Widening the Perspective: An Approach to Evaluating the Multiple Benefits of the 2030 EU energy efficiency potential

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Abstract

The European Horizon 2020-project COMBI ("Calculating and Operationalising the Multiple Benefits of Energy Efficiency in Europe") aims at estimating the energy and non-energy impacts that a realisation of the EU energy efficiency potential would have in the year 2030. The project goal is to cover the most important technical potentials identified for the EU27 by 2030 and to come up with consistent estimates for the most relevant impacts: air pollution (and its effects on human health, eco-systems/crops, buildings), social welfare (including disposable income, comfort, health and productivity), biotic and abiotic resources, the energy system and energy security and the macro economy (employment, economic growth and the public budget). This paper describes the overall project research design, envisaged methodologies, the most critical methodological challenges with such an ex-ante evaluation and with aggregating the multiple impacts. The project collects data for a set of 30 energy efficiency improvement actions grouped by energy services covering all sectors and EU countries. Based on this, multiple impacts will be quantified with separate methodological approaches, following methods used in the respective literature and developing them where necessary. The paper outlines the approaches taken by COMBI: socio-economic modelling for air pollution and social welfare, resource modelling for biotic/abiotic and economically unused resources, General Equilibrium modelling for long-run macroeconomic effects and other models for short-run effects, and the LEAP model for energy system modelling. Finally, impacts will be aggregated, where possible in monetary terms. Specific challenges of this step include double-counting issues, metrics, within and cross-country/regional variability of effects and context-specificity.

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.

One important meta-study published by the IEA in 2014 is the report *Capturing the multiple benefits of energy efficiency* (IEA 2014). It provides a comprehensive overview of existing approaches and research findings on five categories of energy efficiency benefits: macroeconomic development, public budgets, health and well-being, industrial productivity and energy delivery.

Although the field of research on multiple impacts is growing rapidly, to date the findings are still disperse, vary widely with regard to the magnitudes of the impacts and have 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). A main challenge of quantification is their context-dependency, i.e. that they vary significantly between technologies, sectors, end-users, countries/geographical location, and policy types etc. (Ürge-Vorsatz et al. 2009). Moreover, a multitude of methods for quantifying and monetising multiple energy efficiency impacts exist, their application is usually highly demanding due to consideration of complex causal chains and data limitations, and results may vary significantly by chosen method. Finally, an aggregation of these impacts can be problematic due to overlaps of impacts (double-counting, interactions) and controversial due to methodological challenges and ethical concerns with respect to their monetisation (e.g. valuing life and health).

These challenges make a consideration of multiple benefits in policy making and policy evaluation difficult. However, they are clearly important given many research findings indicate that the magnitude of multiple benefits is large and in many cases – particularly in the buildings sector – even outweigh the value of direct energy benefits (Ürge-Vorsatz et al. 2009, IPCC 2007, Kats 2006, Schweitzer and Tonn 2002).

The European Horizon 2020-project COMBI ("Calculating and Operationalising the Multiple Benefits of Energy Efficiency in Europe") addresses these challenges and aims at 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, energy efficiency cost curves) and 5) providing a simple online visualisation tool for customisable graphical analysis and assessment of multiple impacts and data exportation. Project outcomes will thus directly contribute to enable the definition of cost-effective policies and support policy-makers and evaluators in the development and monitoring of energy efficiency strategies and policies in the future. The following impacts of energy efficiency improvements are assessed in COMBI:

- impacts of reduced pollution on health, eco-systems, crops and built environment
- resource impacts: abiotic/biotic and economically unused resources
- social welfare impacts: disposable income/fuel poverty, comfort, 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, the most critical methodological challenges with such an ex-ante evaluation and with aggregating the multiple impacts. The structure is as follows: The next section gives an overview on the data derived from the TED/LEAP database for a set of 30 energy efficiency improvement actions grouped by energy services covering all sectors and EU countries. Based on this, multiple impacts will be quantified with separate methodological approaches, following methods used in the respective literature and developing them further where necessary. In the following sections, the paper outlines these approaches applied by COMBI: socio-economic modelling for air pollution and social welfare, resource modelling for biotic/abiotic and economically unused resources, input-output modelling for short-run macroeconomic effects and Computable General Equilibrium (CGE) modelling for long-run macroeconomic effects, and the Long-range Energy Alternatives Planning System (LEAP) model for energy system modelling. Specific challenges of aggregation including double-counting, metrics, within and cross-country/regional variability of effects and context-specificity will be discussed subsequent to that. The paper concludes with a discussion of further research needs and provides first recommendations.

