-coefficients, in this case originating from PRIMES
- Predictions of efficiency developments of H2 and e-fuel-generation

2.3 Impact factor/functional relationship

The functional relationship is described in the quantification part.

2.4 Monetization

The indicator will be monetised using energy price data from Enerdata. These include taxes and differ between sectors. The energy cost savings $\xi\Delta E_{c,e,ss,u,y}$ are calculated using the following formula ($EP_{c,e,s,y}$ being the energy prices):

$$\xi\Delta E_{c,e,ss,u,y} = \Delta E_{c,e,ss,u,y} \cdot EP_{c,e,s,y}$$

This database covers the past but not the future. Thus, the prices are projected using either data from PRIMES or from the IEA World Energy Outlook.

Since some data points are missing, a three-stepped approach to estimating missing values has been used:

- When merely some values are missing for a country and energy carrier in a time series, the price trend across the years is assessed along the time series of countries with full data and then multiplied with the existing data to inter- and extrapolate missing values
- When the whole time series is missing for a country, the European average is used
- When the European average is missing, the non-weighted average of the full time series is calculated and also used for countries with no data at all

2.5 Aggregation

This indicator can be aggregated with any monetised multiple impact representing a profit and not merely a turnover.

2.6 Conclusion

This indicator is central to energy efficiency and sufficiency, as it represents the main motivation to invest in measures. As a consequence, it is also relevant on all three governance levels. Thus, a sound quantification and monetisation is paramount.

Although there is a severe risk of double counting with a number of other indicators, this should not mean that this indicator is shelved, as it is the most important indicator among those it might risk double counting with.

3 SAVINGS ON MATERIAL RESOURCES

Authors: Jens Teubler, Severin Hackspiel (Wuppertal Institute)

Reviewer: Barbara Schlomann (Fraunhofer ISI)

Executive Summary

The Material Footprint (MF) is an aggregated indicator of raw material savings from the extraction of fossil fuels, minerals, metal ores, biotic materials as well as the extraction of materials that are not put to an economic use (unused extraction). In MICAT the MF represents the differences (usually savings) in removing material resources from nature before and after energy-efficiency measures take effect (pre- and post-action). In some cases, the scope of the indicator is not limited to direct effects from lower energy demand (use phase) but include effects from changes in technologies (production phase). Although the measures itself can take place on a small spatial scale (e.g., a city) the extractions (or savings thereof) take place on a global scale.

MF and its sub-indicators are expressed in form of intensities (gram of material per functional unit) that are derived from the input data (e.g., mix of energy carriers for electricity) and models (e.g., material demand for producing an electric vehicle). They can usually be multiplied with the marginal changes in the system (e.g., kg of hard coal for heat) and summed up.

The data required for material savings during the use-phase (energy demand pre- and post-action) are usually included in energy efficiency scenarios like PRIMES. By including or adding additional data on the key technologies (usually products) that are necessary to achieve the energy savings, the production phase can also be included in many cases. This requires at least data on changes in product stocks and basic assumptions or technical parameters for the technologies considered (e.g., the type and size of cars exchanged).

As MF is based on bottom-up modelling (similar to life cycle assessment (LCA)) its calculation reflects the status quo or ex-post calculations. If additional data is provided, ex-ante calculations are possible to the extent that databases for life-cycle-inventories allow for it. An example for that would be the integration of future electricity mixes into the use-phase.

For monetization, both direct (embodied) material costs and indirect (external) material costs are suitable approaches. However, they are limited to certain materials (usually metal commodities) and can overlap with investment costs or energy cost savings.

3.1 Scope of MI indicator

3.1.1 Definition

The Material Footprint (MF) is an aggregated indicator that quantifies the accumulation of natural material resources for providing a service or product. In the context of MICAT it is defined as "*Savings of abiotic (fossil fuels, metal ores, minerals) and biotic (not further specified) raw materials from nature; including raw materials without economic use (unused extraction)*". Further information on the indicator for resource impacts of energy efficiency measures as well as its associated impact method can be found in the literature review[2] and quantification report[3] of the COMBI project.

3.1.2 Relevance on EU, national and/or local level

MF is usually calculated from bottom-up models aimed at quantifying impacts on project or product level (similar to LCAs). Additional modelling steps are required when MF values are to be reported for national or regional environmental accounts. As MF was originally developed on the basis of the material-flow methodology, it is possible to report impacts that are consistent with the SDG 12 Goal4 of reducing the MF and domestic material consumption (DMC). It is also feasible to report MF values on national or local levels, although the life-cycle approach entails material extractions from outside of the perspective system. The MF therefore is caused by and attributed to the specific actions in Europe, the country or local community but its effects (less use of natural material resources) take place on a global scale.

