Calculating and Operationalising the Multiple Benefits of Energy Efficiency in Europe

Synthesis Methodology

D2.4 Final report

Grant Agreement No. 649724

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Budapest/Wuppertal, April 2018

Coordinated by Wuppertal Institut

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 649724. This document reflects only the author's view. The Agency is not responsible for any information it contains.

Content

List of tables

List of figures

1 Introduction

The COMBI project quantifies different multiple impacts (MI) of energy efficiency improvement (EEI) actions, which require different type of assessment approaches (methodologies). In addition, many of the impacts overlap with each other either due to estimation techniques or theoretically, which makes their aggregation challenging. In addition, different impacts are quantified in different units, rendering aggregation impossible until and unless a common unit is found. Therefore, there is a need for an overarching aggregation methodology in order to incorporate quantified impacts into a decision-making framework such as cost-benefit analysis.

The purpose of this report is to document the methodology used to aggregate and synthesise the multiple impacts in the COMBI project. It also eludes to the general lessons learned in terms of aggregating quantified multiple impacts from energy efficiency actions in a general sense.

As one of the key conclusions of the project is that quantifying and aggregating multiple impacts of energy efficiency actions is very complex, resource and time intensive due to their major context dependency. Therefore it is pivotal that as many generally applicable lessons can be drawn from the project as possible in order to minimise future efforts for MI aggregation and catalyse more simplified future MI quantifications.

The COMBI project considers only *incremental impacts* which means that the impacts studied here only happen if further policy action is undertaken and additional EEI actions implemented as a consequence. More precisely, not the total impact of EEI actions (e.g. all building refurbishments) are assessed, but only *additional* impacts following actions that are not yet being realised are assessed.

These impacts are quantified at a EU member state level and by single energy efficiency improvement (EEI) action. The size and magnitude of impacts depend on the number and type of EEI actions that are used as a basis for quantification. Furthermore, the size and magnitude of the impacts depend on many other aspects of quantification such as the definition of the reference scenario (baseline), additionality, distributional effects, perspective and scale. Each of these factors is discussed in the below sections.

This synthesis report summarises general challenges and their possible solutions related to 1) quantification of the distinct individual impact and 2) aggregation of multiple impacts (MI) in order to incorporate them into a common cost-benefit analysis framework as incorporated in the COMBI online tool.

The objective of this report is to provide a methodology to systematically quantify multiple impacts (MI) and also to aggregate impacts comprehensively by avoiding double counting. In the following sections, the challenges, and solutions related to the quantification and aggregation of impacts are described.

2 General challenges related to the quantification of impacts

2.1 Baseline and additionality

Baseline

The size of an impact depends on the definition of the baseline (Burtraw & Toman 2000). The most popular definition of baseline is "the energy use or emissions that would occur without policy intervention" (COAG 2012). However, sometimes the definition of what can be regarded as the baseline is not entirely clear. Also, a baseline can be static (holding parameters constant) or dynamic (including forecasted changes). The degree to which a baseline is static or dynamic may have important implications in terms of which impact can be considered as additional. A fully dynamic baseline reflects all changes in context-relevant factors that are expected to take place in the future anyway (without further intervention). This includes taking account of e.g. the autonomous improvement in energy efficiency, changes in energy and climate-relevant policies that are certain to be implemented, changes in drivers of energy demand (e.g. GDP, population growth), fuel price changes and other relevant factors. If done correctly, such a baseline reflects what would have happened without the action/intervention. In contrast to such an approach is a baseline which (generally due to lack of sufficient information on how context-specific factors evolve in future) takes some important factors as fixed over time. An example of this approach is a frozen efficiency scenario, which assumes that energy efficiency does not change over time and is "frozen" at the level of the base year. It is difficult to interpret such a baseline as being reflective of what would have happened without the action, as it is probable that even without additional actions or measures, improvements in energy efficiency would have taken place as a result of technological advancements. Therefore, not all energy efficiency improvements compared with a frozen efficiency scenario can be considered additional.

Without modelling, it is difficult to select a baseline, which is reflective of what would have happened without the action. For example, if a partial equilibrium approach is used in a cost-benefit analysis (CBA), the demand and supply curves are often estimated from observed data, and most CBA studies do not make assumptions about how these curves would shift over time due to future changes in technologies, policies, population growth, etc. Modelling approaches are generally able to deal with such changes in a much more consistent and transparent manner, although the source of estimation of parameter values may still be contentious. For example, computable general equilibrium (CGE) models generally use an autonomous energy efficiency improvement parameter to denote energy efficiency improvement over time. The source of estimation of this parameter value and thus its reliability has given rise to some discussion (see e.g. Jacoby et al, 2004).

COMBI approach

Thus in COMBI, to deal with these methodological uncertainties related to baseline the following steps are followed:

1. A detailed bottom-up stock model is used calculate reference/baseline and efficiency scenarios through extrapolations of past developments and accounting for current policies (reference/baseline). The (efficiency) scenario, in turn, is modelled accounting for addition-

al actions considered in this project.

2. COMBI thus uses a dynamic baseline that incorporates existing EU policies. This implies that **substantial energy efficiency improvements are already incorporated in the baseline.**
3. Only the *incremental* impact of EEI actions (without cost optimization) are taken into account in the project – for all estimations: energy savings, investment costs and estimated multiple impacts.

These three specific steps ensure that the baseline is dynamic enough to project both reference and efficiency scenario to assume that quantified impacts are incremental.

Additionality: It is important to determine what portion of the impact of the energy efficiency action (EEI action) is additional compared to the baseline. The rationale behind determining the portion is that the size of impact depends strongly on baseline and additionality and from a policy maker's perspective, it is crucial to only take the additional impacts into account to avoid overestimation of the policy effect (Davis et al 2000). Even with an appropriate baseline selection, additionality remains an issue in order to avoid overestimation. The issue of additionality relates to three layers:

1. **Additionality of the clean energy action/policy:** It is important to identify whether an energy efficiency action is itself additional compared to business-as-usual. Thus in COMBI, based on a dynamic baseline a realistic and yet ambitious efficiency scenario is determined. This efficiency scenario is itself additional compared to baseline scenario.
2. **Additionality of the impact:** Additionality can be influenced by several factors and thus, while quantifying impacts, one needs to be careful whether it is a result of an EEI action. In other words, impacts which are induced by EEI actions should be considered as additional.
3. **Additionality compared to alternatives:** This layer of additionality arises when multiple impacts of investments or other expenditures are quantified (which means, basically all climate action that in the end results in any form of expenditure). As investments/expenditures will always have some economic impact, only the additional impacts should be counted as attributed to the action. Any impact from energy efficiency investment needs theoretically to be compared to all potential alternative uses of the capital that is invested.

As the additional impacts are likely to be much smaller than the full impacts, these decisions about meeting additionality criteria, and therefore the baselines to which actions and impacts are compared to, make a fundamental difference in the overall value of the impacts. Thus, while the assessment of the multiple impacts, the partners examine all these three additionality layers for their respective work packages and it is consistently carried out when calculating the size of an impact.

COMBI approach

Clearly the most challenging additionality assessment is the one related to alternatives as there are always large numbers of alternatives. Therefore finding streamlined ways to conduct this assessment is an important research priority. For instance, for employment impacts, one can look at the employment intensity of investments in the specific investment area. If there is full employment, there will be no net employment effects. For instance, energy efficiency retrofits have been found to be more employment intensive than other infrastructure investments (Ürge-Vorsatz et al. 2010). Other areas can also be estimated if alternative spending of resources may have resulted in significantly different outcomes.

Another way to address this additionality is to analyse the distributional impacts. For instance, while there may not be a very high number of additional jobs created for some actions, however, sometimes they involve shifting unhealthy jobs towards healthier, greener jobs more compatible with the 21st data-driven society, such as from coal mining to building monitoring.

The COMBI project has evaluated the additionality of the multiple impacts it has quantified in a qualitative way where a quantitative option was not feasible. For instance, the health and productivity gains from retrofits will only occur as a result of deep retrofits, therefore alternative spending of resources (e.g. on more shallow retrofits) will not result in these benefits.

2.2 Perspectives

When assessing multiple impacts, the perspective of the assessment needs to be defined, both in terms of which groups of stakeholders to take into account in the assessment and in terms of the geographic scale of the assessment. This section focuses on the groups/types of stakeholders to consider in the analysis.

The question of whose benefits count is decided by the analyst, taking into account political considerations of decision-makers who will use the results of the analysis as a basis for decision-making. One standard reference for these "evaluation perspectives" are the five different cost-effectiveness tests developed in the US by CPUC. For illustrative purpose, Table 1 shows the five CPUC evaluation perspectives. These "cost-effectiveness tests" consider the different components relevant for each perspective and thereby provide different information for decision makers (NAPEE 2008).

