More than energy savings: quantifying the multiple impacts of energy efficiency in Europe

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Abstract

Energy efficiency improvements have numerous benefits/impacts additional to energy and greenhouse gas savings, as has been shown and analysed e.g. in the 2014 IEA Report on "Multiple Benefits of Energy Efficiency". This paper presents the Horizon 2020-project COMBI ("Calculating and Operationalising the Multiple Benefits of Energy Efficiency in Europe"), aiming at calculating the energy and non-energy impacts that a realisation of the EU energy efficiency potential would have in 2030. The project covers the most relevant technical energy efficiency improvement actions and estimates impacts of reduced air pollution (and its effects on human health, eco-systems/crops, buildings), improved social welfare (incl. disposable income, comfort, health, productivity), saved biotic and abiotic resources, and energy system, energy security, and the macroeconomy (employment, economic growth and public budget). This paper explains how the COMBI energy savings potential in the EU 2030 is being modelled and how multiple impacts are assessed. We outline main challenges with the quantification (choice of baseline scenario, additionality of savings and impacts, context dependency and distributional issues) as well as with the aggregation of impacts (e.g. interactions and overlaps) and how the project deals with them. As research is still on-going, this paper only gives a first impression of the order of magnitude for additional multiple impacts of energy efficiency improvements may have in Europe, where this is available to date. The paper is intended to stimulate discussion and receive feedback from the academic community on quantification approaches followed by the project.

Introduction

In recent years, research and practice have shown that energy efficiency improvements hold numerous wider benefits for the economy, society and end-users than energy and cost savings. These multiple or also often called non-energy or co-benefits include e.g. increases in employment, GDP, productivity and energy security, positive impacts on health, ecosystems and crops and reduced GHG emissions and resource consumption. The improvement of energy efficiency is not an end in itself but a means to address major challenges such as climate change, energy supply security and/or economic downturns. In order to develop more cost-effective energy efficiency policies and long-term strategies, these multiple impacts have to be accounted for more comprehensively in the future.

Although the field of research on multiple impacts is growing rapidly, to date the findings are still dispersed, varying widely with regard to the magnitudes of the impacts and with significant gaps with respect to coverage of sectors, technologies, geography and policy impacts. Moreover, many impacts are often not quantified and monetised and sometimes even not identified by decision-makers and affected stakeholders (Ürge-Vorsatz et al. 2009). There are also a number of scientific challenges to the quantification of impacts that we discuss in the next section of this paper.

The European Horizon 2020 project COMBI ("Calculating and Operationalising the Multiple Benefits of Energy Efficiency in Europe") addresses these challenges focuses on five central research innovations in this respect: 1) data gathering on energy savings, potentials and technology costs per EU country for the 30 most important energy efficiency actions in the residential, commercial, industrial and transport sectors, 2) developing adequate methodologies for impact quantification, monetisation and aggregation, 3) applying these methods in order to derive (ranges of) values for the most important multiple impacts and where adequate, monetising 4) incorporating the derived values into decision-support frameworks for policy-making (e.g. cost-benefit analysis) and 5) providing an online visualisation tool for customisable graphical analysis and assessment of multiple impacts and data exportation. The following impacts of energy efficiency improvements are assessed in COMBI:

- impacts of reduced pollution on health, eco-systems, crops
- resource impacts: abiotic/biotic and economically unused resources
- social welfare impacts: disposable income/fuel poverty, health
- impacts on productivity in commercial and public buildings
- macroeconomic impacts: employment, GDP, public budgets

The objective of this paper is to present and discuss the COMBI methodologies and the most critical challenges, and where possible to give first indications of impact size. This however is based on preliminary input data of energy savings and thus still subject to revision.

The next section describes sources and methodologies for the assessment of the energy savings potential and costs in COMBI. Based on this input data, multiple impacts will be quantified with individual methods. In the following sections, the paper outlines the individual methods applied by COMBI and gives first indicative effect sizes. The final section gives an outlook on challenges for the monetisation and aggregation of multiple impacts and possible approaches the COMBI project may follow.

Challenges for quantification

The evaluation of impacts has to deal with a number of challenges, that are briefly discussed in this section. **Baseline and additionality:** The size of impacts depends on the baseline and additionality. The baseline can be of two types: static or dynamic. The static baseline assumes factors such as technological advancement, behaviour etc. will be unchanged over time whereas a dynamic baseline considers most of the factors as variable. COMBI applies a dynamic baseline, including existing policies (see next section).