3.1.3 Impact pathway figure

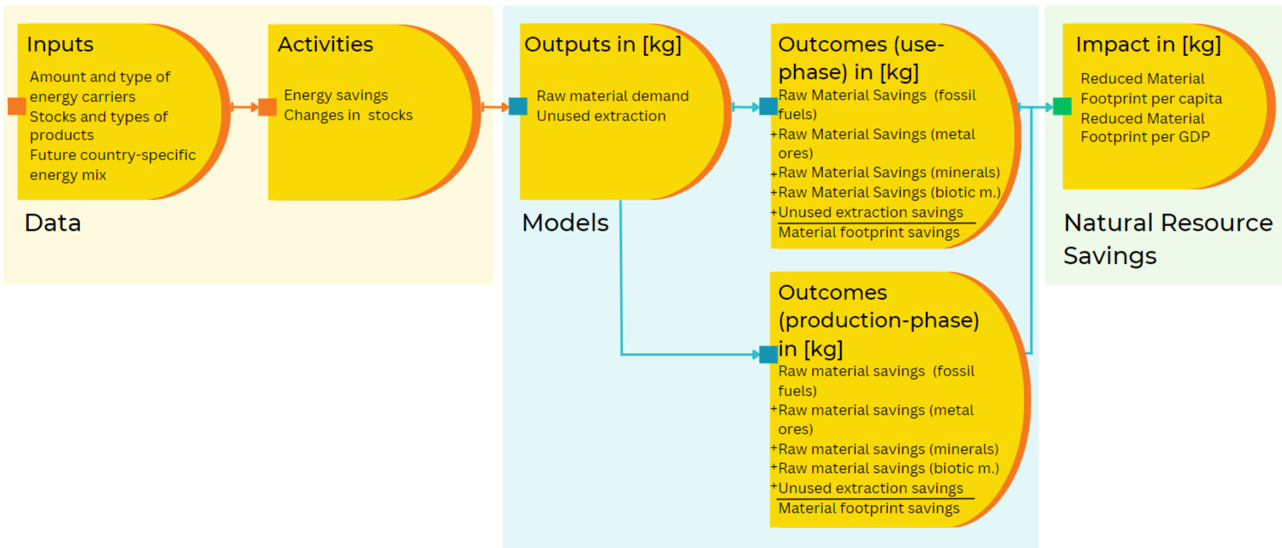

FIGURE 3: LOGIC MODEL (THEORY OF CHANGE) FOR MATERIAL FOOTPRINT

3.1.4 Overlaps with other MI indicators and potential risk of double-counting

MF *correlates* with the accumulated energy demand on the input side of systems and with greenhouse gas (GHG) emissions on the output side (especially in regard to the use of energy carriers). As such, no double-counting occurs. However, there are overlaps with these types of indicators if impacts are monetized. Both energy cost savings and

2 https://combi-project.eu/wp-content/uploads/2015/09/D4.1.pdf
3 https://combi-project.eu/wp-content/uploads/D4.4_20180321_final.pdf
4 https://sdgs.un.org/goals/goal12

investment costs include partially or fully (depending on monetization method) the direct or external costs of raw materials.

3.2 Quantification method

3.2.1 Description

All sub-indicators (biotic, fossil fuel, metal ore and mineral raw material savings) refer to the raw materials that are extracted or permanently removed from nature from cradle-to-grave (or for MICAT from cradle-to-gate). They are summed up over the entire life cycle and expressed as material intensity in grams of resources per gram of economically used material [g/g]. This includes e.g., the residues of extracted ores but not the overburden from mining which is only included in the so-called unused extraction (UU) and only added to the overall MF.

Although it is possible to quantify MFs with the help of Input-Output Tables (IOTs) (top-down) it usually requires a bottom-up perspective (e.g., material and energy flows in life-cycle inventories). By its nature, raw material demands are very difficult to quantify for the future which is why they can be considered to be results from an ex-post assessment. Certain changes in the surrounding systems can be integrated though that result in changes in the material intensity of services. The most likely use-case for MICAT is to account for the reduced demand of different energy carriers from electricity or heat production but also e.g., changes in the material composition of vehicles from batteries compared to internal combustion machines. The changes in direct energy use are incorporated via **use-phase models** while the changes in product types and product stocks are captured by **production-phase models**.