Table 1: Summary of benefits and costs in CPUC (2008) cost tests

Test	Benefits	Costs
PCT – participant cost test	Benefits and costs from the perspective of the end-use actor installing the end-use action Guiding question: is the end-use action economically attractive for the actor?	
	Incentive payments Bill savings Applicable tax credits or incentives	Incremental equipment costs Incremental installation costs
PACT – program administrator cost test	Perspective of utility, government agency, or third party implementing the program Guiding question: Is energy efficiency cheaper than expansion of energy supply?	
	Energy-related costs avoided by the utility Capacity-related costs avoided by the utility, including generation, transmission, and distribution	Program overhead costs Utility/program administrator incentive costs Utility/program administrator installation costs
RIM – ratepayer impact measure test	Impact of efficiency measure on non-participating ratepayers overall (only for EEOs) Guiding question: Will energy prices increase or decrease?	

	Energy-related costs avoided by the utility Capacity-related costs avoided by the utility, including generation, transmission, and distribution	Program overhead costs Utility/program administrator incentive costs Utility/program administrator installation costs Lost revenue due to reduced energy bills
TRC – total resource cost test	Benefits and costs from the perspective of all citizens in the country (region, municipality…) Guiding question: Will the total costs of energy services in the territory decrease?	
	Energy-related costs avoided by the utility Capacity-related costs avoided by the utility, including generation, transmission, and distribution Additional resource savings (i.e., gas and water if utility is electric) Monetised environmental and non-energy benefits	Program overhead costs Program installation costs Incremental measure costs (whether paid by the customer or utility)
SCT – societal cost test	Benefits and costs to all in the utility service territory, state, or nation as a whole Guiding question: Is the nation (region, city,…) better off as a whole?	
	Energy-related costs avoided by the utility Capacity-related costs avoided by the utility, including generation, transmission, and distribution Additional resource savings (i.e., gas and water if utility is electric); Monetised and non-monetised co-benefits such as cleaner air or health impacts	Program overhead costs Program installation costs Incremental measure costs (whether paid by the customer or utility) Monetised and non-monetised co-costs

Source: National Action Plan for Energy Efficiency (2008), adapted by Wuppertal Institute

For COMBI, theoretically three evaluation perspectives are relevant:

1. **End-use actor perspective (CPUC: PCT)**
2. **Societal perspective (CPUC: SCT)**
3. **Public budget perspective (CPUC: PACT for government but only cost side without lost revenues)**

End-use actor/investor perspective: The issue of whose benefits count is also referred to in cost-benefit analysis as 'standing'. Standing is well addressed in the theoretical CBA literature. The 'standing' from the final energy consumers or investors perspective indicates whether the energy efficiency actions are cost-effective for such end-user actors. From this evaluation perspective, (incremental) costs of the end-use actions are considered, while the energy cost savings over the action lifetime are counted as benefits. In addition, there can be non-energy benefits or costs, which COMBI aims to add to the energy benefits and energy efficiency costs. Higher benefits (energy alone or total) than costs indicate that end-user actors have economic incentives for implementing an action, which may normally be a precondition for an adoption of the respective actions. In COMBI, financial incentives (like tax, subsidy etc.) are not assessed (at least not comprehensively) as the focus is on the analysis of end-use actions, not on the impact of policies or programmes. Also, other hidden costs such as transaction costs are not quantified. Therefore, an end-user evaluation has not been carried out within COMBI.

Societal Perspective: In CBA, societal costs and benefits are equal to the sum of all individual costs and benefits, but net of taxes and transfers. 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 with no overall impact on societal welfare. From a societal perspective, only those costs and benefits count, which are not simple transfers but have an impact on the well-being of society as a whole.

Public budget perspective: Impacts can also be evaluated from the perspective of the public budget. If policies or programmes are funded from public budget, there are programme costs including financial incentives, overhead costs, and installation costs. In addition, reduced energy tax revenues of the government through decreasing energy sales and increased tax revenues from technology sales as well as relevant monetary impacts should be taken into account on the cost side when evaluating the net public budget impact. Benefits include energy cost savings for public operations (if any), reduced energy subsidy payments (if existent), additional corporate and value added tax (VAT) revenues due to induced investments and turnover (if any), and additional income tax revenues as well as reduced unemployment expenses (if employment increases). In addition, from various multiple impacts, effects on public budgets are possible, such as reduced public health spending, decreasing external costs for environmental degradation (e.g. soil, climate change adaptation).

COMBI approach

In early stages of the project, all three relevant evaluation perspectives were pursued. Due to resource constraints, only the evaluation perspective most relevant to policymaking was studied in detail and included in all reports and the COMBI online tool. However, the investor/end-user perspective can also partially be evaluated as information on energy cost savings, investment costs and many of the effects are studied and available also including taxes. The public budget analysis is not studied as separate perspective but treated as one impact studied in WP6, albeit with a methodologically limited approach not accounting for the manifold impact chains on public finances.

2.3 Scale

In terms of the geographic scope of whose benefits should count, in general, the appropriate scale of analysis depends on the type of multiple impact assessed and to which end the assessment is made. Different multiple impacts affect different geographic scales and it may be appropriate to take the boundary of the impact as the boundary for the assessment in order to avoid ignoring some impacts. Some air pollutants (e.g. PM10) have rather local impacts, while other air pollutants (e.g. SO_2) can have trans-boundary impacts. However, policymakers are generally interested in impacts to those within their jurisdiction, thus local authorities are generally interested in local impacts, whereas national authorities are interested in impacts at the national level. In practice, therefore, the appropriate geographic level of analysis depends largely on political considerations rather than analytical considerations.

Geographic scale also relates to context dependency – aggregation at a larger geographic scale entails a loss of information about the variation in the impact among different locations and the geographically uneven distribution between groups of stakeholders. Therefore, an approach with a higher level of e.g. geographic aggregation results in cost and benefit values that may not be useful to regional or local stakeholders, let alone individual cost-benefit considerations. For example, European (average) values for MI costs and benefits cannot convincingly be used for the purpose of national or local-level policy analysis without adjusting these to be reflective of local circumstances. The question of geographic scale also influences available methodologies.

Therefore, in order to be able to answer such questions, it is crucial that the basic geographic and temporal unit of analysis, as well as the total (system) boundaries of the analysis, are carefully chosen so that the results provide insights into such questions. Hence, in COMBI, each output values is assessed by action level output generation at the national level and these output would include trans-boundary effects as well where possible.

2.4 Context dependency

The specific context in which energy efficiency is implemented provides the background for a particular policy or energy efficiency action. For example, a study on energy efficiency policy impacts on employment in Hungary found that the *mode* of financing and not only the level of ambition of the energy efficiency action impacted the level of employment benefits. "[A]dditional negative employment effects can be expected if the renovation programme increases the expenditure of the government (depending on how the programme is actually financed) and reduces State revenues through, for instance, decreased energy tax collection. [...] Such elements are important because the employment effects depend not only on the actual size of the intervention, or the sector whose energy efficiency is enhanced but also on the types of financing of the measures that actually implement the energy efficiency enhancements, as found by Wade et al (2000) in their revision of the EU-funded SAVE programme" (Ürge Vorsatz et al, 2010). Employment impacts are affected by financing mode, because this influences the amount of disposable income that is available to different economic agents at different times. This, in turn, affects consumption and investment patterns, which again drives demand for goods and consequently employment in different sectors.

In COMBI, to tackle these kinds of context-dependent issues, partners identified the context dependency for their respective work packages and then fed the same into the methodological report. Table 1 shows some contexts relevant to COMBI.