It is important to understand what portion of the impact of the energy efficiency action, which is being assessed, is additional (i.e. going beyond the baseline) compared to the baseline, because only additional impacts can be accounted in order to avoid overestimation (Davis, Krupnick and McGlynn 2000). There are three layers of additionality identified in Urge-Vorsatz et al (2016): 1) additionality of the policy/measure – means whether the measure is additional itself to the baseline, 2) additionality of the impact – implies additional portion of the impact which is occurring due to energy efficiency measure, and lastly, 3) additionality compared to alternatives – means any impact from energy efficiency investment, need to be compared to all potential alternative uses of the capital that is invested. In COMBI, all the impacts are tested according to these three layers before being considered an end-point.

Perspectives: When assessing multiple impacts, the perspective of the assessment matters and needs to be defined, because the effect may vary (e.g. different energy prices, different impacts are relevant for society than for investors). COMBI will assess MIs from the end-use actor/individual perspective and societal perspective.

Context dependency: Context refers to variables providing the background for a particular energy efficiency action and, at the same time, are not directly related to the aim of the energy efficiency (EE) action, but influence the outcome of policy actions (Ürge-Vorsatz et al 2016). For example, road congestion is more an urban problem and thus, gains by avoiding road congestion rather an urban gain. Therefore, while evaluating impacts, these factors need to be acknowledged at least qualitatively.

Distributional aspects: Emphasis on the total impact may not always show the importance of an impact. The total impact may be minor, but at the disaggregated level, it may be very relevant such as local employment generation etc. Therefore, these distributional aspects of a policy are of high importance.

The EU energy efficiency potential assessed in COMBI

COMBI analyses the EU energy efficiency potential in the year 2030. As data on the stock of energy efficiency technologies are crucial for the analysis of resources in COMBI (work package 4), the models for the buildings and transport sector are based on stock analysis. A detailed stock analysis for industry proved impossible, given the complexity and diversity of this sector. Comprehensive information on the energy carrier mix in the different scenarios is vital for the analysis of pollution-related issues in COMBI and is therefore also modelled.

The models were used to calculate "reference" and "energy efficiency" scenarios based on literature values from existing scenarios. The results are used by the other COMBI partners for evaluation and use in their specific models. The advantage of not having to rely completely on pre-existing scenarios results is a certain amount of freedom in the COMBI project to adjust the scenario results (e.g. when new data becomes available).

RESIDENTIAL AND TERTIARY BUILDINGS

In the first instance, a distinction is made between single and multi-family dwellings for residential buildings; and between offices, education, health, trade, hotels and restaurants, and other non-residential for non-residential buildings. However, whenever detailed data are available they are aggregated to the level of residential or non-residential buildings, because in many instances data at the level of subsectors are non-existent. The following energy efficiency improvement actions will be considered in COMBI:

- Actions 1 (residential) and 7 (non-residential): replacement of heating systems in surviving, non-refurbished dwellings

- Actions 2 (residential) and 8 (non-residential): refurbishment of building shell + replacement of building systems (space heating, cooling and ventilation);
- Actions 3 (residential) and 9 (non-residential): energy efficiency improvements for water heating, mainly the use of solar thermal systems;
- Actions 4 (residential) and 10 (non-residential): energy efficiency improvements of new dwellings or buildings, focusing on Passive House standards;
- Actions 5 (residential) and 11 (non-residential): energy efficiency improvements for lighting systems;
- Actions 6 (residential) and 12 (non-residential): energy efficiency improvements of cold appliances (residential) or product cooling (non-residential).

For residential buildings, the stock analysis is conducted as follows. EUROSTAT and PRIMES projections of the population, as well as of the average household size, lead to forecasts of the number of households in each of the EU member states. For simplicity, it is assumed that the number of households equals the number of required dwellings. The number of dwellings that are annually permanently abandoned or demolished is determined from historical data (Housing statistics in the EU, EUROSTAT, ODYSSEE, ZEBRA2020). Given the number of required dwellings and the number of dwellings permanently abandoned each year, it is straightforward to calculate the number of new dwellings needed. For non-residential buildings, the stock analysis is similar, except that the projected floor areas are based on projections of value added (VA) for the different subsectors, as obtained from the PRIMES reference scenario. Further assumptions are required number of employees per unit of value added (VA), and the needed floor area (m^2) per employee. For space cooling (air conditioning systems) and cold appliances or product cooling systems, further information on ownership rates is taken from ECODESIGN, ODYSSEE, JRC and REMODECE.

The energy system model for buildings revolves around energy intensities, expressed as energy consumption per conditioned (heated, cooled and/or ventilated) floor area (kWh/m^2). Figures for the average floor area are based on data from ODYSSEE, EPISCOPE, BPIE, inSPIRE, ENTRANZE and ECOHEATCOOL.