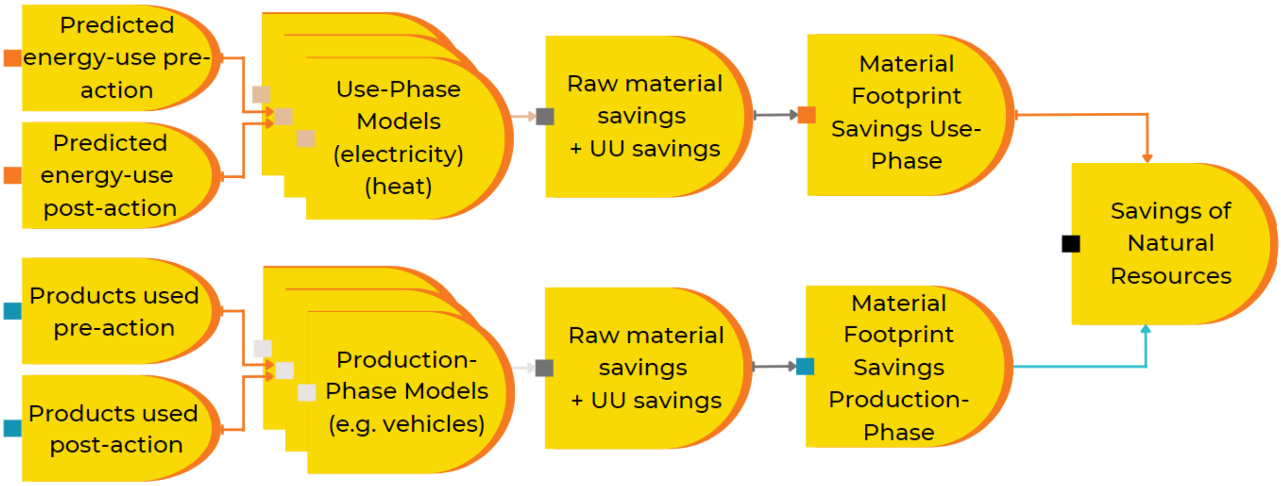

FIGURE 4: CALCULATION STEPS

3.2.2 Methodological challenges

Using stock data for a variety of possible current and future products is limited to available life-cycle inventories and their potential matching to product classes in the input data. A number of assumptions are necessary to represent the best-available average, or rather, generic product type. This limitation not only affects the products and their use themselves but especially the upstream material and energy flows for the provision of materials. For some materials like metals, although a global production is assumed, differences in the material intensity of raw material exporting countries and even between mines can be very high. For local applications in particular, this might not reflect the conditions in a specific case. The existing and further developed models will try to account for that fact by using secondary sources (e.g., EUROSTAT statistics) to identify the most appropriate level of aggregation.

3.2.3 Data requirements

The following data is needed to calculate the MF for the use-phase (resource savings from reduced energy demand) and the production-phase (savings and trade-offs for providing key technologies).

TABLE 3: MINIMUM DATA REQUIREMENTS FOR MATERIAL FOOTPRINT

All phases	Use phase	Production phase
electricity & heat demand	energy carriers for electricity pre-/post-action	definition of key technologies
changes to energy systems (e.g., new technologies)	energy carriers for heat pre-/post-action	stock of products in base-case/reference scenario
		stock of products post-action/energy efficiency scenario

In addition, a number of assumptions and parameters influence the results and should therefore be streamlined with other models if possible. Examples for that are grid losses in a country, the sourcing of biotic energy carriers or the energy content of materials.

3.3 Impact factor/functional relationship

All effects are based on direct or derived (modelled) intensity factors that usually can be directly multiplied with the input data (in line with e.g., Carbon Footprint Intensities). If these intensities are consistently mapped to the inputs, it should therefore be possible to calculate the MF and its sub-indicators directly from changes in the input data (linear relationship). As for spatial differentiation, it is not possible to differentiate the direct impacts within the dimension (causing the effects) from impact outside of any dimension as all material extractions take place on a global scale. However, resulting MF values can directly be attributed to different levels.

3.4 Monetization

Two types of monetization approaches can be applied: embodied or direct costs and indirect or external costs (see also the quantification report[3] of the COMBI project for further details and monetization factors). 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. The indirect material costs are externalized 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.

Double-counting can occur for embodied material costs if material costs are not excluded from investment costs.

3.5 Aggregation

MF impacts (or midpoints) should not be aggregated with other inputs or outputs, even if the unit is nominally the same. The aggregation within the method is formulated as a sum of all sub-indicators as follows:

$$\textbf{Material Footprint}\ (\text{MF}) = \text{Fossil Fuel Demand} + \text{Metal Ore Demand} \\ + \text{Mineral Demand} + \text{Biotic Raw Material Demand} + \text{Unused Extraction}$$

3.6 Conclusion

This indicator shows the material usage in the production phase and use-phase. Thus, it shows how much material has to invested and is saved over the time period the measure is introduced. The MF is calculated in a Bottom-Up approach, which makes it difficult to combine with the Top-Down approach of the measures. Therefore, just a few production-phase MFs will be included. The Use-Phase can be integrated easily and can maybe also be monetized.

4 IMPACTS ON RES TARGETS

Authors: Frederic Berger (Fraunhofer ISI)

Reviewer: Felix Suerkemper (Wuppertal Institute)

Executive Summary

Defined in the bloc's Renewable Energy Directive (RED), Member States are subject to binding targets regarding the share of energy originating from renewable energy sources (RES targets). By reducing total energy consumption with energy efficiency, necessary additional renewables capacities to achieve the RED's binding targets are reduced.

This indicator has mainly a relevance on the national level, since the binding targets apply to the Member States. Thus, they are responsible for their achievement and have an interest in facilitating it using energy efficiency.

In order to quantify this indicator, the gross available energy (GAE) from renewable energy sources (RES) is divided by the total GAE to assess the reference as well as the GAE from RES is divided by the total GAE minus the energy savings. The difference between both shows the impact of a given energy efficiency measure on the national RES share.