Table 2: Identifies and classifies a few further contexts that matter while evaluating multiple impacts

Impacts	Context-dependencies
Disposable income and employment effect after energy efficiency actions in residential buildings	Details of financing schemes for retrofit (Ürge-Vorsatz et al., 2010)
Level of energy savings or comfort benefits/rebound effect	Take back in comfort (increased indoor temperatures; Milne & Boardman, 2000) are influenced by income levels, thermal comfort conditions before retrofits and the level of intervention – easy versus deep retrofits (Clinch and Healy 2001).
Number of traffic-related injuries and deaths due to modal shift in passenger transport	Baseline level of modal split in the studied locality and the "safety in numbers" effect (Elvik, 2009; Jacobsen, 2003; Vandenbulcke et al., 2009); differences between short-term and long-term risks and effects (Bhatia & Wier, 2011), general transport/city infrastructure, local traffic, vehicle operation and transport safety regulations (Bhatia & Wier, 2011; Jacobsen, 2003); existence of pedestrian- and cycling-friendly infrastructure (Pucher & Buehler, 2008), age of a person switching the transportation mode (de Hartog, Boogaard, Nijland, & Hoek, 2010), cultural and behavioral norms in relation to cycling (Vandenbulcke et al., 2009).
Avoided damage to human health, ecosystems and materials due to reduced air pollution emissions	Technological and fuel mix, geographic and climatic conditions, atmospheric transport, distribution of receptors and pollution sources, baseline air pollution concentrations, atmospheric chemistry, variation in receptor sensitivity, height of emission stack, air pollution control technologies (Amann, 2012; European Commission, 1995; Rabl, Spadaro, & Holland, 2014), energy prices (Zhang et al., 2015), GDP, industrial structure (Dong et al., 2015), developed vs developing country context (Takeshita, 2012)
Transaction costs	Type and size of technologies, regulatory frameworks, the complexity of transactions, and the maturity of policy instruments reducing transaction costs (Mundaca et al., 2013)

Source: (Ürge-Vorsatz et al 2016)

2.5 Distributional aspects

Emphasis on the total impact may not always show the importance of an impact. Also, as discussed above, due to the additionality criteria, sometimes the qualitative and distributional aspects of the multiple impacts could be more important than the aggregate, net effects. In some cases the total impact may be minor but at the disaggregated level, it may be relevant (such as local employment generation vs. exportable jobs, health impacts for a very specific group etc.). Therefore, it is crucial that multiple impacts also capture these distributional aspects of a policy rather than only the total effect.

For example, cost-benefit analysis (CBA) does not consider the difference of marginal utility of money, a standard economic textbook concept. The idea is that the additional utility from additional income is diminishing over income levels. If this concept holds true, ignoring the issue in CBA implicitly assumes equal marginal income utility among different income groups and may thus undervalue the effect for lower income groups.

The issue of distributional effects are mostly discussed in the context of developing countries but it is also relevant within the EU. For instance, Miller (2000) reviews variations between countries in the value of statistical life (VSL) by using regression analysis on a number of VSL studies conducted in different countries. Miller applied a benefit transfer method involving the transfer of the equation to estimate VSLs. The result shows that even within EU Member States there is a large variation between VSLs. The best-estimate value of a statistical life for Hungary and Poland is 610 and 480 thousand '97 USD, while for e.g. Sweden and France the values are 3230 and 2990 respectively. The values for developing countries, outside the scope of the current study, are one magnitude lower than estimates for poorer EU Member States. Miller (2000) concludes that due to the stability of the models he used and the robustness of his results, benefit transfer applied to VSL is "credible" (see Miller 2000; Urge-Vorsatz et al. 2015).

Thus in COMBI, distributional effect is defined as a sub-group/evaluation perspective and if necessary, impacts can be analysed separately during monetization and a narrower unit of analysis (i.e., a particular stakeholder group) may be used as a complement to understand the co-benefits/co-costs for particularly important groups of the society, such as the poorest, rural etc. at least qualitatively.

2.6 Rebound effects

A detailed study of rebound effects was not within the scope of COMBI and could not be undertaken due to resource constraints. Direct rebound was partially included in estimations of energy savings as provided by the COMBI input data modelling (see D2.2 and D2.2 annex). Indirect rebound effects (e.g. from increased GDP) would have entailed feedback loops after MI modelling which was not possible within this project. This remains as further study needs.

Table 3 provides a synopsis of challenges and line of action in COMBI;

Table 3: Recommended lines of action for the identified methodological challenges

Methodological challenges to the assessment of multiple impacts	Recommended line of action
Baseline, additionality and context dependency	Forecast the baseline incorporating as many dynamic variables as required to accurately quantify the true additional impact of energy efficiency action considering displacement effects (i.e. impacts taking place elsewhere). To the extent that is practical and feasible, consider multiple impact pathways in the baseline as well as in the scenario(s) under assessment
Distributional aspects	Define how the assessment is positioned with respect to pre-existing inequalities, and whether and how the quantification methods addresses them through adjustment factors. Bear in mind that applying no adjustment endorses the status quo by default
Perspectives	Prioritize the societal perspective in the calculation of net gains and losses but also consider the standing of individual actors (investors/end-users) when a technology option results in sizeable private gains or losses that prevent or facilitate investments in energy efficiency
Scale	Evaluate the impacts at national level first then analyze the possibility of transboundary issue

Source: (Urge-Vorsatz et al. 2016) and own elaboration

3 Methodological challenges of integrating quantified multiple impacts

The biggest challenge in the overall evaluation of multiple impacts (MI) is their integration i.e. aggregation of the individually assessed impacts. This section reviews several challenges that have been faced during the research efforts.

3.1 Accounting of MI

One main goal of COMBI is the integration of MIs into cost-benefit analysis. At the same time, COMBI does not cover all existing multiple impacts, and some only in physical terms that cannot be integrated into a CBA. However, integrating only a subset of all existing MI certainly creates a bias. For instance, if the risks, adverse effects, transaction cost etc. associated with an MI are not accounted for, this may lead to overestimation. Some impacts cannot be calculated for all actions due to resource constraints, other impacts are certain to exist but the data end empirical evidence base is insufficient yet to quantify them. Certainly, any quantification of multiple impact will only be a "state of the art" snapshot of currently possible evaluations and thus the best estimate under the given constraints rather than the exact truth.

3.2 Double counting

Some of the impact categories overlap with each other and this may lead to double counting. This is especially relevant when monetary values are incorporated into decision-making frameworks, such as in a cost-benefit analysis (Urge-Vorsatz et al 2014). For example, due to the improvement of building envelopes, indoor air quality improves. Indoor air pollutants such as pollen spores etc. affect health and productivity that ultimately also affect economic impacts like disposable income or public budget. Here, productivity, health, and economic impacts partially overlap with each other. Therefore, a careful analysis of impact end-points is required to avoid double counting. In section 4, further steps that have been taken in order to avoid double counting in COMBI are discussed.

3.3 Physical units and monetization

In order to *aggregate* outcomes from different physical units, or compare magnitudes of outcomes, a common metric is essential. This is typically done by converting different units into a monetary value. However, for several impacts like health, ecosystems etc., monetization is controversial (Luck et al 2011). Monetization of health and ecosystems are debated and their methods also have certain shortfalls. For instance, most of the ecosystem-related impacts are monetised using the "willingness to pay" (WTP) approach which basically reflects people's preference for environmental goods and services (Söderholm and Sundqvist 2003). However, use of WTP approach can be an underestimation because people may be unaware about the actual social costs of damaging environmental goods and services (Stirling 1997).

To compare the benefits with costs, we need a common metric, but some benefits such as environmental goods and services or health are not traded on the market, hence they do not have an established market value. Thus, as an alternative physical indicator can be used where monetized value is absent or monetization methodology is controversial (Stiglitz, Sen and Fitoussi 2009). The physical indicator can justify the intensity of these impacts where monetization method is absent or controversial, it can be used as a proxy for monetized value. However, physical values are in most cases not comparable between impact categories.

Therefore, in COMBI project, for each impact end-point physical metrics are quantified, and then according to the physical metric, monetization is be done where possible.

4 Methodological framework to mitigate the challenges related to the aggregation of impacts

The aggregation of multiple impacts is challenging because many of the impacts overlap and interact, and thus, not accounting this overlap may lead to over- or underestimation. Therefore, a comprehensive accounting is required (Ürge-Vorsatz et al 2016). That is why in the COMBI framework, the multiple impact pathway mapping approach was applied as a main scheme to systematically prevent this over-or under-estimation. Concretely, these steps were followed in order to accurately measure and aggregate multiple impacts:

1. Identify the impacts and root causes of the impacts explicitly
2. Identify the causal effects of an impact i.e. whether the impact results in another impact
3. Choose significant end-points
4. Quantify the incremental impacts in physical units
5. Monetize the physical value
6. Aggregation of impacts
7. Incorporate the monetised value in a decision-making analysis such cost-benefit analysis (CBA), marginal abatement cost curve (MCA).

Without following the first three steps, quantification of impact and hence aggregation of impacts are not possible. Thus, COMBI uses the impact pathway approach in order to identify the interactions among the impacts and also in order to understand the causal effects of impacts in a detailed manner.