The 2030 EU energy efficiency potential

The COMBI project separates three main factors that determine energy consumption in the residential, tertiary, transport and industry sectors, namely activity levels, structural factors, and the energy efficiencies themselves. The selection of end-use energy efficiency actions studied is based on the following principles:

- The “energy services” (e.g. heating, cooling, domestic hot water production, lighting, etc.) of the different sectors are taken as a starting point;
- Existing EU energy efficiency scenarios are used as reference for both activity levels (e.g. population and GDP growth) and structural factors (e.g. shares of single and multifamily dwellings, activity shares of the different subsectors in the tertiary and industrial sectors; and transport modes);
- The focus is on varying the “technical” energy efficiency improvements, while in principle accepting the behavioural changes and structural assumptions of the referenced EU scenarios;
- The actions should in principle cover 80% of the EU energy saving potential by 2030.

The estimated final energy savings potentials for the EU27 by 2030 (relative to a PRIMES final demand baseline scenario) are currently based on Fraunhofer ISI (2009; 2012), but will be updated once new figures are released in the course of 2016.

Residential and tertiary sector

For both the residential sector (households) and the tertiary sector the relevant energy efficiency improvement actions are:

- Improvements of the building envelopes (existing buildings);
- Passive House standards for heating and cooling demands (new buildings);
- Improvements of domestic hot water (DHW) systems;
- Improvements of (room and/or central) air-conditioning systems and fans;
- Improvements of lighting systems;
- Improvements of refrigerators / freezers (residential) and commercial refrigeration and freezing;

For existing buildings in the residential sector, improvements of the building envelope and heating systems account for 45% respectively 24% of the total energy saving potential. Adding the 16% energy savings potential resulting from new dwelling gives a total of 85%. By including the 7.1% potential of improved domestic hot water systems and the 4.7% potential of more efficient lighting, almost 97% is covered. Household appliances are good for the remaining 3%, but COMBI opted for looking only at refrigerators/freezers, as they have the largest potential of residential appliances.

The potentials for the tertiary sectors are very similar, where improvements of the envelopes of existing buildings and more efficient heating and space cooling systems give rise to energy savings of 40% respectively 24%. New buildings would contribute another 15%, giving a grand total of 79%. Lighting has a much larger share in the savings potential as compared to the residential sector, namely 12% (but including 3% savings from better street lighting). Ventilation systems (or "fans") are more prominent in tertiary buildings, and may contribute 4.5% of the total energy saving potential. Also typical for the commercial sectors are the large refrigeration and freezing systems, with a saving potential of 3%. This means that COMBI would cover more than 98% of energy savings potentials identified in existing EU scenarios.

Transport

Although COMBI in principle does not vary "structural" elements, which remain fixed at the referenced EU scenario levels, modal shifts in the transport sector have to be included, because of their large energy saving potentials. The retained energy efficiency improvement actions for passenger and freight transport are thus:

- Improved efficiency of road vehicles, mainly cars (passenger transport);
- Improved efficiency of light and heavy duty trucks (freight transport);
- Improved efficiency of rail transport vehicles, mainly trains (passenger and freight transport);
- Modal shift (passenger and freight transport).

In the transport sector, improved efficiencies of road vehicles contribute almost 49.5% of the energy saving potential, compared to 1.5% for more efficient trains. In other words, "pure technical" improvements would only cover about half of the total potential. This makes it necessary to include modal shifts (10%), and probably (other) behavioural changes as well (25%).

Industry

For industry, the most relevant energy services are high temperature process heating, steam systems, machine drive, and industrial facilities (or buildings); leading to the following list of actions:

- More efficient blast furnaces and basic oxygen furnaces (iron and steel);
- More efficient electric arc furnaces (iron and steel);
- More efficient kilns (cement);
- More efficient glass melting furnaces (glass);
- More efficient steam crackers (chemical)
- More efficient driers (paper and pulp);
- More efficient primary aluminium production (electrochemical);
- More efficient chloralkali production (electrochemical);
- More efficient steam systems, including combined heat and power CHP;
- More efficient fan and pump systems (machine drive);
- More efficient space heating (industrial facilities).