The considered RES energy carriers are in line with the RED and mainly consist of solar, wind, geothermal, biomass, and renewable waste.

$$\Delta RES_y = \left[\sum_{e=4}^{5} GAE_{P,e,y} / (\sum_{e=1}^{6} GAE_{P,e,y} - \sum_{e=1}^{6} \Delta E_{P,e,y}) - \sum_{e=4}^{5} GAE_{P,e,y} / \sum_{e=1}^{6} GAE_{P,e,y}\right] \cdot 100$$

$\Delta RES_y =$ change in RES share in percent points

$\sum_{e=1}^{6} \Delta E_{P,e,y} =$ saved primary energy due to energy efficiency

$\sum_{e=1}^{6} GAE_{P,e,y} =$ total gross available energy

$\sum_{e=4}^{5} GAE_{P,e,y} =$ gross available energy generated from renewables energy sources (Renewables and biomass + waste)

It is recommended to monetise the indicator and to aggregate it with other monetised indicators.

4.1 Scope of MI indicator

4.1.1 Definition

Defined in the bloc's Renewable Energy Directive (RED), Member States are subject to binding targets regarding the share of energy originating from renewable energy sources (RES targets). By reducing total energy consumption with energy efficiency, necessary additional renewables capacities to achieve the RED's binding targets are reduced.

4.1.2 Relevance on EU, national and/or local level

This indicator has mainly a relevance on the national level, since the binding targets apply to the Member States. Thus, they are responsible for their achievement and have an interest in facilitating it using energy efficiency.

More generally, the EU as a global player striving to spearhead the global shift to a more sustainable economy might also be interested in assessing the potential of energy efficiency to increase the share of renewables in energy consumption.

4.1.3 Impact pathway figure

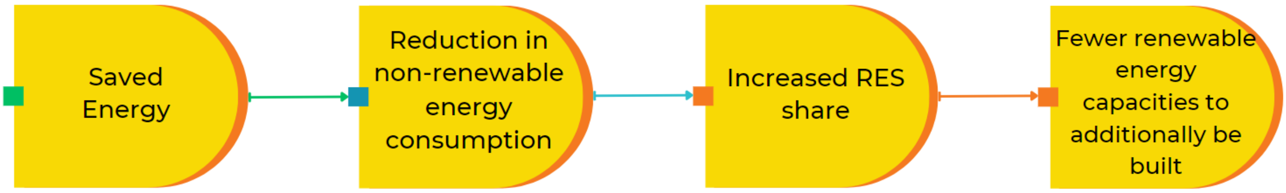

FIGURE 5: IMPACT PATHWAY FOR IMPACTS ON RES TARGETS

4.1.4 Overlaps with other MI indicators and potential risk of double-counting

This indicator does not have any overlaps with other indicators. Thus, there is no risk of double counting.

4.2 Quantification method

4.2.1 Description

In order to quantify this indicator, the gross available energy (GAE) from renewable energy sources (RES) is divided by the total GAE to assess the reference as well as the GAE from RES is divided by the total GAE minus the energy savings. The difference between both shows the impact of a given energy efficiency measure on the national RES share and is generally stated in percent.

The considered RES energy carriers are in line with the RED and mainly consist of solar, wind, geothermal, biomass, and renewable waste (the indices are specified in the section "Impact factor").

$$RESy = \sum_{e=4}^{5} GAE_{P,e,y} \Big/ \sum_{e=1}^{6} GAE_{P,e,y}$$

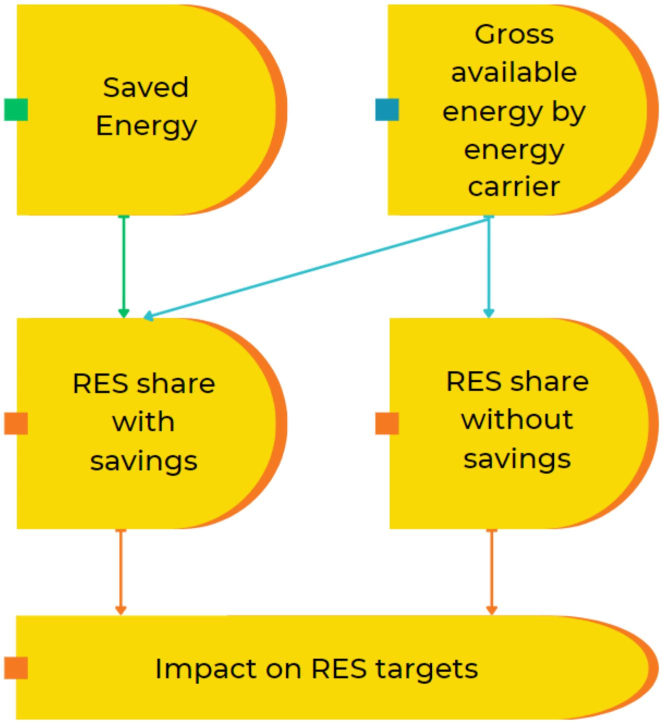

FIGURE 6: CALCULATION STEPS FOR IMPACTS ON RES TARGETS

4.2.2 Methodological challenges

There are no methodological challenges.