The concept of impact pathway was first proposed in the ExternE project and has been demonstrated in the context of multiple impacts (Ürge-Vorsatz et al. 2014). It is a bottom-up approach where benefits and costs are estimated by following the pathways considering the causality chain. The pathway map starts from implementing an energy efficiency action and ends at the 'end-point'. Here, the endpoint can be defined as the last impact which is not transferring to another impact and also it is a policy target.

The impact pathway approach decomposes the chain of effects linking a root cause or causes starting from the implementation of an energy efficiency improvement (EEI) action until all the way to the impact receptor or welfare endpoint, i.e. the impact that directly leads towards utility. The aim of this approach is to better identify and characterize the interaction among impacts. An impact pathway map enables the representation of the multiple impacts in a way that facilitates a more consistent and comprehensive accounting of impacts and also, catalyzes their integration in a way that minimizes double counting and the under- and overestimation problems.

Before discussing further details of each step, the basic principles of the approach are discussed in the below section.

4.1 Advantages of the impact pathway approach

There are three key advantages of the impact pathway approach: transparency, consistency and marginal analysis (European Commission , 1995):

1. **Transparency**: The impact pathway approach precisely shows the impacts and their causal chain. Hence, it provides transparency in the time of calculation. Furthermore, uncertainties associated with impacts and their results can also be understood from the impact pathway.
   In the context of multiple impacts of energy efficiency actions there could be mainly three kinds of uncertainties found, i.e. a) some of the impacts and their sequential chain may not yet be fully understood or acknowledged, b) as stated in Urge-Vorsatz et al 2014 study "for analytical purpose, operating with distinct individual impact may hide complex relation. For example, renewables and energy efficiency reduce air pollution, which decreases health care costs versus a baseline and may release public resources that can be invested or spent on alternative uses and further enhance employment or gross domestic product levels", c) for some of the impacts, the quantification methodology is less reliable or not yet ready at all, hence they cannot be incorporated into the analysis quantitatively. Through the impact pathway approach, these uncertainties can be identified easily, because impact pathway maps enable the causal relationship between impacts which reveals all the details interactions among impacts and also for the impacts cannot be quantified due to methodological issues can be acknowledged through impact maps at least qualitatively.
2. **Consistency**: The approach enables a more systematic comparison between different impacts by considering different context dependencies and distributional aspects
3. **Marginal analysis:** Impact pathway approach analyses the impacts on a marginal basis hence, only the incremental effects of energy efficiency are considered in this approach. The impact pathway maps are designed to see the effects resulting from the implementation of EEI. This marginal analysis of effects tests the additionality criteria and hence ensure the inclusion of only incremental effects. Thus, this approach also avoids the chances of any bias as well.

In figure 1, a synthesis graph for all COMBI impacts shows all the significant pathways and its end-points.

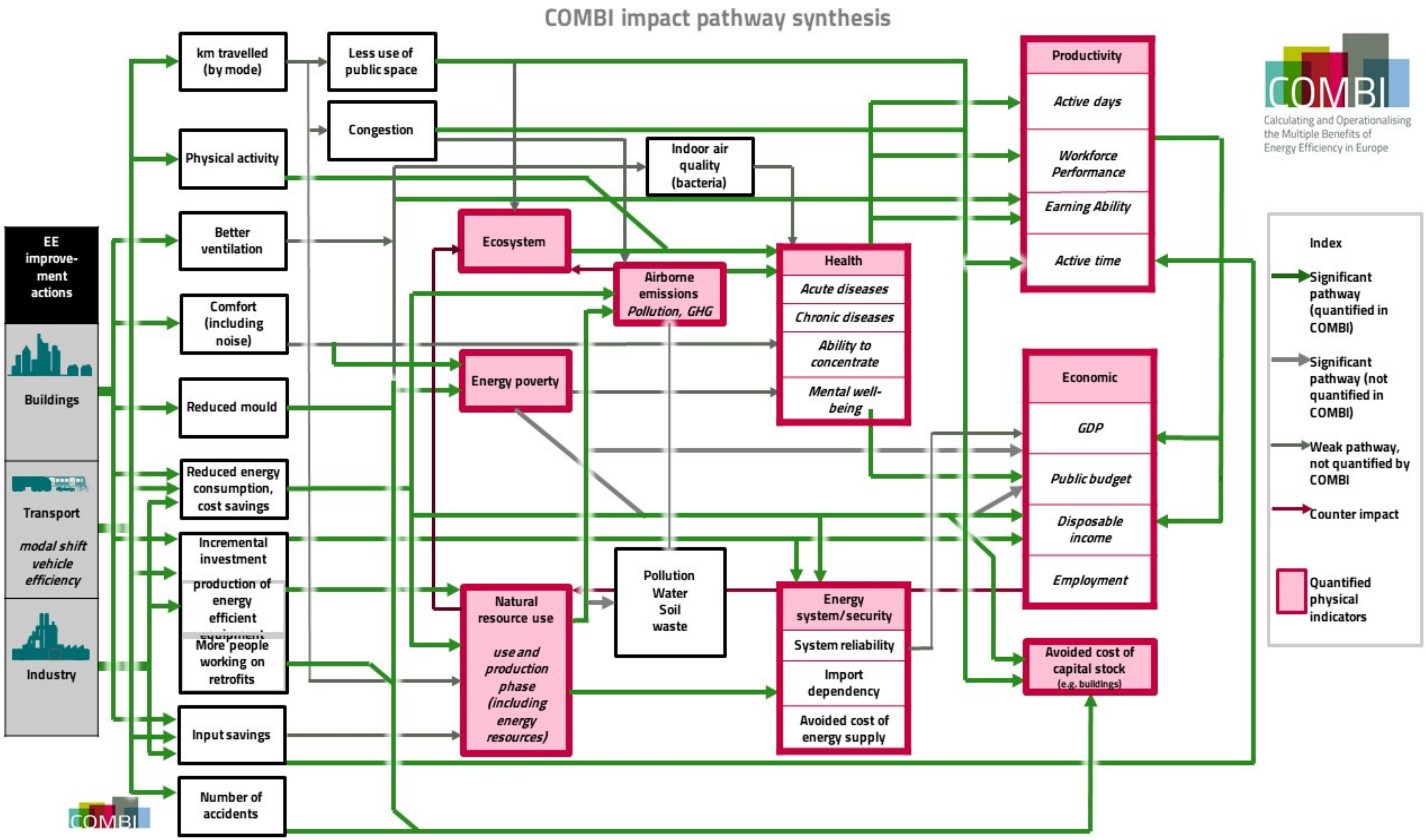

Figure 1: Impact pathway map incorporating all the impact category

Source: Own elaboration

Figure 1 portrays a causal chain of impacts starting from implementing all 21 energy efficiency actions from different sectors (buildings, transport, industry). Following this impact map, for each EEI action and impact a more detailed impact map has been carefully elaborated in the respective COMBI work packages where impacts are decomposed into as many pathways as can be differentiated, and each pathway into as many individual impact steps as key effects can be identified on the pathway for the specific EEI action. This helps us in aggregating all the incremental impacts while minimising the risk of double counting. Again, such graphical representation is only the snapshot of the current state of research and subject to constant amelioration.

As an example, installing a ventilation system in an airtight building would have four primary consequences such as better ventilation, reduction in mould growth, enhancement in comfort and lower energy consumption. These primary impacts would lead towards further impacts such as improvement in air quality, savings in natural resources and having less energy poor households. Improvement in air quality, saved natural resource and less energy poverty would lead to the impact end-points such as health improvement, productivity gain, reduced import dependency and macro-economic benefits, resulting additionally in public budget and energy price effects. Thus, while aggregating endpoints (for example: health, productivity and macro-economic impacts), extra precautions need to be taken so that only the additional, non-overlapping impacts are accounted. For example, installing HVAC system (in an airtight building) have both health and productivity benefits and productivity benefits are accounted as an addition to health benefits. For instance, diseases that are not considered in health impact estimations but affect productivity such as allergies due to indoor air pollutant exposure, are accounted separately which avoids double accounting of the same impact.

Ürge-Vorsatz et al (2016) summarizes the three key advantages of using an impact pathway approach for evaluation of the impacts:

1. Impact pathway maps provide a systematic accounting and thus, it accounts all the possible impacts – in other words, it reduces the risk of missing any impacts.
2. The detailed identification of the interactions among the impacts enables a much more systematic and precise calculation.
3. Causal chains and precise identification of impacts minimises the risk of over counting.

While the framework also cannot fully ensure that all multiple impacts are appropriately considered, it creates a more systematic and structured way of accounting for the various impacts that result from the EEI action/policy and thus help ensuring that all relevant impacts are identified (Urge-Vorsatz et al. 2016). In order to aggregate the impacts without committing any double counting, we need to understand how the impacts are defined and what is the specific quantification methodology used. Thus, in the next sections, these issues are discussed in more detail.