For the actual scenario analysis investment cost data for the different energy efficiency improvement actions is needed. For the refurbishment of retrofit or existing buildings and the additional investment costs for new buildings data were obtained from ENRANZE, ECOFYS and SUSREF, as well as Urge-Vorsatz et al (2015). These sources also supplied investment costs of heating and cooling systems, although additional sources were used such as FRAUNHOFER-ISI. For air-conditioning, lighting and cold appliances / product cooling systems sources were – amongst others – ECODESIGN and TOPTEN.EU. All investment costs are ultimately expressed as euro per unit of floor area (EUR/m^2).

The main scenario input variables are the number of existing buildings that get retrofitted or refurbished each year; the annual share of light (shallow), medium and deep retrofits; the share of new buildings that conform to prevalent building standards (nZEB as of 2020) or to the more ambitious Passive House standard; the share in annual new sales of space heating (non-condensing and condensing oil and gas boilers, district heating, direct electricity, air or ground source heat pumps and biomass boilers) and space cooling (air conditioning systems), including solar thermal systems; as well as the share in annual new sales of lighting systems (halogen, linear or compact fluorescent, LED or HID) and of cold appliances (A+, A++ or A+++).

TRANSPORT

The transport sector is subdivided into passenger and freight transport. A distinction is further made between different transport modes, namely slow modes (walking and cycling), mopeds, motorcycles, passenger cars, vans, buses and coaches, light rail or urban rail (metro and tram), passenger trains and aviation for passenger transport; and heavy duty trucks, light duty trucks, freight trains and inland waterways for freight transport. Vans, light rail, aviation and inland waterways however are not explicitly modelled, as they fell outside the scope of the COMBI project. The transport sector actions include:

- Actions 13 and 18: modal shifts for both passenger and freight transport;
- Action 14: energy efficiency improvements of motorized two-wheelers;
- Action 15: energy efficiency improvements of passenger cars;
- Action 16: energy efficiency improvements of public road transport, i.e. bus or coach;
- Actions 17 and 21: electrification of passenger and freight rail;
- Action 19: efficiency improvements of light duty trucks (LDTs);
- Action 20: efficiency improvements of heavy duty trucks (HDTs).

The transport models are based on vehicle stock analysis for the different transport modes. Projections of passenger-km (passenger transport) and ton-km (freight transport) are derived from the PRIMES reference scenario. In combination with assumed values for occupancy rates (number of passengers per vehicle) and load factors (ton of freight per vehicle) and average annual mileages, the required total stock of vehicles for each mode is calculated. The values of occupancy rates, load factors and mileages are inferred from existing transport models such as TREMOVE, SULTAN and ASTRA as well as from the TRACCS database.

The number of vehicles that are no longer used or scrapped is determined by the use of survival functions, which in principle differ not only per mode but also per drive train technology. The considered drive train technologies for road transport are internal combustion engine vehicles (ICEVs), hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs) and fuel cell vehicles (FCVs). For ICEVs, HEVs and PHEVs a further division is made between petrol, diesel, retrofit LPG, and retrofit CNG/LNG vehicles as well as dedicated bio-ethanol vehicles. The required share of biofuels (bio-ethanol or biodiesel) for other ICE vehicles is likewise taken into account. All passenger cars are further subdivided into light, medium and large cars. For trains a distinction is made between (electric and diesel) locomotives and diesel and electric multiple units (DMUs and EMUs).

Projections of the activity levels (passenger-km or ton-km) for the different model, derived from the PRIMES reference scenario, in combination with information on the current vehicle stock and the annual number of vehicles that leave the stock, determine how many new vehicles are needed each year.

The crucial scenario input variables are thus the shares in annual new sales of the different energy efficient vehicle technologies, transport per mode. The shares are mostly derived from existing EU scenarios, mainly SULTAN, but also ASTRA, JRC and CE Delft.

The scenario analysis moreover requires extensive data on fuel efficiencies (in MJ per vehicle-km) of all the different technologies, as well as on investment costs (in euro per vehicle). These were obtained from the existing models previously mentioned along with IEA-ETSAP, McKinsey (2014) and ICCT (2016). From there onward it is straightforward to calculate the final energy consumption for the different modes (number of vehicles times average annual mileage times fuel efficiency) and investment costs (number of annual sales of new vehicles times investment costs per vehicle).

The contribution of modal shifts in the total energy savings potentials of the transport sectors is large, therefore we also include this as one action, although COMBI focuses on energy *efficiency* improvements.

INDUSTRY

The industry sector in COMBI covers the following subsectors: iron and steel, non-ferrous metals, chemicals, non-metallic minerals, pulp paper and print, food and beverage, machinery, and other industry (including wood and textiles). However, detailed data per subsector are aggregated to the industry level, because in many instances detailed information at the level of subsectors is not available. The following energy efficiency improvement actions are considered in COMBI:

- Action 22: energy efficiency improvements of high temperature process heating (furnaces, ovens, kilns, dryers, …)
- Action 23: energy efficiency improvements of low and medium temperature process heating (boilers and steam systems in general);
- Action 24: energy efficiency improvements of industrial process cooling and refrigeration;
- Action 25: energy efficiency improvements of process specific use of electricity, mainly electrochemical processes in non-ferrous metals and chemicals;
- Action 26: energy efficiency improvements of motor drive systems, including pumps, compressed air for utilities, compressed gas/air systems for processes; fans and blowers, and other motor applications;
- Action 27: energy efficiency improvements of heating, ventilation and air-conditioning (HVAC) systems in industrial buildings.