4.2.3 Data requirements

The only necessary input apart from the energy savings (which are converted from final into primary energy savings in the indicator "Energy savings) is the gross available energy (GAE) disaggregated by energy carriers, which come from Eurostat and PRIMES.

4.3 Impact factor/functional relationship

$$\Delta RES_y = \left[\sum_{e=4}^{5} GAE_{P,e,y} / \left(\sum_{e=1}^{6} GAE_{P,e,y} - \sum_{e=1}^{6} \Delta E_{P,e,y}\right) - \sum_{e=4}^{5} GAE_{P,e,y} / \sum_{e=1}^{6} GAE_{P,e,y}\right] \cdot 100$$

$\Delta RES_y =$ change in RES share in percent points

$\sum_{e=1}^{6} \Delta E_{P,e,y} =$ saved primary energy due to energy efficiency

$\sum_{e=1}^{6} GAE_{P,e,y} =$ total gross available energy

$\sum_{e=4}^{5} GAE_{P,e,y} =$ gross available energy generated from renewables energy sources (Renewables and biomass + waste)

4.4 Monetization

There would be three approaches to monetise this indicator:

- Looking at the effective investment costs linked to the alternative, a massive investment in additional renewable energies would be necessary. However, since the majority of Member States have not significantly reacted to missing the 2020 RES targets, it cannot be expected that there is a strong link between the RES share and effective investments in RES. Furthermore, this would constitute double counting with the indicator "Avoided investments in capacity and grid".

- Looking at fines imposed in the framework of infringement proceedings for missing the RES targets. However, the missing of the 2020 RES targets does not seem to have entailed any infringement proceedings, despite a majority of Member States falling short.

- A third and possibility would be monetisation via statistical transfer costs. This will be probably the first option proposed by the EC for achieving the RES objectives for countries where the level of RES is too low. A statistical transfer is the administrative purchase by one European Member State of a quantity of renewable energy from another member state that has achieved its target and has a surplus. The possibility to statistically transfer RES surpluses has been introduced in the RED in 2009.

As a result, it is recommended to monetise this indicator using the third method. In order to define a price of RES, past statistical transfers have been assessed in Table 4. Consequently, the average unit price (14.1 €/MWh) is used to monetise this impact. Since surplus capacity will be transferable, the monetisation encompasses sales (in case of surplus) as well as purchases (in case of shortfall) of statistical capacities.

TABLE 4: DETAILS OF PAST STATISTICAL TRANSFERS OF RES CAPACITIES

Date	Capacity	Price	Unit price
12/2022[5]	132 GWh	1.65 mio €	12.5 €/MWh
12/2022[6]	208 GWh	2.04 mio €	9.8 €/MWh
11/2020[7]	3 500 GWh	50 mio €	14.3 €/MWh
11/2017[8]	700 GWh	10.5 mio €	15 €/MWh
Sum/Average	4 540 GWh	64.19 mio €	14.1 €/MWh

4.5 Aggregation

This indicator can be aggregated with other monetised impacts which relate to profits and not merely turnover.

4.6 Conclusion

This indicator describes how energy savings affect the share of renewable energy sources in the EU's or the Member States' energy mixes. Thus, it shows how energy efficiency can help to attain the RED's renewable energy targets, requiring fewer additional renewable capacities to be installed to comply with the targets.

[5] https://valtioneuvosto.fi/en/-/1410877/finland-and-the-brussels-region-agree-on-statistical-transfers-of-renewable-energy-finland-sells-surplus-for-eur-1.65-million
[6] https://balkangreenenergynews.com/slovenia-secures-statistical-transfer-of-renewable-energy-from-czech-republic/
[7] https://www.irishtimes.com/news/ireland/irish-news/ireland-to-pay-denmark-estonia-50m-for-statistical-renewable-energy-transfer-1.4418420
[8] https://renewablesnow.com/news/estonia-to-help-luxembourg-meet-2020-renewables-goal-report-590343/

5 GHG SAVINGS (SAVINGS OF DIRECT CARBON EMISSIONS)

Authors: Fabian Wagner (IIASA), Gregor Kiesewetter (IIASA), Frederic Berger (Fraunhofer ISI)

Reviewer: Chun Xia-Bauer (WI)

Executive Summary

- This indicator describes the CO2 emissions saved as a result of energy efficiency measures. Nearly all combustion processes emit greenhouse gases, causing climate change through the greenhouse effect.
- Other greenhouse gases might also be reduced (or increased) as a result of an energy efficiency measure. However, these effects are neglected here, as they typically do not affect the GHG balance significantly.
- Biomass combustion here is not considered necessarily carbon neutral, as the biomass combusted may not have been produced entirely sustainably.
- The resulting equation for the saved CO2-emissions ΔCO2c,e,ss,u,y is the following: ΔCO2c,e,ss,u,y=kCO2, c,e,ss,y· ΔEc,e,ss,u,yΔCO2c,e,ss,u,y=kCO2, c,e,ss,y· ΔEc,e,ss,u,y
- In this equation, kCO2, c,e,ss,y represents the specific CO2-emission factor for a given region, energy carrier, subsector, and year, whereas ΔEc,e,ss,u,y specifies the energy savings generated in a given region, energy carrier, subsector, improvement action, and year.
- The only data requirements for this indicator are the CO2-emission coefficients for each region-energy carrier-subsector-year-combination as well as one monetisation factor which has to be corrected for inflation.