In industry, the largest energy saving potential, approximately 29%, can be attributed to improved space heating in industrial facilities, very similar to residential and tertiary buildings. Improvements of steam systems, including higher shares of combined heat and power (CHP) systems, contribute another 30%. It is difficult to assess the exact shares of the other retained actions in the total savings potential, but more efficient high temperature processes in the iron and steel, cement, glass, paper and pulp and chemical sectors (steam crackers and electrochemical processes) should cover at least 20% to 30%, thus enabling COMBI to reach the targeted 80%.

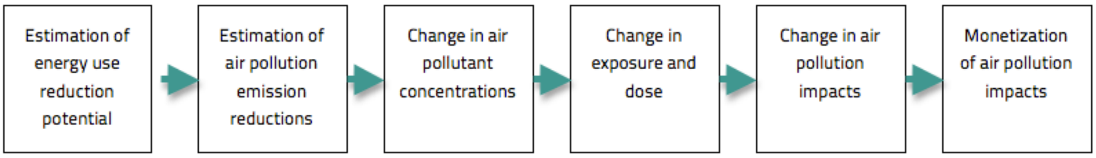
Methodologies for the quantification and monetisation of multiple benefits of energy efficiency improvements

Impacts of reduced pollution on health, eco-systems, crops and built environment

Air pollution and climate change are phenomena that are intrinsically linked to each other in many complex ways, but for historical reasons have been studied and modelled separately. There is a growing number of voices that both problems need to be addressed within a common framework in order to enable synergies, avoid antagonistic outcomes and ensure cost-effectiveness of policies (M. Amann et al. 2014; Kuylenstierna et al. 2012; Alcamo et al. 2002; Markus Amann et al. 2011). Most energy efficiency studies end with an estimation of the greenhouse gas emission potential. Nevertheless, there is a growing number of studies that aim to investigate the implications of climate change mitigation policies on air pollution, or vice versa (Mzavanadze 2015). If fossil fuel combustion is at the core of both problems, then decreasing energy consumption without compromising the quality and quantity of energy services – i.e. energy efficiency – would yield double dividends in terms of avoided climate change and avoided air pollution.

A multiple step framework is needed to quantify and monetize the air pollution impacts of energy efficiency interventions. Each step illustrated by an arrow (Fig. 1) represents a separate area of studies with distinct methodologies: environmental sciences, environmental chemistry, meteorology, geography, epidemiology, environmental economics. A number of climate change mitigation studies with an aim to study ancillary air pollution effects do not complete the whole chain of assessment steps (Mzavanadze 2015). Air pollution dispersion modelling in the geographical scope area is one of the most complex steps and oftentimes many studies end with avoided quantities of air pollution emissions. Human health is the most studied receptor of negative air pollution effects, with ecosystem and the built environment.

Figure 1. Multi step assessment framework of air pollution impacts of energy efficiency



Source: Mzavanadze 2015

In the context of European air pollution policies, many generic and sector-specific modelling tools have been developed during the last two decades to estimate the cost of air pollution externalities. The most straightforward approach used in cost-benefit analyses is to use energy consumption activity data by energy carrier and calculate the total air pollution emissions based on the most up to date emission factors (Department for Environment, Food and Rural Affairs (DEFRA) 2013; European Commission and Directorate-General for Regional Policy 2015). Emission factors are coefficients that describe the relationship between a raw energy material consumed and air pollution emitted as a result. They are based on scientific observations of technologies and can also be country- and industry-specific and customized depending on the level of detail required. The list of air pollutants covered by this approach includes all pollutants listed under the protocols of the Long Range Transboundary Air Pollution Convention. Monetization of the air pollution impacts can be carried out using damage values per ton of pollutant to the human health, ecosystems and the built environment from the most up to date report from the ExternE research stream series (European Commission 1995).

In order to decrease scientific uncertainty modelling tools, such as *GAINS (successor of RAINS model by IIASA) or EcoSense Web (product of ExternE stream of research)* could be used. These include modelling of air pollution dispersion, atmospheric chemistry, climatic conditions and distribution of receptors. They could also help to illustrate the geography of avoided air pollution impacts and could increase policy-relevance. Whichever method is used by COMBI, the methodology will involve construction of two scenarios – "business as usual" and "energy efficiency" - and estimating the difference in air pollution impacts.