Industry is a very difficult sector to model, due to its diversity and complexity. Data availability in general is very low, in particular in terms of current stocks and practices as well as in the domain of investment costs of energy efficiency technologies. For the base year 2012, a lot of data concerning heating and cooling demands in industry, except costs, were taken from FRAUNHOFER-ISI. For other years, data on industrial energy consumption are available from EUROSTAT and to a lesser extent the ODYSSEE database.

The model is based on the use of simple energy intensities, expressed as energy consumption per unit of value added (kWh/EUR). The main source for this is ICF (2015) along with JRC, European Parliament (2010), UN-Energy (2010) and Ecofys (2009). The energy intensities are defined for each of the above-mentioned industrial energy services. The model also recognizes industrial lighting and "other industrial energy consumption (e.g. internal transport systems) as separate energy services, but they fell outside the scope of the COMBI project.

Projections of GDP or value added (VA) for the different subsectors are obtained from the PRIMES reference scenario. In combination with the assumption that energy intensities do not change except for a certain amount of energy savings through "autonomous innovation", this allows the energy consumption levels of the different energy services to be calculated for the reference scenario.

The efficiency scenario is based on a list of energy efficiency improvement actions, per subsector and energy service. This list contains for each action the energy saving potential, as well as the required payback time. The energy savings, per energy carrier, in combination with projected energy prices for industry, enable energy costs savings to be calculated. The latter, in combination with the known payback periods, permit making a rough estimate of the investment costs.

Multiple impacts of energy efficiency improvements in Europe: methodologies and results

IMPACTS OF REDUCED POLLUTION ON HEALTH, ECO-SYSTEMS AND CROPS

Thema et al. (2016) have set out a few possible modelling tools available for estimation of air pollution-related impacts on health and ecosystems: The ExternE approach based on estimated average values of damage per ton of pollutant, EcoSense Web modeling tool and the GAINS modeling tool. GAINS is the most advanced air pollution modelling tool used in formulating air quality policies in the European Union and the COMBI team gives a priority to this tool. The GAINS model was created by the International Institute for Applied Sciences (IIASA) in Austria, who also provide details on the methodology of the tool (EC4MACS 2012, Amann et al. 2011). The model requires substantial amount of detailed sectoral data and currently COMBI scenario data is in the process of being tested to verify if it is sufficient to run it on GAINS. Only when final COMBI input data is ready, this will be fed to the GAINS model, therefore no preliminary results are available to date.

RESOURCE IMPACTS: ABIOTIC AND BIOTIC

The extraction of natural resources leads to environmental impacts like land conversion, loss of biodiversity and emissions to air, water and soil (Akcil & Koldas, 2006; Bringezu et al., 2009; Kumari, Udayabhanu, & Prasad, 2010). Many abiotic raw materials will be depleted in the future and can therefore become a critical supply risk for the European Union (Alonso et al., 2012; European Commission, 2014b, 2014a; Sonoc & Jeswiet, 2014). Resource extraction itself has increased over the past decades and is closely linked to economic growth. Moreover, most raw material exporting countries are developing countries, shifting the value of processed materials to more developed countries, but suffering from the corresponding local environmental damage (Bringezu, 2015; Fischer-Kowalski & Swilling, 2011; Wiedmann et al., 2015). Therefore, it is not surprising, that the reduction of the overall amount of extracted raw materials is also a sustainable development goal (UN 2015).

In respect to energy conversion and energy efficiency, raw materials are not only required to produce energy, but also to provide the corresponding utilities such as power grids and power plants. Additionally, many actions towards higher energy efficiency require new technologies or the adoption of existing ones, adding to the already high demand of raw materials for final energy use. In COMBI, we therefore focus on the extraction of abiotic and biotic resources from nature (opposed to other environmental media like water or natural services such as biodiversity). Positive impacts occur, if less raw materials have to be extracted in order to provide final energy after implementation of an EE action. This includes savings from the resulting direct final energy savings and the lifecycle-wide resource demand for its utilities (use phase extraction), but also potential net savings from the implementation of actions and substitution of technologies in the European stock (production phase extraction). The latter includes the production of lighting systems, vehicles and cold appliances required to provide the savings in energy.