5.1 Scope of MI indicator

5.1.1 Definition

This indicator measures the impact of energy efficiency measures on greenhouse gas (GHG) emissions, specifically emissions of CO2.

The indicator takes into account the amount(s) of fuel(s) being saved, as well as CO2 emission factors that are fuel-specific, and in principle also country-specific (the country-specificity is most relevant for coal, as the calorific values of lignite and hard coal different, and different countries use lignite and hard coal in different proportions).

5.1.2 Relevance on EU, national and/or local level

Reducing GHG emissions is the key objective of climate mitigation policies at all governance levels and their relevance is permeating all energy-related policies.

5.1.3 Impact pathway figure

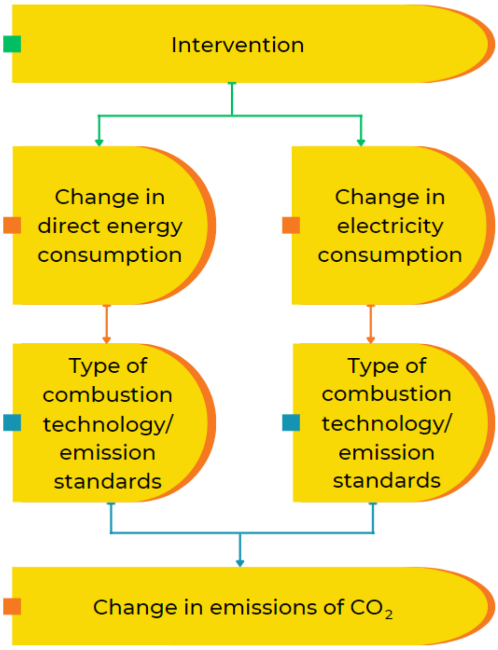

FIGURE 7: IMPACT PATHWAY AND CALCULATION METHOD FOR CHANGES IN GHG/CO2 EMISSIONS FROM ENERGY EFFICIENCY MEASURES

5.1.4 Overlaps with other MI indicators and potential risk of double-counting

No overlap has been identified.

5.2 Quantification method

5.2.1 Description

Energy efficiency measures GHG emissions through the channel described in Figure 7.

- Step 1: Quantify the amount of energy (direct combustion and electricity) saved by an intervention. Such an intervention can affect the direct consumption of fuel as well as the consumption of electricity. For example, heat pumps replace direct combustion, but consume electricity.

- Step 2: Determine the corresponding supply-side changes in the use of technologies. For example, saving electricity would result in less electricity being produced. An assumption needs to be made about what kind of source of electricity is being reduced, whether the most carbon-intensive (coal-based electricity), or an average (country) fuel mix, or else. Moreover, for the emission characteristics further assumptions would need to be made whether, in the case of thermal power plants, whether the cleanest, the dirtiest, or the average device (in terms of air pollutants) are assumed to be reduced. Finally, if the energy efficiency measure reduces direct combustion of fuel, the emission characteristics of that reduction needs to be specified. For example, increasing the energy efficiency of a particular process in the chemical industry may result in all direct fuel uses being reduced proportionally, or may result in only one particular fuel (e.g., gas) being reduced, and again the vintage of the installation may be relevant. The allocation of saved fuels is done using default values representing the average energy mix of the selected improvement action in the relevant subsector or user-defined values.

- Step 3: Calculate the resulting changes in the emissions of carbon dioxide.

All calculations (e.g., energy saved, emissions) are performed on an annual basis and at the level of individual member states of the EU. These results can easily be aggregated.

5.2.2 Methodological challenges

- In principle, CO2 emission factors on an energy basis depend on the fuel quality. However, differences among different domestic and import sources are typically small and are neglected here. [differences in net calorific values may be larger].

- Emission reductions of non-CO2 greenhouse gases have not been estimated, as this requires a detailed assessment of the changes in the upstream emissions (e.g., methane from mining and pipeline transport) or the exact power distribution technologies (e.g., SF6 in switches).

- Biomass combustion is sometimes considered carbon neutral, as biomass can be grown sustainably. However, this is a simplistic and potentially misleading assumption, and there are studies that estimate significant net emissions factors for biomass combustion. A central value from these studies is being used in the tool.

5.2.3 Data requirements

- The analysis is performed with GAINS model (Amann et al., 2011) which typically uses, for Europe, PRIMES energy system data for analysis of alternative scenarios, though for the assessment of interventions the link to PRIMES is actually not required.

- For CO2 emission calculations the IPCC tier 1 method is used (IPCC, 2006).