4.2 Overview of impacts quantified in COMBI

In COMBI, each work package is responsible for a specific impact category and each impact category consists of different aspects of that particular impact category and its specific impact end-points. Therefore the COMBI online tool includes two versions: the expert mode (including the full set of individual end-points) and standard mode (including as far as possible end-points pre-aggregated to impact categories). For instance, health-related impacts from building refurbishments comprise different effects: due to outdoor air pollutant concentration, and due to various diseases which are caused by exposure to indoor air pollutants. In the standard mode, only one value of all health-related effects is shown (as far as available in a consistent unit) whereas in the expert mode different disease- (or burden-of disease-) related values are shown. Furthermore, each work package consists of many aspects. For example, work package 3 (air pollution) analyses not only health-related effects of air pollution but also the effects of air pollution on eutrophication and acidification etc. Similarly, the macro-economy work package not only analyses GDP effects of energy efficiency actions but other aspects such as fossil fuel price and employment effects.

To provide an overview of impacts quantified in COMBI, table 4 shows different aspects of impacts under different work packages evaluated in COMBI:

Table 4: Overview of work package category and impact indicators

Work packages	Impact indicators	Description of the impact
WP3: Air pollution	Human health	Premature mortality due to the exposure of different outdoor pollutants namely PM2.5,ozone and NOx
	Eco-systems: acidification	Total ecosystem area spared from acidification
	Eco-systems: eutrophication	Total ecosystem area spared from eutrophication
	Air pollution: Emissions (mid-points)	Outdoor air pollutants emission from energy production and transportation (by air pollutant)
WP4: Resource	Material Footprint (sum fossil fuels, minerals, biotic, unused)	Life-cycle wide use of abiotic and biotic resources from nature.
	– Life-Cycle wide fossil fuel consumption	Life-cycle wide demand of fossil fuels from used extraction.
	– Minerals	Life-cycle wide demand of minerals from used extraction.
	– Biotic raw materials	Life-cycle wide demand of biotic raw materials from nature.
	– Unused extraction	Life-cycle wide demand of biotic and abiotic materials from economic unused extraction.
	Direct carbon emissions	Direct greenhouse gas emissions from combustion.
	Carbon Footprint (GWP, lifecycle emissions incl. direct emissions)	Global warming potential (including direct and indirect/upstream emissions).
WP5: Social welfare	Excess cold weather mortality	Premature mortality due to inadequate heating and cooling
	Excess winter morbidity attributable to inadequate housing	Morbidity due to inadequate heating and cooling
	Indoor dampness/asthma	Asthma incidence due to dampness in the building
	Active days (impact through health- asthma, allergy, cardiovascular disease, cold and flu and traffic time saved)	Change in active work days due to health impacts from high efficiency building shells and HVAC systems and time gained by opting for modal shift towards active transportation

	Workforce performance	Quantity of gains from labour effectiveness after working in passive-house standard buildings.
WP6: Macro-Economic impacts	Temporary (business-cycle) aggregate demand	Additional investment-driven economic stimulus. Effect will 'die out' over time and conditional on existence of national output gap.
	Temporary (business-cycle) employment	Economic stimulus-driven increase in employment. Effect will 'die out' over time and conditional on existence of national output gap.
	Temporary (business-cycle) public budget effects	Economic stimulus-driven effect on public budgets. Negative if stimulus is driven by public money. Can be positive otherwise. Effect will 'die out' over time and conditional on existence of national output gap.
	Fossil fuel price effects*	Energy efficiency measures will reduce the prices of fossil fuels, as overall demand is reduced. This may spur rebound effect
	ETS price effect*	Energy efficiency measures will reduce the need for alternative mitigation actions, thereby lowering the ETS price
	Terms of Trade effect*	When the price of imports is reduced and/or the price exports is increased, this constitutes an overall welfare improvement know as a terms of trade effect
	Sectoral shifts*	Energy efficiency measures will give rise to economic sectoral shifts depending on the relative cost effectiveness of the measures in the different sectors. When the overall cost of production (including both investment costs and energy costs) is reduced, the sector will expand relatively, and vice versa
WP7: Energy security	Energy intensity	Final energy demand divided by GDP
	Import dependency	Net imports and monetary value of net imports of primary coal, crude oil and natural gas in energy supply
	Aggregated energy security index	Herfindahl-Hirschman Index (HHI) capturing the effects of COMBI actions on import dependency, diversification of energy sources and geographical diversification (origins of the energy sources).
	Avoided electric power output & investment costs	Avoided domestic electric power output and resulting avoided investment costs in power plants and cogeneration plants
	Derated reserve capacity rate	Derated reserve capacity of the power sector, divided by its total installed capacity, multiplied by 100. Derated capacity is a reduced capacity that takes into account that not all generation capacity will run at its theoretical maximum at times of peak demand.

* These impacts are only quantified on a total-EU scale and thus cannot be included to the COMBI online tool but are only included in the D6.4 quantification report.

Source: Own elaboration (data provided by OMBI partners)

Table 3 provides a complete overview of the impacts studied in COMBI. There are additional impacts which are not quantified in COMBI due to resource constrains but each work package report discusses about these non-quantified impacts in their respective reports.

All these different indicators are obtained by implementing different energy efficiency actions. To understand and evaluate them, it is important to describe the causal effects of impacts. Thus, a detailed impact pathway map is needed where the causal effects for the impacts are established.

4.3 Summary of methodologies

As discussed in the beginning of the section 1, it is important to understand the different impact quantification methodologies in order to have a better understanding of the interactions between impacts. Even with a detail impact pathway map, there still exists a chance of double counting due to different methodological overlaps. For instance, one of the productivity indicator namely active days is calculated based on indoor exposure (indoor exposure is a combination of indoor pollution concentration and outdoor pollution infiltrating indoor). Now if outdoor pollution reduces due to some reason (for example due to furnaces or ovens efficiency improvement) then it would have an impact on productivity as well. In other words, a part of productivity impact quantification methodology is dependent on outdoor pollution concentration. Thus, without knowing the methodology if we try to add productive healthy life years with WP 3's outdoor pollution-related health effects then it would lead to double counting. From the impact pathway though the interaction between outdoor pollution and productivity is visible but without knowing to what extent they are dependent, it is almost impossible to avoid double counting. Hence, table 5 below provides a summary of quantification methodology for all the impacts studied in COMBI:

Table 5: Summary of quantification methodologies

Work packages	Impact indicators	Description of the quantification methodology
WP3: Air pollution	Human health	Premature mortality due to the exposure of different outdoor pollutants by using GAINS model
	Eco-systems: acidification	Total ecosystem area spared from acidification by using GAINS model
	Eco-systems: eutrophication	Total ecosystem area spared from eutrophication by using GAINS model
	Air pollution: Emissions(mid-points)	Outdoor air pollutants emission from fuel combustion and transportation by using GAINS model
WP4: Resource	Material Footprint (sum fossil fuels, minerals, biotic, unused)	The Material Footprint is the sum of extracted abiotic (fossil fuels, metal ores, minerals) and biotic raw materials from nature, including the extraction of economic unused materials. Quantified using Material Flow Accounting.
	Life-Cycle wide fossil fuel consumption	Accounting (Material Flow Accounting) of all raw materials from nature, that can be classified as fossil fuels and are put to an economic use.
	Minerals	Accounting (Material Flow Accounting) of all raw materials from nature,that can be classified as minerals and are put to an economic use.
	Biotic raw materials	Accounting (Material Flow Accounting) of all raw materials from nature, that can be classified as biotic raw materials and are put to an economic use.