Resource impacts: abiotic and biotic

The methodology for abiotic and biotic resource quantification in COMBI was preceeded by a literature review on the relevance of resource impacts and natural resource costs, a review on existing methods for quantification and a discussion on methodological challenges for natural resource accounting within multi-impact assessments (Teubler, Bienge, & Wiesen 2015). Since there are no aggregated and well accepted indicators for the environmental impacts of global resource use at the moment (compared to e.g. indicators for global warming potential), a number of very different methods were analysed for this study. In general, there are four different types or method families, which deal with natural resource extraction or related subsequent economic issues: Life Cycle Assessment (LCA), Material Flow Accounting (MFA) or Input-/Output (I/O) modelling and Criticality Assessments. The latter was presumed to be not feasible in COMBI for resource quantification, due to its normative and qualitative nature. None of the reviewed methods includes social impacts of resource extraction and only one method (RECiPE) accounts for loss of functionality. LCA methods are well established in the scientific community, but often suffer from a lack of comprehensive data and require sufficient method knowledge for result interpretation. From the LCA family, impacts for abiotic depletion potential (adp), anthropogenic stock extended resource depletion (aadp) (see also Guinée & Heijungs 1995; Schneider, Berger & Finkbeiner 2011; Stewart & Weidema 2005) and mineral resource depletion (mrd) (see also Goedkoop et al. 2009) were reviewed in detail. Adp and aadp are mass-based indicators and include economic reserves, but do not incorporate impacts of mining, do not include all resources (and no biotic resources at all) and do not consider economical unused extraction. While mrd is a cost-based indicator considering the loss of functionality, it lacks from the same limitations. From the family of Material Flow Accounting methods, economy-wide material flow accounting (EW-MFA) and Material Input per Service (MIPS) were analysed to a higher degree. EW-MFA (see also Fischer-Kowalski et al. 2011; Giljum et al. 2011) uses reliable and robust data, regards all abiotic and biotic resources, can be linked to socio-economic data and includes unused extraction, but it quantifies resources on a high level of aggregation. It is assumed that it does not allow for a detailed quantification of resource impacts by energy effiency actions in COMBI. MIPS on the other hand (see also Liedtke et al. 2014; Giljum et al. 2011; Stewart & Weidema 2005) quantifies all abiotic and biotic resources from nature (including unused extraction) from cradle-to-grave and is suitable for technologies and services. However, it suffers from the same limitations like LCA in regard to data requirements, consistency and robustness.

After discussing the methodological challenges for COMBI, the MIPS method was selected for quantification. Its application for resource impacts (abiotic and biotic resources) is limited to the use phase of actions, and in some cases the production phase of technologies behind actions. Resource impacts (Material Footprint, MF) during use are all abiotic and biotic raw materials from nature in tons of material (endpoint is "natural resource use and preservation"), required to provide energy at final consumption. This includes the energetic carriers, auxiliary materials, their used and unused extraction, upstream processes to final consumption, energy transport and power plants. The production of energy (electricity, heat, fuels) is differentiated for different energy markets in the EU 28. Resource use for the production phase regards only relevant technologies for energy efficiency actions. Criteria for technology selection are type (technological improvement, substitution or shift), share in the technology mix and the ratio of resource use between production and use phase (stemming from literature and LCI databases).

Impacts are monetised by two different ways: Direct material costs and external costs for abiotic depletion. Direct material costs refer to the amount and price (global market price) of critical raw materials (CRM). The materials in question are the 20 CRMs published by the European Union (European Commission 2014). The amounts of CRMs are quantified life-cycle-wide for production of the selected technologies, but are restricted to available datasets in LCI database ecoinvent 2.2. External costs represent the mitigation and prevention costs for resource use and are based on ecocost characterisation factors in the ecocost-value-model by Vogtländer (2001). They are quantified life-cycle-wide for use phase of all actions and production phase of selected actions. The same material and energy flows are used for both - Material Footprint and ecocost accounting.

Social welfare impacts: disposable income/energy poverty, comfort, health

A comprehensive literature review has determined that social welfare impacts of energy efficiency interventions are relevant mostly in the building and urban transport sectors (Mzavanadze, Kelemen, and Urge-Vorsatz 2015). In the residential building sector the biggest societal gains are to be reaped when energy efficiency interventions target low-income groups, especially those suffering from energy poverty – a condition defined by the inability of a household to secure a socially- and materially-necessitated level of energy services in the home (International Energy Agency 2014, Bouzarovski and Petrova 2015).