- For CO2 emission factors, typically IPCC default factors have been used, unless country-specific information was available.

5.3 Impact factor/functional relationship

- The emission reductions are calculated as follows:

$$\Delta CO2 \;=\sum_{s,u,t,e} \mathrm{EF}_{s,u,t,e} \times \Delta E^{i}_{c,s,u,t,e}$$

The independent variable ΔE^i_c describes how an intervention i in country c affects the energy consumption of carrier e using technology t for end-use in sector s. The factor EF describes the emission factor relevant for the change in energy consumption ΔE.

- Strictly speaking, the factors EF may depend on scenario assumptions, as they can reflect different fuel mixes, though the calculation can of course be performed fuel by fuel. The main scenario dependence actually lies in the independent variables ΔE^i_c , i.e., in the narrative and specification of how an energy saving intervention i actually affects the consumption of different fuel uses in different sectors etc.

5.4 Monetization

- The easiest way to monetize CO2 emissions (or reductions thereof) is to multiply them with the price in a given carbon market, for example, the European ETS. Thus, the CO2-savings ΔCO2c,ss,u,y are multiplied with a monetisation coefficient kCO2, y: ξCO2 c, ss,u,y= ΔCO2c,ss,u,y ·kCO2, y
- Alternatively, the so-called social cost of carbon could be used, which typically represents higher values than actual and projected carbon price values.
- The coefficient used in the MICAT tool comes from the German Federal Environmental Agency and assumes costs of 199 €/tCO2 in 2020, 219 €/tCO2 in 2030, and 255€/tCO2 in 20501. All monetary values are stated in €2021.

5.5 Aggregation

- Member state data can be aggregated to the EU level and also downscaled to the city level.

5.6 Conclusion

This indicator describes the reductions of CO2 associated with energy efficiency measures. The emission reductions of other greenhouse gases are typically smaller (in GWP equivalent units) and are much more difficult to quantify as they depend on the upstream energy production system (wells, mines, pipelines) and assumptions on how marginal changes in the energy system affect the upstream operations. Hence these are not quantified here. CO2 emission reductions can be monetized by multiplying them with a corresponding carbon market price or the social cost of carbon.

6 Reduction in air pollution emissions

Authors: Fabian Wagner, Gregor Kiesewetter (IIASA)

Reviewer: Chun Xia-Bauer (WI)

Executive Summary

- This indicator describes the emissions of primary fine particles (PM2.5), sulfur dioxide (SO2), and nitrogen oxides (NOx) saved as a result of energy efficiency measures. Nearly all combustion processes emit the precursor substances in varying amounts and relative importance.

- The emissions and emission reductions of these pollutants can be viewed as a proxy for environmental problems caused by the chemical species, including fine particle and ozone pollution in ambient air, as well as resulting physical impacts, such as crop damages, impacts on human health and mortality. The latter two are actually covered in Task 2.3. There the focus is on PM2.5 pollution, because the ozone chemistry is more complicated and the relationship between emission reductions and impact reductions is less certain than for PM2.5 and its precursors. Thus, in order to reduce uncertainties in the outcome, we do not include ozone related impacts. It also implies that the benefits in Task 2.3 tend to be underestimated.

- Given that the health and mortality impacts of air pollutants are already covered in Task 2.3, the benefits of reducing emissions of air pollutants are not monetized here, in order to avoid double counting.

- The emission reductions of air pollutants as a result of implementing energy efficiency measures are calculated analogously to the emission reductions of CO2. The only difference is that for the air pollutants from many sources, end-of-pipe control technologies and specific emission limits are in place. We use the GAINS model (which is used in the EU for planning new air pollution emission ceilings) for deriving source-specific emission reduction factors, because the GAINS model reflects all existing air pollution-related legislation and thus can realistically assess the actual emission reductions for specific measures.

- The data required for this indicator include the effective emission factors by region, sector and carrier (and time) for each pollutant.

6.1 Scope of MI indicator

6.1.1 Definition

This indicator describes the reduced emissions of primary fine particles (PM2.5), sulfur dioxide (SO2), and nitrogen oxides (NOx) as a result of energy efficiency measures. Nearly all combustion processes emit the precursor substances in varying amounts and relative importance.

6.1.2 Relevance on EU, national and/or local level

Reducing the emissions of air pollutants is a key objective of air quality policies at all governance levels and their relevance is permeating all energy-related policies. However, reducing emissions of air pollutants is only a means to actually reduce the impacts of poor air quality and deposition. Thus, while emission reductions can be used as a proxy for environmental pollution, the actual health impact reductions are assessed in Task 2.3.