Work packages	Impact indicators	Description of the quantification methodology
	Unused extraction	Accounting of materials that are extracted from nature (Material Flow Accounting), that are not translocated from site or put to an economic use. This includes overburden and by-catch as well as waste on site.
	Direct carbon emissions	Direct carbon emissions are based on emission factors for different fuel types found in the IPCC reports. Values are listed in CO_2 equivalents per unit of energy.
	Carbon Footprint (GWP, lifecycle missions incl. direct emissions)	Life-cycle Assessment of characterised greenhouse gases and their global warming potential in 100 years (GWP 100a). Characterisation factors are based on the IPCC reports.
WP5: Social welfare	Excess cold weather mortality attributable to inadequate housing	Premature mortality due to inadequate heating and cooling, quantified by dedicated modelling.
	Excess winter morbidity attributable to inadequate housing	Morbidity due to inadequate heating and cooling, quantified by dedicated modelling.
	Indoor dampness/asthma	Asthma incidence due to dampness in the building, quantified by dedicated modelling.
	Active days (impact through health-asthma, allergy, cardiovascular disease, cold and flu and traffic time saved)	Indoor exposure dose-response model is used to calculate the indoor exposure-related active days and basic reduction method is used to calculate congestion-related active days, quantified by dedicated modelling.
	Workforce performance	Basic performance improvement equation is used to calculate workforce performance, quantified by dedicated modelling.
WP6: Macro-Economic impacts	Temporary (business-cycle) aggregate demand	Input/output analysis and fiscal multiplier analysis
	Temporary (business-cycle) employment	Input/output analysis and fiscal multiplier analysis
	Temporary (business-cycle) public budget effects	Input/output analysis, fiscal multiplier analysis and budgetary semi-elasticities
	Fossil fuel price effects	General equilibrium modelling (Copenhagen Economics Global Climate and Energy Model - CECEM)
	ETS price effect	General equilibrium modelling (Copenhagen Economics Global Climate and Energy Model - CECEM)
	Terms of Trade effect	General equilibrium modelling (Copenhagen Economics Global Climate and Energy Model - CECEM)
	Sectoral shifts	General equilibrium modelling (Copenhagen Economics Global Climate and Energy Model - CECEM)
WP7: Energy security	Energy intensity	Final demand reduced by COMBI actions (WP2) divided by GDP
	Import dependency	COMBI Energy balance model. Main input is final demand) reduced by COMBI actions (WP2). Relevant output is net imports. Net imports of fuels multiplied by their respective energy prices
	Aggregated energy security	COMBI Energy balance model. Relevant output is net imports. Allocation model to determine country of origin of imports. Use of risk indicators to assess political risks.
	Avoided electric power output & investment costs	COMBI Energy balance model. Power sector model to determine mix of power plant and cogeneration plant

Work packages	Impact indicators	Description of the quantification methodology
		technologies and capacities. Relevant output is net power output. Avoided power output multiplied by specific capital costs per technology.
	Derated reserve capacity rate	COMBI Energy balance model and power sector model. Model to determine peak loads and required reserve capacities based on annual load duration curves.

Source: Own elaboration (data provided by COMBI partners)

Table 5 provides a brief overview of quantification methodologies for each impact end-point studied in COMBI. Along these descriptions of methods, at least the common assumptions also need to be understood in order to have a complete overview on quantification methodologies. For instance, both WP 3 and WP 4 need to apply assumptions on the decarbonisation trend in the energy supply sector. And both WP 3 and WP 4 apply the same assumptions on the 2030 energy mix: "the shares in the power plant and CHP production mix of flow renewables (hydro, wind, PV, tide/wave/ocean, geothermal and solar thermal) and of nuclear remain fixed throughout the scenarios in 2030, and that only the generation, and thus required capacities (MW) of the combustible fuel based plants) plants will change (decrease) as a result of the energy savings" (Couder, J. and Verbruggen, A. 2017).

From Table 5, another potential methodological interaction is identified between WP 3 (health from air pollution) and WP 5 (productivity from health). More precisely, one of the indicators of productivity (active days) can be measured through disability adjusted life years (DALY) due to indoor exposure i.e. indoor pollution plus outdoor pollution infiltrating indoor. If the outdoor air pollution reduces say due to building renovation, then automatically less pollutants would infiltrate and thus, less productivity loss would occur. Hence, to avoid this overlap between WP 3 health and WP 5 productivity, in the time of aggregation, only DALY due to indoor air pollution would be accounted in the CBA from WP 5 productivity and outdoor pollution-related health impact would be taken from WP 3 health impact. In other words, active days is further disaggregated to DALY due to outdoor air pollution and DALY due to indoor air pollution with a help of a country –specific infiltration factor. This infiltration factor varies country to country since both outdoor and indoor air pollution level varies across different countries (Hänninen, O., & Asikainen 2013).The values of these infiltration factors for different countries are taken from the healthvent project. Moreover, as per methodological description, there is an overlap within productivity impact. More precisely, both absenteeism and presenteeism calculate the morbidity due to indoor exposure and DALY also calculates morbidity due to indoor exposure. However, DALY not only calculates morbidity, it also measures the mortality aspect due to indoor exposure. Thus, in the CBA, for productivity impact, only DALY is incorporated to measure the indoor exposure-related health effects[1].

[1] For more information about why DALY is incorporated and how these specific indicators are defined, please see COMBI report D 5.a at https://combi-project.eu/

4.4 Avoiding double counting of impacts

As discussed in section 3.3, in order to aggregate impacts, or compare magnitudes of outcomes, a common metric is needed. This is typically done by converting different units into a monetary value. However, from the discussion across section 3 and with the help of figure 1, it is clear that aggregation of different impacts is not easy or even impossible. One of the key concerns of aggregation is double counting error. Monetised values of impacts need to be additional and independent of other impacts in order to be eligible for aggregation and included in the cost-benefit analysis, in order to avoid overestimation. Thus, this section shows the detailed interactions and proposes a solution to, varying between impacts.

Considering these impact end-points (marked in red in figure 1), in Table 4, the authors have already described the end-points of different work packages and in Table 5, end-point quantification methodologies and common assumption are described to provide a complete overview of impact end-point.

Now table 6 below shows the unit of disaggregated impacts studied in the COMBI project. This micro-level disaggregation helps to avoid double-counting of impacts. Moreover, the detailed analysis of impacts provides a comprehensive understanding of which impact can be monetised and hence can be incorporated in the CBA.

Table 6: List of impact end-points, units and evaluation perspective

Work package	Impact end-point	Units	Monetization possible	Interactions with other MIs	Overlaps with other impacts and solutions
WP3	Human health from outdoor air pollution	DALY	Yes	-	Health effects due to outdoor pollution overlaps with productivity due to productivity quantification methodology. Thus, to avoid the overlap section productivity impact is further disaggregated to outdoor sources and indoor sources which clarifies the extent of overlap and accordingly productivity is adjusted before incorporating into CBA.
	Eco-systems: acidification	% change in area affected by excess acidification	not within COMBI	-	No overlaps with other impacts
	Eco-systems: eutrophication	% change in area affected by eutrophication	not within COMBI	-	No overlaps with other impacts
	Air pollution: Emissions(mid-points)	In tons	No	Productivity-specifically with Active days	Percentage of active days loss due to outdoor exposure is can be calculated and hence that percentage can be deducted from active days.
WP4	Material Footprint (sum abiotic & biotic &	In tons	Partially	-	Material footprint is a summation of abiotic, biotic

Work package	Impact end-point	Units	Monetization possible	Interactions with other MIs	Overlaps with other impacts and solutions
	unused)				and unused materials hence incorporation of material footprint automatically includes abiotic, biotic and unused materials. However, since material footprint is partially monetized due to methodological complexities, the monetary value is underestimated for resources. Full overlap with investment costs (material inputs part of production costs)
	Life-Cycle wide fossil fuel consumption (additional to direct combustion)	In tons	Yes	-	Overlap with energy cost savings hence not included in the CBA
	Metal Ores	In tons	Yes (partially)	-	See above: full overlap with investment
	Minerals	In tons	Not within COMBI	-	See above: full overlap with investment
	Biotic raw materials	In tons	Not within COMBI	-	See above: full overlap with investment
	Unused extraction	In tons	No	-	–
	Direct carbon emissions	Mt CO2eq (GWP 100a)	Yes	Interacts with carbon footprint	Double counting does not occur as carbon footprint is not monetised.
	Carbon Footprint (GWP, lifecycle missions incl. direct emissions)	Mt CO2eq (GWP 100a)	Not within COMBI	Interacts with direct carbon emission	Double counting does not occur as carbon footprint is not monetised
	Excess winter mortality attributable to inadequate housing	Number of deaths avoided due to improved building ventilation	Yes	-	No overlaps with other impacts
	Excess winter morbidity attributable to inadequate housing	DALY	Yes	-	No overlaps with other impacts
WP5	Indoor dampness/asthma	DALY	Yes	-	No double counting between dampness related asthma and active days loss from asthma as dampness related asthma only considers dampness from inadequate heating. On the other hand, active days from asthma does not consider the any temperature related health effects.