Endpoints for resources are extracted abiotic and biotic raw materials as well as the Material Footprint (MF). MF includes all raw materials, but also extracted material which is not put directly to an economic use (unused extraction), such as overburden from mining. Midpoints are metal ores, fossil fuels and minerals. All end- and midpoints are calculated in tons of material. The method for calculating resource impacts is a bottom-up approach, based on Material Flow Accounting (Fischer-Kowalski et al., 2011), the Material Footprint method, Material Input per Service (MIPS) (Liedtke et al., 2014) and Life Cycle Assessment (ISO, 2006a, 2006b). The life-cycle wide material and energy flows (Life Cycle Inventories) of products (including EE action technologies) and services (including energy services) are transferred into endpoint- and midpoint factors, which can directly be linked to final energy savings and stocks for EE action technologies. Most Life Cycle Inventories (LCI's) are generic and drawn from the database ecoinvent 3.1.

For final energy savings (use phase), energy conversion in the EU-28 (from energy use to final energy for electricity, heat and fuels) is based on the PRIMES model for the use of energy sources in 2030, EUROSTAT for shares of energy carriers, the SULTAN model for shares of bioethanol and biodiesel and the Well-to-Wheel studies by the Joint Research Centre (Edwards et al., 2014). The implementation of EE efficiency actions (production phase) is limited to selected technologies, as not all technologies could be provided for in terms of type and stock per country. They are based on current technologies and include the production of vehicles (all but trains), lighting devices and cold appliances.

The monetisation of impacts from raw material extraction is based on direct and indirect costs for metals and fossil fuels. Because average costs from mining could not be found in literature, direct costs for materials are based on world market prices for metals and fuels in form of commodities. This simplification required a number of subsequent steps of matching and iteration of products to ores. Indirect costs are based on the ecocost model and current oiconomy database (P. Croes, 2012; P. R. Croes & Vermeulen, 2016; Vogtländer, 2001), which provides costs for the mitigation of scarcity (externalised costs) for most metal ores and fossil fuels.

As of now, only parts of the calculations have been concluded. First results suggest overall net savings of resources for EE actions in the residential, non-residential and transport sector. However, some actions such as new efficient dwellings with higher shares of heat supply by electricity could either have significant lower savings in comparison to other actions or even require additional raw materials for providing a lower energy use.

SOCIAL WELFARE IMPACTS: DISPOSABLE INCOME/ENERGY POVERTY, COMFORT, HEALTH

Two sectors are relevant for this group of impacts as outlined in Thema et al (2016): buildings and transport. As new evidence keeps emerging of potential additional co-impacts of building retrofits, the list of impact end points is still in the process of finalization and the methodological approach is currently being refined. The methodological approach however still rests on the burden of disease methodology – a scientific method to attribute a share of the total disease burden in a country to certain factors in relation to prevalence of exposure indicator and a documented relative risk estimate (Pruss-Ustun et al 2003; Braubach et al. 2011). Scenarios will be built assuming that the distribution of the multiple impacts will be proportional to the share of the housing stock retrofitted. Finally, the quantification of impacts of modal shift will be omitted from COMBI due to lack of resources, despite its inclusion in the energy efficiency improvement action list (see above).

Excess winter deaths currently stand at around 228,000 in the EU-28 on average every year. According to the preliminary calculations based on the preliminary input data (subject to changes still), a low five-digit number of excess winter deaths could be avoided yearly by 2030. This figure is based on 1996–2014 monthly mortality data from Eurostat. Between 30 and 50 % of those could be attributed to indoor cold (Braubach et al. 2011). Results for other impact end points are not available at the moment of writing of this paper.

IMPACTS ON PRODUCTIVITY IN COMMERCIAL AND PUBLIC BUILDINGS

Productivity can be broadly defined as a relation between input and output. There are many measures such as multi-factor, capital and labour productivity. This study only deals with building-related labour productivity. This can be further segregated into the three key aspects active days loss, workforce performance and earning ability. Each of these aspects is discussed below.

Active work days loss

This study considers this as a linear combination of absenteeism (absent from work due to illness) and presenteeism (Caverley et al. 2007) where presenteeism can be defined as working with illness or working despite being ill (Mattke et al. 2007).

For instance, a person might work more slowly than usual with respiratory diseases or make mistakes in work during his illness. Thus, presenteeism refers to productivity loss resulting from health problems such as asthma, cardiovascular diseases, and mental well-being. These diseases affect both quantity and quality of work (Paul 2004). Several studies show how poor indoor quality can cause diseases such as asthma, cold and flu, cancer, cardiovascular disease (Fisk 2000, 2002; Mudarri and Fisk 2007, Kadir, et al. 2015). One of the key reasons behind this poor indoor air quality is inadequate air exchange rate inside the building and lack of filtration system (Asikainen, et al. 2016). Installing an efficient heating ventilation and air conditioning (HVAC) system with filtration in an airtight building can reduce up to 58 % of global burden of disease at EU-26 level (Hänninen and Asikainen 2013). A study suggests that a proper ventilation rate (i.e. more than 12 L/s per person) can reduce sick days by 1.2–1.9 days per person per year (Carrer, et al. 2012, Mudarri and Fisk 2007). This can be considered as productivity gain per person/year due to this energy efficiency action.