6.1.3 Impact pathway figure

The illustrative impact pathway is given in Figure 8

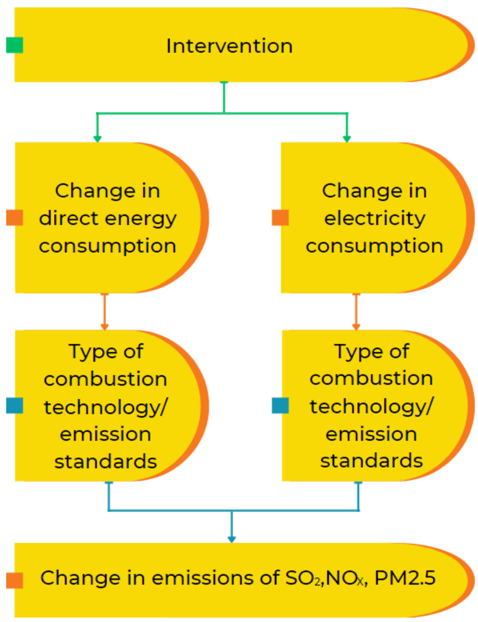

FIGURE 8: IMPACT PATHWAY FROM ENERGY SAVINGS TO AIR POLLUTANT EMISSIONS

6.1.4 Overlaps with other MI indicators and potential risk of double-counting

Benefits would be double counted if emission reductions of air pollutants were to be monetized here and added to the health benefits calculated in Task 2.3. There-fore no benefits associated with the emission reductions of SO2, NOx, and PM2.5 are quantified here.

6.2 Quantification method

6.2.1 Description

Energy efficiency measures affect air pollutant emissions through the channel described in Figure 8.

- Step 1: Quantify the amount of energy (direct combustion and electricity) saved by an intervention. Such an intervention can affect the direct consumption of fuel as well as the consumption of electricity. For example, heat pumps replace direct combustion, but consume electricity.

- Step 2: Determine the corresponding supply-side changes in the use of technologies. For example, saving electricity would result in less electricity being produced. An assumption needs to be made about what kind of source of electricity is being reduced, whether the most carbon-intensive (coal-based electricity), or an average (country) fuel mix, or else. Moreover, for the emission characteristics further assumptions would need to be made whether, in the case of thermal power plants, whether the cleanest, the dirtiest, or the average device (in terms of air pollutants) are assumed to be reduced. Finally, if the energy efficiency measure reduces direct combustion of fuel, the emission characteristics of that reduction needs to be specified. For example, increasing the energy efficiency of a particular process in the chemical industry may result in all direct fuel uses being reduced proportionally, or may result in only one particular fuel (e.g., gas) being reduced, and again the vintage of the installation may be relevant. The allocation of saved fuels is done using default values representing the average energy mix of the selected improvement action in the relevant subsector or user-defined values.

- Step 3: Calculate the resulting changes in the emissions of air pollutants and precursors by taking into the effective emission factors that are consistent with the respective emission standards and air pollution legislation.

All calculations (e.g., energy saved, emissions) are performed on an annual basis and at the level of individual member states of the EU. These results can easily be aggregated.

6.2.2 Methodological challenges

- Representative emission factors can be very source-specific. However, the sectoral and energy carrier structure of the MICAT tool is limited. The corresponding resolution is much higher in the GAINS model. In reality, the spectrum of emission factors in a source category are broader.

- Specifically, e.g., biomass combustion in the household sector can be associated with very different emission factors, depending on whether the biomass is burned in a fire place, a stove or a pellet boiler. Thus, at the higher aggregation of the MICAT tool, the emission reductions resulting from a concrete intervention can be higher or lower than the average calculated by MICAT.

6.2.3 Data requirements

- The analysis is performed with GAINS model (Amann et al., 2011) which typically uses, for Europe, PRIMES energy system data for analysis of alternative scenarios, though for the assessment of interventions the link to PRIMES is actually not required.

- The representative emission factors are available in the GAINS online model and reflect all existing and relevant legislation on emission controls and ambient air quality standards. They cover around 1,000 different emission source categories in each EU member state. From these the representative emission factors for the MICAT tool are aggregated.

6.3 Impact factor/functional relationship

- The emission reductions of pollutant p are calculated as follows:

$$\Delta EM_p = \sum_{s,u,t,e} \mathrm{EF}_{s,u,t,e} \times \Delta E^{i}_{c,s,u,t,e}$$

- The independent variable ΔE_c^i describes how an intervention i in country c affects the energy consumption of carrier e using technology t for end-use in sector s. The factor EF describes the emission factor relevant for the change in energy consumption ΔE.

- Strictly speaking, the factors EF may depend on scenario assumptions, as they can reflect different fuel mixes, though the calculation can of course be performed fuel by fuel. The main scenario dependence lies in the independent variables ΔE_c^i , i.e., in the narrative and specification of how an energy saving intervention i actually affects the consumption of different fuel uses in different sectors etc.

6.4 Monetization

- In order to avoid potential double counting and in the absence of meaningful average impact values for the air pollutants, no monetization is carried out.

6.5 Aggregation

- Member state data can be aggregated to the EU level and also downscaled to the city level.

6.6 Conclusion

This indicator describes the emission reductions of the important air pollutants precursors SO2, NOx, and PM2.5 as a result of energy efficiency measures. The emission reductions serve an indicative proxy for environmental benefits. This indicator however, is not monetized as the actual impacts of air pollutants on human health are quantified already under Task 2.3.

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