Work package	Impact end-point	Units	Monetization possible	Interactions with other MIs	Overlaps with other impacts and solutions
	Active days (sick days ,DALY[2] and avoiding road congestion) due to asthma, cold and flu, Cardiovascular disease, cancer and COPD)	Number of days gained from indoor exposure-related diseases and time saved by avoiding traffic congestion	Yes	-	As mentioned above, as active days calculations do not incorporate any heating-related effects whereas indoor dampness/asthma methodology is based on heating condition.
	Workforce Performance	Labour input per hour	Yes		No overlaps with other impacts
WP6	Temporary (business-cycle) GDP effects	€	Yes		Overlaps with energy costs, investments and potentially all multiple impacts
	Temporary (business-cycle) employment/GDP effects	Number of job years	Not within COMBI		If monetized, full overlap with GDP
	Temporary (business-cycle) public budget effects	€	Yes		No overlaps with other impacts
	Fossil fuel price effects*	€/MWh, % change	Yes	-	The price of fossil fuel is adjusted to maintain consistency with energy import end-point. However, since they are not aggregated, there would be no double counting.
	ETS price effect*	€/tCO2	Yes		No overlaps with other impacts
	Terms of Trade effect*	TOT index change	Not within COMBI		No overlaps with other impacts
WP7	Energy intensity	ktoe/1000€	Not within COMBI		
	Import dependency	Herfindahl-Hirschman index HHI	No	-	Only consider energy cost saving that captures import dependency
	Aggregated energy security index	No	Not within COMBI		No overlaps
	Avoided electric power output & investment costs	TWh	Yes		No overlaps
	Derated reserve capacity rate	Share (%)	No		No overlaps

* not included in the COMBI online tool, because quantified only at total EU level. Results available from D6.4 report.

As it can be seen from the impact pathway map and from the above table as well, many of the impacts (such as, energy intensity etc.) cannot be expressed in monetary unit mostly because of the uncertain methodology and resource constraints.

[22] Sick days is calculated based on absenteeism and presenteeism due to asthma, cold and flu and cardiovascular disease and DALY is calculated due to asthma, cold and flu, cardiovascular disease, Chronic obstructive pulmonary disease (COPD)and cancer

The COMBI online tool gathering all quantification outputs from Work Packages thus has 3 sections: physical quantifications (including all quantifications), monetary values (including only impacts where monetization was viable) and Cost-Benefit Analysis (see section below). As it can be seen from the above table, some of the impacts are not additional and many of them are overlapping. These cases have to be analysed well before including to CBA (see below). At least, in COMBI it was possible to identify possible overlaps. There are two specific reasons behind this:

1. Due to categorization of impacts and detailed impact pathway map, it became clear which of the impacts are overlapping and hence what portion of the impacts is additional. For example, indoor cold-related health effects are additional to indoor pollutant and dampness-related health and productivity effects. Thus, both of them are additional impacts and can be added in a CBA.
2. Some of the impacts (such as Derated capacity margin, mineral and biotic resource damage etc.) are not monetised due to methodological issues and hence in these cases chances of double counting is avoided. For example, carbon footprint (total emissions incl. upstream emissions) and direct carbon emissions (from combustion only) overlap but since carbon footprint is not monetised (and can thus not enter CBA) in COMBI, double counting is avoided.

In work package 6 there are four impacts (fossil fuel price effects, ETS price effect, terms of trade effect and sectoral shifts) which are calculated only at the EU level to show the overall impact at EU level. Thus, although these effects can be quantified in monetary terms, they cannot be included in the CBA, since they are at EU level only and not attributed to single countries and actions. Details about these impacts are discussed in the work package 6 methodology report (D6.4).

4.5 Selection of impacts for aggregation

In COMBI, all the impacts are calculated at per country basis in the year 2030, as this is the year of policy targets on energy efficiency currently being set in EU legislation.

As discussed above, aggregation of multiple impacts is only possible if impacts are quantified in a common unit, i.e. if they are possible to monetize. DALY might be another attractive unit for the aggregation of many impacts. From the above Table 6 thus immediately follows a first shortlist excluding all non-monetizable impacts from aggregation. In order to provide maximal transparency and open access to quantification and monetization results, COMBI follows a two-step approach in the online tool. We make sure that only those monetized impacts enter Cost-Benefit Analysis where double-counting can be definitely ruled out and additionality assured. But as well, we provide the option to select and compare monetized impacts even if there are overlaps and double-counting highly certain (but only outside CBA). Both steps are explained below.

4.5.1 Monetized impacts analysis

Following the step of quantification in physical units (and display of only one indicator in physical units) in the online tool, there is a second step of "monetized impacts". In this step, analysts may select one to all monetized impacts in the tool for direct comparison, irrespective of potential overlaps and double-counting.

For this case, impacts are aggregated directly by the below formula:

$$\boldsymbol{MI_{ac}} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{n}} (\boldsymbol{IM_{aci}})$$

With MI = multiple impacts, a = energy efficiency action, c = country, IM = impacts, i = type of impacts.

Thus, IM_i denotes different impacts from different work packages. For instance, IM_1 denotes health effects due to outdoor exposure.

The online tool offers display options to also visualise different impacts stacked on top of each other either by country or by EEI action.

4.5.2 Cost-Benefit Analysis: selection of impacts

Equally, in the third step of the online tool, the Cost-Benefit Analysis (CBA), analysts may select one to multiple impacts into the graphical (and numerical) analysis. However, for CBA, insights gained from the impact pathway analysis on potential overlaps and double-counting were applied to prohibit impacts entering CBA with any danger of double-counting leading to over-estimation.

The below Table 7 lists impact end-points with their possible inclusion (✓) or exclusion (✗) to the COMBI CBA and gives a brief reasoning their in-/exclusion.

Table 7: Inclusion of impacts to COMBI CBA

Work package	Impact end-point	Overlaps with other impacts and solutions	Inclusion/ exclusion to CBA	Reasoning
WP3	Human health	Health effects due to outdoor pollution overlaps with productivity due to productivity quantification methodology. Thus, to avoid the overlap section productivity impact is further disaggregated to outdoor sources and indoor sources which clarifies the extent of overlap and accordingly productivity is adjusted before incorporating into CBA.	✓	Overlaps accounted in WP5
	Eco-systems: acidification	→	✗	not monetized
	Eco-systems: eutrophication	→	✗	not monetized
	Air pollution: Emissions(mid-points)	→	✗	not monetized
WP4	Material Footprint (sum abiotic & biotic & unused)	Material footprint is a summation of abiotic, biotic and unused materials hence incorporation of material footprint automatically includes abiotic, biotic and unused materials. However, since material footprint is partially monetized due to methodological complexities, the monetary value is underestimated for resources. Full overlap with investment costs (material inputs part of production costs)	✗	Full overlap with investment costs (material inputs part of production costs)
	Life-Cycle wide fossil fuel consumption (additional to direct combustion)	Overlap with energy cost savings	✗	Full overlap with investment costs (material inputs part of production costs)

Work package	Impact end-point	Overlaps with other impacts and solutions	Inclusion/ exclusion to CBA	Reasoning
	Metal Ores	See above: full overlap with investment	✗	Full overlap with investment costs (material inputs part of production costs)
	Minerals	→	✗	not monetized
	Biotic raw materials	→	✗	not monetized
	Unused extraction	→	✗	not monetized
	Direct carbon emissions	Double counting does not occur as carbon footprint is not monetised.	✓	No overlaps with other impacts
	Carbon Footprint (GWP, lifecycle missions incl. direct emissions)	Double counting does not occur as carbon footprint is not monetised	✗	not monetized
WP5	Excess winter mortality attributable to inadequate housing	No overlaps with other impacts	✓	No overlaps with other impacts
	Excess winter morbidity attributable to inadequate housing	No overlaps with other impacts	✓	No overlaps with other impacts
	Indoor dampness/asthma	No double counting between dampness related asthma and active days loss from asthma as dampness related asthma only considers dampness from inadequate heating. On the other hand, active days from asthma does not consider the any temperature related health effects.	✓	Overlaps with outdoor air pollution accounted for in dedicated quantification efforts
	Active days (sick days ,DALY[3] and avoiding road congestion) due to asthma, cold and flu, Cardiovascular disease, cancer, and COPD)	As mentioned above, as active days calculations do not incorporate any heating-related effects whereas indoor dampness/asthma methodology is based on heating condition.	✓	Overlaps with outdoor air pollution accounted for in dedicated quantification efforts
	Workforce Performance	No overlaps with other impacts	✓	No overlaps with other impacts
WP6	Temporary (business-cycle) GDP effects	Overlaps with energy costs, investments and potentially all multiple impacts	✗	Overlaps with energy costs, investments and potentially all multiple impacts
	Temporary (business-cycle) employment/GDP effects	If monetized, full overlap with GDP	✗	not monetized
	Temporary (business-cycle) public budget effects	No overlaps with other impacts	✗	Rather analysable as separate evaluation perspective, not aggregable
	Fossil fuel price effects*	The price of fossil fuel is adjusted to maintain consistency with energy import end-point. However, since they are not aggregated, there would be no	✗	quantified only at EU level