Workforce performance

Workforce performance can be defined as overall performance of a workforce (defined as cumulated employees). Workforce performance basically measures the quantity of labour input per hour after implementing energy efficiency measures such as installing HVAC system in airtight commercial buildings. Studies (Seppänen and Mendell 1999, Wargocki et al. 2000) show how improving indoor air quality and thermal comfort can improve a person's productivity. Singh's 2005 study shows that shifting into an energy efficient building can gain additional 2.02 work hours per person/year.

Earning ability

In addition to earning ability, future earning ability is also a consideration. This aspect of productivity is mainly concerned with two issues 1) impact on future earning ability due to loss of school days 2) Parents' absenteeism due to care-taking of sick children. If a child misses school days due to building-related symptoms, this also affects the earning ability of the parents (being absent from work) and also the future earning ability of the child. In fact, excessive absenteeism from school may disrupt a child's learning process and could be one of the causes for dropping out from school. It is seen that children with asthma are more frequently absent from school compared to their healthy classmates without asthma (Moonie, et al. 2006).

MACROECONOMIC IMPACTS: EMPLOYMENT, GDP

Macroeconomic impacts are either business-cycle or structural impacts. These two types of impacts are fundamentally different, and analysing them requires distinct methodologies. Both types of macroeconomic effects may also lead to effects on the public budget balance.

Short-run macroeconomic effects, or business-cycle effects

Short-run effects stem from the fact that economies go through cyclical changes in investment, output (GDP) and employment, which fluctuate around a long-run level or trend. Macroeconomic policy, principally monetary and fiscal policy, are used to smooth out such fluctuations. Investments in energy efficiency improvements will function as a fiscal-policy investment stimulus, and as such can potentially have positive effects on GDP and employment, under the right conditions. In COMBI, business-cycle impacts are quantified using a business-cycle macroeconomic model, which combines an input-output model with Keynesian multipliers and measures of the output gap. This model is capable of addressing two main questions:

- What is the magnitude of the additional Aggregate Demand that each EEI action can potentially create?
- To what extent will this Aggregate Demand boost lead to an increase GDP and employment, rather than just shifting productive resources (labour, capital) between sectors?

The first point refers to how investment spending leads to increased economic activity through bringing, potentially idle, resources into use. In terms of employment effects, this includes direct employment effects related to each EEI action, as well as indirect (supply-chain) effects that follow from the direct effect. Through the input-output model framework, the analysis takes into account the labour intensity of each EEI action, as well as to what extent the actions boost domestic economic activity, as opposed to, e.g., importing new capital equipment.

The second point stresses that, crucially, investment spending will only be beneficial (in a short-run macroeconomic sense) if the economy is in a situation where the output gap is negative. The mere fact that there is unemployment in the economy does not automatically mean that there is a negative output gap. The analysis must therefore include an assessment of the size of the output gap over the relevant time period, to identify when, if at all, EEI actions might result in multiple short-run macroeconomic benefits.

Preliminary results suggest that the investment spending needed for the EEI actions in COMBI could potentially create a temporary Aggregate Demand boost of around 2 % of GDP in 2030, on average across the EU-28 countries. Negative output gaps are likely to be significantly smaller than that, however. Based on historical data, it is likely that some EU countries will have positive output gaps in 2030, which again would mean no multiple impact in terms of GDP and employment. It is also likely that some countries have negative output gaps, but it is not meaningful to speculate about which countries this might be, or the size of these potential output gaps. To the extent that short-run macroeconomic benefits are present, these will also have a short-run (temporary) effect on the balance of the public budget, e.g., through reduced expenditure on unemployment benefits. The estimated GDP effect for 2018 suggests an improvement of public budgets in EU countries of over EUR 20 billion, corresponding to 0.16 % of total EU-28 country budgets, for 2030 the effect cannot yet be assessed.

Long-run, or structural, macroeconomic effects

Long-run, or structural, macroeconomic effects are unrelated to short-run business-cycle fluctuations, and instead pertain to an economy's properties in equilibrium, or along the long-run growth trend. Energy efficiency improvements may lead to a range of structural effects, including the direct effect of reduced spending on energy consumption, as well as pollution and other health effects, all of which are studied in other parts of COMBI. These effects may again have a (structural, or per-

Table 1. Overview of impact indicators.