Energy efficiency in residential buildings (insulation of the building envelope and replacement/improvement/installation of heating, air conditioning and venting technologies) has the potential (1) to improve health, both physical and mental, of those suffering from poor housing conditions such as cold homes, damp and mould (Braubach et al. 2011; Chapman et al. 2009; Howden-Chapman et al. 2008, Liddell and Morris 2010), (2) to increase overall comfort as a result of the increase in indoor temperatures and the area of living space heated as well as improved insulation against outdoor noise (Clinch and Healy 2003; Milne and Boardman 2000; Hong et al. 2009; Diamant 1986) and (3) to increase disposable income due to energy cost savings and/or household energy subsidies foregone (Schweitzer and Tonn 2003; Ürge-Vorsatz and Tirado Herrero 2012; International Energy Agency 2014). Some other health hazards may be eliminated intentionally or unintentionally during the intervention, such as radon, lead, asbestos and noise (Braubach et al. 2011; Brophy et al. 1999; Chapman et al. 2009; Canadian Environmental Law Association 2011).

The first step in estimation of energy efficiency related human health improvements is evaluation of the current disease burden attributable to inadequate housing in Europe. This includes mortality (excess winter deaths attributable to indoor cold) and morbidity (respiratory and cardiovascular diseases attributable to indoor cold, cardiovascular diseases attributable to noise, asthma attributable to indoor dampness) (Braubach et al. 2011). The second step is defining scenarios – to what extent energy efficiency interventions during the study period would reach the population currently experiencing health inequalities due to inadequate housing affecting mostly the energy poor or various other health hazards related to housing, distribution of which may not be restricted to particular socio-economic groups (like noise). It will be assumed that the distribution of the social welfare benefits will be proportional to the share of the housing stock retrofitted. The third step is to model and estimate the health damage avoided due to energy efficiency interventions.

Modal shifts in urban transportation from private vehicles to walking and cycling have implications for (1) human health due to improved physical activity and air pollution exposure, (2) human health due to traffic accidents, (3) human health due to reduced exposure to noise and (4) reduced congestion (Rabl and de Nazelle 2012; Woodcock et al. 2009; Götschi et al. 2015; Rojas-Rueda et al. 2012). Estimating noise and congestion may pose too many complexities at this scale and also a risk of double counting in case of noise. The Health Economic Assessment Tool of the WHO can be used for estimating the increased physical activity effects on the human health (Kahlmeier, World Health Organization, and Regional Office for Europe 2013). Modelling of traffic accidents due to modal shift has not been unanimous. Some predict an increase in the traffic accidents (de Hartog et al. 2010; Macmillan et al. 2014; Rojas-Rueda et al. 2012), while others argue for a decrease (Maizlish et al. 2013; Woodcock et al. 2009; Xia et al. 2015). The reason of the split may be context dependency and also differences in the temporal scale. The "safety in numbers" effect happens over many years along with changing attitudes, while in the short term an increase in traffic injuries can be expected in places where "safety in numbers" effect has not yet occurred. Although modal shift is likely to be limited mostly to urban populations, modelling of traffic related risks per vehicle/km on a country level may be the most practical approach for the scale of assessment (Bickel et al. 2006).

The monetization of human health impacts will rely on the estimates from the contingent valuation literature and also from observed costs, e.g. cost of illness. The remaining impacts, such as comfort and disposable income would be operationalized through modelling of technical and financial aspects of housing retrofits.

Impacts on productivity in commercial and public buildings

Productivity can be defined as achieving higher levels of output with the same or less level of input, or conversely, requiring same/lower levels of inputs to achieve the higher/same level of output. Among energy efficiency measures in the building sector to be studied in COMBI, building envelope and heating system upgrades are the biggest drivers which influence the human productivity. Housing renovation interventions may result in three physically measurable outcomes: changes in indoor air quality, changes in temperature and changes in humidity. All of them impact human productivity in direct or indirect form (through mortality/morbidity rate). For example, humidity or dampness affects human health via mould growth in building. Almost 13% of European dwellings have dampness problems (Kolokotsa & Santamouris 2015). Building retrofitting can cure this problem, lowering the probability of having respiratory diseases, allergies, and asthma. A mix of indoor air pollution with dampness may be a cause of the Sick Building Syndrome (Redlich, Sparer & Cullen 1997) that can be alleviated with renovation, leading to an increase in active work and school days. Many studies (see e.g. Worrell et al. 2003; Healy 2003; Federspiel et al. 2004; Lovins 2005; Chapman et al. 2009) establish a strong link between productivity and various energy efficiency measures, but despite this evidence on productivity impacts, they are often not accounted in quantitative decision support frameworks due to methodological challenges (Ürge-Vorsatz, Herrero, Dubash & Lecocq 2014).