[33] Sick days is calculated based on absenteeism and presenteeism due to asthma, cold and flu and cardiovascular disease and DALY is calculated due to asthma, cold and flu, cardiovascular disease, Chronic obstructive pulmonary disease (COPD)and cancer

Work package	Impact end-point	Overlaps with other impacts and solutions	Inclusion/ exclusion to CBA	Reasoning
		double counting.		
	ETS price effect*	No overlaps with other impacts	✗	quantified only at EU level
	Terms of Trade effect*	No overlaps with other impacts	✗	quantified only at EU level
WP7	Energy intensity		✗	not monetized
	Import dependency	Only consider energy cost saving that captures import dependency	✗	not monetized
	Aggregated energy security index		✗	not monetized
	Avoided electric power output & investment costs	No overlaps	✓	
	Derated reserve capacity rate		✗	not monetized

From the above table follows, that only a very limited list of COMBI-monetized actions could be allowed to enter Cost-Benefit Analysis for which double-counting could be ruled out. The COMBI CBA can thus be regarded as a conservative estimation of multiple impacts as many impacts that do certainly exist could not be monetized (or even physically quantified).

Cost-Benefit Analysis

In a first step, all base data (energy savings, energy cost savings, investment costs, action-specific lifetimes) and multiple impacts are included to the online tool, disaggregated by country and EEI action. In a second step, the online tool performs a calculation of various cost-benefit indicators such as net values (over the action lifetime and annualised), cost-benefit ratios and the levelisation of net values by energy savings and GHG emissions. These values are also used to construct marginal cost curves.

The details of these calculations are explained in the manual/documentation of the online tool (D8.1) and the full quantification report (D2.7).

5 Discussion

In order to understand the full potential of energy efficiency actions, all the benefits (i.e. all multiple impacts) and costs need to be accounted for in the ex-ante analysis. However, the inclusion of all the benefits i.e. both direct and indirect impacts, especially to an enhanced Cost-Benefit Analysis are often difficult due to mainly four reasons:

1. Lack of systemic account of all the impacts for energy efficiency improvement (EEI) actions.
2. Even if the effects of EEI actions are identified, it is often the case that they are not quantified due to lack of quantification and aggregation methodology

3. Even if multiple impacts are possible to quantify, the monetization method for some impacts (such as ecosystem, resource, health) is controversial and in some cases, not possible (for the list of non-monetised impacts refer to table 5).
4. Even if possible to monetize, there may be dangers of double-counting resulting from impact pathway analysis and theoretical considerations

For any CBA including multiple impacts it is thus crucial to be very transparent about the above steps to provide scientifically robust results. In COMBI this transparency is given:

- for reasons 1 to 3 in the respective quantification reports of individual impacts
- for reason 4 in this synthesis report

However, the question emerges about the issue of double counting what constitutes as most robust quantification. While potentially double counting through hidden methodological complexities is problematic, not counting important impacts can also lead to biased policy advice.

In the COMBI project the project team decided to stay with the most conservative solution – i.e. exclude impacts where any potential double counting may occur. However, for each project this needs to be individually decided: which type of error (potential double counting, or excluding the impact in order to prevent this risk) may introduce larger or policy-wise riskier biases?

In principle, COMBI results (and CBA) could relatively easily be adjusted to include additional impacts that are currently excluded, if new insights on double-counting emerge or policymakers are interested.

The main objective of the COMBI project is to initiate the process of systematic quantification of impacts and also, post quantification, aggregation of impacts in order to incorporate them into a common evaluation framework such as CBA. Throughout this synthesis report, different issues related to quantification and aggregation of impacts are discussed. Even after these thorough discussions, there are still some issues such as distributional effects or identification of impacts which could not be solved comprehensively in this project mainly due to limited time and resource constraints. For instance, higher spatial disaggregation of impacts would multiply data gathering needs and modelling requirements substantially.

However, despite these data and resource-related challenges, COMBI attempted to quantify and aggregate the impacts for all 21 EEI actions as comprehensively as possible. The most crucial challenges of impact aggregation are comprehensively discussed in this report. With the help of a detailed impact way map, the risks of double counting can be identified and thus reduces for CBA if respective impacts are excluded. However, along with the impact pathway map, we also need to understand the individual impact quantification methodologies and their assumptions in order to avoid any methodological overlaps. With the help of table 6 and 7 we have been able to identify most of the possible overlaps and propose solutions accordingly to avoid counting an impact more than once.

Selected further research directions

The COMBI project has advanced European and global knowledge on the quantification and aggregation of multiple impacts in a significant way, both on the theoretical and empirical/modelling levels. However, one project can only scratch the surface of the large unknown world of the interactions of the multiple impacts with societal and economic processes.

We collect a few selected priorities for future research directions that are needed to further advance our ability to better integrate multiple impacts into quantitative decision-making frameworks.

- Perhaps one of the most important conclusion of the COMBI project is that quantifying and aggregating multiple impacts is a very complex task, and due to the high level of context dependencies, much less transferrable than other cost/benefit assessments such as related to the direct costs and benefits of energy efficiency actions. While COMBI has created frameworks and pioneered procedures that can streamline such efforts, significantly more work is needed to create further tools, methods and templates that can make multiple impact assessment work significantly less resource-, time and data intensive. Equations with elasticities/parameters that could be easily calculated based on standard, easily accessible or estimate-able data from projects/actions/policies/investments could make such efforts much less costly and thus feasible on a project basis.
- However, due to the specific context dependencies and interrelatedness of impacts, such elasticities cannot be simple factors (e.g. on energy savings), but would rather have to be more complex equations accounting for levels (of e.g. energy consumption, air pollution, energy poverty etc.) and changes in other impacts.
- If the COMBI tool could be further developed based on such theoretical and data advances, this could provide a more long-lasting policy and planning impact to the project.

Annex:

Table 8: Avoided/saved disability adjusted life years loss (DALY) due to indoor and outdoor pollution for each EU member states

Countries	Total DALY saved	Total DALY saved by avoiding indoor pollution	Total DALY saved by avoiding outdoor pollution exposure at indoor
Austria	898	421	477
Belgium	696	252	444
Bulgaria	285	72	213
Cyprus	47	18	29
Czech Rep.	811	227	584
Denmark	286	119	168
Estonia	100	33	67
Finland	238	96	143
France	2908	1376	1532
Germany	4062	1700	2362
Greece	577	182	395
Hungary	1657	440	1217
Ireland	182	85	97
Italy	4672	1670	3002
Latvia	73	19	54
Lithuania	97	24	73
Luxembourg	24	15	9
Netherlands	926	374	553
Poland	1984	470	1514
Portugal	434	130	304
Romania	1993	346	1647
Slovakia	265	57	208
Slovenia	160	53	107
Spain	1540	608	933
Sweden	431	181	251
United Kingdom	3137	998	2139

Table 9: Avoided/saved disability adjusted life years loss (DALY) due to indoor and outdoor pollution for each EU member states and their monetary values

Countries	Total DALY saved by avoiding indoor pollution	Monetised value for DALY saved from indoor polution (Million Euro)	Total DALY saved by avoiding outdoor pollution exposure at indoor	Monetised value for DALY saved from outdoor polution exposure at indoor (Million Euro)
Austria	421	69.7	477	79.0
Belgium	252	39.5	444	69.6
Bulgaria	72	1.1	213	3.3
Cyprus	18	1.6	29	2.5
Czech Rep.	227	12.9	584	33.1
Denmark	119	27.6	168	38.9
Estonia	33	1.6	67	3.1
Finland	96	16.3	143	24.2
France	1376	200.9	1532	223.7
Germany	1700	251.9	2362	350.1
Greece	182	13.0	395	28.3
Hungary	440	15.3	1217	42.4
Ireland	85	17.9	97	20.6
Italy	1670	188.0	3002	337.9
Latvia	19	0.7	54	2.0
Lithuania	24	0.8	73	2.6
Luxembourg	15	5.1	9	3.0
Netherlands	374	65.4	553	96.6
Poland	470	15.5	1514	50.0
Portugal	130	8.4	304	19.6
Romania	346	7.2	1647	34.2
Slovakia	57	2.7	208	9.8
Slovenia	53	3.7	107	7.4
Spain	608	58.1	933	89.2
Sweden	181	37.9	251	52.6
United Kingdom	998	143.9	2139	308.4

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