Impact indicator	Quantitative metric	Monetary metric
Energy system related impacts	Primary energy intensity of the economy	Avoided costs of energy (supply) infrastructure
Power reliability related impacts	De-rated capacity margin	Value of lost load (VoLL)
Energy security related impacts	Aggregated energy import dependency, diversity and stability index	Import dependency

manent) effect on public budgets, through less public spending on energy consumption, or reduced health care spending.

In addition, the EEI actions studied in COMBI are likely to lead to a number of other macroeconomic effects, which are not necessarily benefits, but nonetheless highly interesting. To analyse such issues, we make use of the Copenhagen Economics Global Climate and Energy Model (CE-CEM), a computable general equilibrium (CGE) model of the world economy, with an explicit representation of how energy is used in the production of goods and services. In particular, we impose a restriction on greenhouse gas emissions consistent with IEA's 4-degree scenario (4DS; IEA, 2015), and run the model both without and with the energy savings stemming from the COMBI EEI actions. The effects we analyse include:

- *Cost of carbon abatement*. Lower energy use across EU countries means that meeting EU emission targets is easier, and marginal abatement costs fall (preliminary calculations: by around 40 %, relative to the reference scenario).
- *Effects on global fossil-fuel prices*. Lower abatement costs allow for a higher use of coal than in the reference scenario, and the price of coal consumed in the EU actually increases by 0.5 %. Consumption of oil and natural gas falls, however, and the prices of both commodities fall by around 1 %.
- *Terms of trade effects for the EU*, i.e. the relative price of imports in terms of exports. The EU sees a fall in the price of oil and gas, which are mainly imported, but there is an equally strong decrease in the prices of export goods, due to falling production costs. This is true for both energy products (refined oil and electricity), as well as energy intensive products (chemicals and metals). In the aggregate, the EU's terms of trade are virtually unchanged, relative to the reference scenario.
- *Sectoral shifts within EU-28 economies*. Unsurprisingly, we see a large decrease in the power sector, relative to the reference scenario – less electricity is needed in the EU, and as a result fewer resources are spent on its production. Sectors that grow significantly in size, compared to the reference scenario, are production of chemicals and metals, as well as transport services. This stems from a combination of lower energy requirements in production, and lower energy prices.

IMPACTS ON ENERGY SYSTEM & SECURITY

Impacts on the EU energy system and energy security are assessed by a model-based scenario analysis with a set of indicators. These indicators are analysed for a reference and an energy efficiency scenario and differences taken as impact. Based on an extensive literature review (Couder, 2015), we account for three categories of impacts: 1) energy system related impacts; 2) power reliability related impacts; and 3) energy security related impacts. For each, two different metrics or indicators were selected, a quantitative and a monetary one (see Table 1). The de-rated capacity margin can also be considered a metric of energy security.

The energy savings resulting from all energy efficiency improvement under a reference scenario and an efficiency scenario are aggregated at the level of the individual (final) energy carriers.

The primary energy intensity, expressed as kWh/EUR, is a non-monetary unit. The indicator is straightforward to calculate, as it is defined in COMBI as the sum of the primary (indigenous) production and net imports, divided by gross domestic product (GDP). The GDP projection is taken from the PRIMES reference scenario. It is assumed that this GDP projection does not change between the COMBI reference and energy efficiency scenarios. Incorporating such feedbacks is beyond the current scope of the project. Primary production relates to the (domestic) production of solid fuels, oil, natural gas, nuclear, renewables (hydro, wind, geothermal, solar and other flow renewables (e.g. tidal), biomass and waste. In all instances production also includes recovery of products. Net imports are estimated for solids, crude oil and feedstock, oil products, natural gas, electricity, and other energy carriers (mainly biomass). The avoided costs of energy supply infrastructure are based on an energy supply simulation model for the 28 EU member states.[1]

The de-rated capacity margin is a non-monetary metric. The gross capacity margin is calculated as

$$gross\ capacity\ margin\ (\%) = \frac{total\ available\ capacity\text{-}peak\ demand}{peak\ demand} \times 100.$$

The total available capacity is the sum of the (theoretical) full rated 'nameplate' capacities of all plants. The de-rated capacity margin takes into account that not all generation capacity will run at its theoretical maximum at times of peak demand. De-rating means that the nameplate capacity of each plant is 'de-rated' by a factor, which reflects the statistically expected level of reliable availability from that specific type of generation technology.