Labour productivity is improved through several ways due to energy efficiency improvements (e.g. healthy labour force, equivalent to more work days). First, sick days can be reduced by healthier conditions as a result of certain energy efficiency investments, such as building renovation and adequate ventilation systems. But people can also be more productive through producing higher-value output as a result of being able to better participate in education (avoiding repeated illnesses, for instance, as a result of energy poverty). If allergies and other productivity-impeding conditions are reduced, human productivity may also improve in terms of value produced per unit of time worked. There are also several studies including Saldiva et al. (1994), Chen at al. (1998) and Smith & Mehta (2003) showing a relationship between lost school days and indoor air pollution. Due to a strong correlation between education and income (Gregorio 2002), a student's ability to earn may decrease as a result of lost school days.

Thus, in COMBI, the possible way to capture productivity impacts is to create an impact map like figure 2, determine the physical units and investigate values accordingly for the relevant impacts and finally monetising. For example, productivity gained through improvement of human health can be measured by the ability to earn per hour or active work or school days before and after energy efficiency measure implementation.

Macroeconomic impacts: employment, GDP, public budgets

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, stem from the fact that economies go through cyclical changes in investment, output (GDP) and employment, which fluctuate around a long-run trend. Macroeconomic policy, principally monetary and fiscal policy, are performed in order 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 will be quantified using a business-cycle macroeconomic model, which is capable of addressing two main questions:

- What is the magnitude of the GDP/employment effects that EEI each action can potentially create?
- To what extent is this GDP/employment boost actually ‘additional’?

The first point refers to how investment spending leads to increased economic activity through bringing 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) and induced (consumption) effects that follow from the direct effect. The analysis will take 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 analysis will make use of input-output analysis to track the aggregate demand effects across countries and sectors.

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 potential for such effects. The analysis must include a rigorous 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.

To the extent that short-run macroeconomic benefits are present, these are likely to also have a short-run (temporary) effect on the balance of the public budget, e.g., through reduced expenditure on unemployment benefits. This effect will also be quantified, with the use of fiscal multipliers.

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 permanent) effect on public budgets, through less public spending on energy consumption, or reduced health care spending. These effects will be quantified, using the results from other parts of COMBI as inputs, together with data on country-level public 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. These include

- Effects on global fossil fuel prices (accounting for associated rebound effects)
- Effects on the quota price within the EU-ETS
- Terms of trade effects (EU vs the rest of the world)
- Structural shifts in consumption between different sectors/uses

Such issues will be analysed using a structural, general-equilibrium type macroeconomic model, with a focus on the markets for fossil fuels.

Impacts on energy system & security

The majority of approaches evaluating the impacts on energy systems and energy security rely on model-based scenario analysis. Energy system models (e. g. the TIMES-MARKAL family of models or the European PRIMES model) are used to generate scenarios of how energy systems could develop. Energy security parameters are either incorporated as a constraint the model has to satisfy (for instance a certain level of installed back-up capacity); or some aspect of energy security is analysed after the model has constructed a scenario. By using energy efficiency policy modelling results under a baseline scenario, i.e. without the effect of the energy efficiency policy, and with a policy scenario, the difference between the evolution of the energy security indicator in each case can be used to determine whether, and to what extent, the policy has increased or decreased the ‘vulnerability’ of the energy system (of a region, a EU Member State, or the EU as a whole) to the earlier identified energy security risks. All assessments based on the use of scenarios and indicators necessarily give a partial and simplified view of energy security. Some of the shortcomings of using energy system models are (Mansson et al. 2014; Kruyt et al. 2009):

- energy security issues related to price volatility are often overlooked. Energy models with a long-term focus are unfit to investigate price volatility. Indicators incorporating price volatility can only be used in models with short-run dynamics;
- energy models generally do not model trade in energy carriers other than coal, oil, natural gas and modern biofuels;
- short-term threats (e.g. fluctuations in production) and problems related to interregional trade are sometimes disguised (depending on the iteration steps and granularity);
- not all models capture macro-economic feedbacks from high energy prices.