Literature values on the value of lost load (VoLLs) are available only for few EU member states. Within the constraints of the COMBI project it is impossible to use sophisticated meth-

1. Relevant data on power plants and transmission and distribution systems include, amongst others, capacity generation type by year; construction lead time; peak demand by year, ramp rates for controllable technologies; maximum intermittent output change; capital costs or "capital expenditures" CAPEX; operations and maintenance (O&M) costs, including variable costs (per kWh produced) and annual fixed costs (per kW); technical lifetime and economic lifetime (for capital amortisation); thermal efficiency rates; types of fuel used; rate of electricity autoconsumption per plant; availability rates; and average and peak interconnector capacities.

ods such as revealed or stated preference to estimate VoLLs for all 28 EU member states. Literature suggests a simplified method based on GDP and "electricity not delivered". The latter can be roughly estimated based on available performance metrics such as the system average interruption duration index (SAIDI). The effects on how energy efficiency actions affect "electricity not delivered" are based on literature.

The cost of imports as a share of GDP, by energy carriers and regions, is a semi-monetary indicator that is affected not only by the level of import dependence, but also by the energy intensity of the economy and the cost of imports (including the effect on the €/$ exchange rate). The energy import, diversity and stability index is a composite indicator, using the Herfindahl-Hirschman index method. It is a non-monetary metric (0–1 index), that also incorporates political stability, based on UNDP and World Bank indicators. The main sources of data for energy security indicators[2] include, amongst many others, Eurostat, Gas Infrastructure Europe (GIE), IEA, OECD, the Nuclear Energy Agency (NEA), the World Bank, and the International Atomic Energy Agency (IAEA).

Integration of multiple impacts

Many of the impacts overlap and without knowing the interaction between impacts, economic evaluation of impacts may lead to over or underestimation. In order to accurately estimate the impacts, a comprehensive accounting method is therefore required (Ürge-Vorsatz et al 2016). COMBI applies an impact pathway notion in order to identify the interactions among the impacts and then evaluate them accordingly.

The impact pathway approach is a bottom-up approach where benefits and costs are estimated by following the pathway of a causality chain. The pathway map starts from implementing energy efficiency actions and ends at the 'end-point'. Here, end-point can be defined as the last impact, which is not transferring to another impact or which is a policy target itself. For instance, health and productivity impacts of energy efficiency would further transfer into disposable income and public budget, but both are a policy target themselves. Therefore, health and productivity impact can be considered as an impact end-point despite the fact that they are further transferring into other impacts.

In order to aggregate outcomes, or compare magnitudes of outcomes, a common metric is needed. This is typically done by converting different units into a monetary value. However, monetization of non-market outcomes can be challenging and the values highly depend on the methods. This implies that any use of monetization will lead to estimates of non-market impacts such as health, eco-system that are dependent on the monetization method (Luck et al 2011, Ürge-Vorsatz et al 2016). In order to minimize the uncertainties and controversial aspects related to monetization, COMBI uses physical metrics and monetized values. For instance, for health-related impacts, QALY or DALY[3] can be used in order to quantify the impact.

However, in order to aggregate physical values of impacts, they need to be converted into a common unit. For example, health values can be pre-aggregated in e.g. DALY, physical values of productivity may be in days absent from work. For aggregation, these need to be converted either in years or in days and the interaction between health and productivity needs to be understood properly to avoid double counting. Therefore, the portion of health impact calculated under productivity impact should not be measured by health impact.

The final results of the integration of impacts in COMBI are accessible per EEI action and country. This also allows for a cost-benefit analysis per action, country and assessment of net values. It has to be noted however, that COMBI aims at covering major multiple impacts, but does not quantify *all possible* impacts. Additionally, not all covered impacts can be monetized and included in a cost-benefit analysis. Therefore, total estimates will probably underestimate real values.

Conclusion and further research

Energy efficiency improvements hold numerous impacts for the economy, society and end-users in addition to energy and cost savings. These multiple impacts have to be accounted for more comprehensively in the future. Their quantification and monetisation is however challenging due to complex causal chains, the context-dependency of multiple impacts, data limitations and ethical concerns in respect to monetisation. In addition, significant overlaps and interactions between these impacts make an aggregation and thus complete consideration in decision-support frameworks for policy-making difficult.

This paper has shown and discussed suitable methodologies for an ex-ante assessment of a set of central multiple impacts of energy efficiency improvement actions and pointed out which methods will be used in the European Horizon 2020-project COMBI.

Although the field of research on multiple impacts has grown rapidly in the past years, there are several areas of further investigation required when assessing these multiple impacts ex-ante. In particular, more research is required in terms of their context dependency, scale, interactions and additionality for developing a suitable synthesis/aggregation approach. But also specific methods for calculating individual benefits need further elaboration in order to be able to assess the complex causal chains in more detail.

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2. Fuel export potential by country for oil and gas; net imports by year; natural gas import arrangements for each EU member state, including share of total gas imports purchased in the scope of bilateral contracts and share purchased on spot markets, supply routes and capacity; flexibility of plants to use various feedstock qualities for power plants and refineries; dual fuel/multi fuel capacity of plants; and political risk ratings.

3. Quality-adjusted life year, disability-adjusted life year.

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