Models trying to quantify the welfare loss of a physical unavailability and/or price impact are invariably based on top-down economic models (Arnold & Hunt 2009; Hunt and Markandya 2004). Forecasts, based on historical data on price movements, determine the probability of a price shock occurring. The impact, i.e. the resulting loss of wealth, of supply disruptions and/or energy price increases is estimated or simulated with the use of general equilibrium macroeconomic models that consider factors such as elasticity of demand. The relationship between energy security, and more in particular increases and volatility of crude oil market prices on the one hand; and gross domestic product (GDP) growth on the other hand, has been an ongoing topic of research since the 1980s. Most evidence tends to be gathered from short-run national or cross-sectional studies (van de Ven & Fouqet 2014). Also, not every oil price shock has led to economic slowdown (Kilian 2008). The link between oil price shocks and GDP slowdown thus continues to be controversial.

COMBI relies on a model-based scenario analysis with a set of vulnerability indicators (see e.g. European Commission 2013), which help to operationalise and hence assess a system as complex as the energy supply chain (Gracceva & Zeniewski 2014, p. 336). Model-based scenario analysis help to assess how various policies put forward by the EU affect energy security (Ecofys 2009). The retained indicators are

- import dependency;
- geographical diversification;
- diversification of energy sources;
- energy intensity of the economy;
- overall investment in new capacity needed;
- capital intensity of energy system investments;
- de-rated capacity margin;
- value of lost load (VoLL).

The decision support tool LEAP is used to build an energy system model for the EU member states and to evaluate existing scenarios of how the energy systems in the EU could develop (Heaps 2012). LEAP stands for the “Long range Energy Alternatives Planning System”, a software tool for energy policy analysis developed at the Stockholm Environment Institute (SEI). All energy efficiency improvement actions are aggregated at the level of the individual energy carriers. These are then fed into the LEAP energy system model. Most of the assumptions concerning the energy system are those implicitly contained in the existing EU (e.g. PRIMES) scenario results.

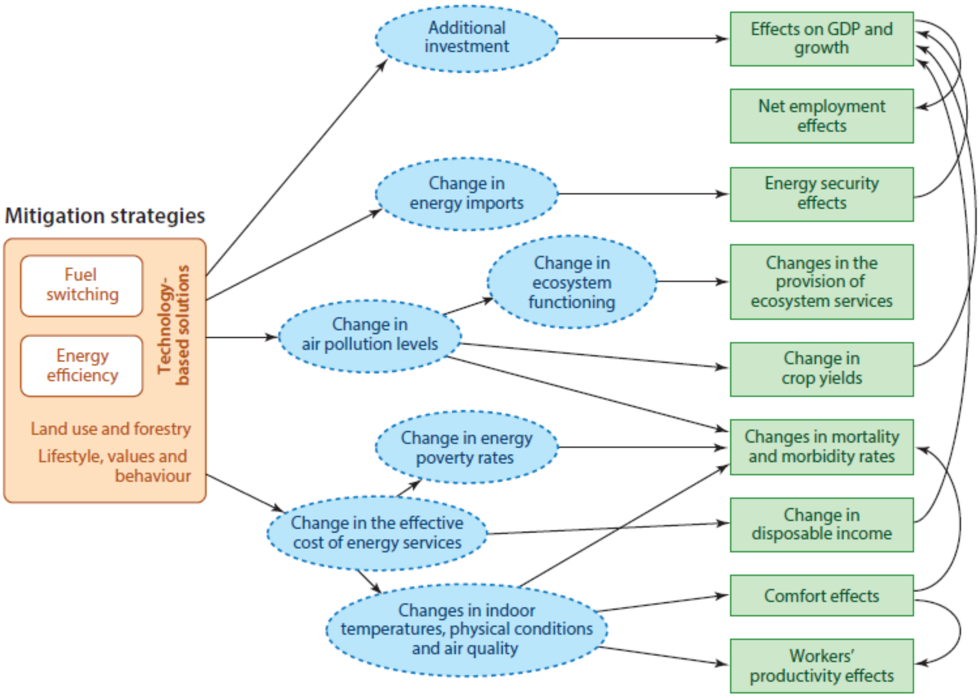
The LEAP model is structured to allow easy updating of the existing EU (e.g. PRIMES) scenario projections as well as other input data. The user can select the combination of indicators, scenarios and Member States to be displayed. The user can quickly change a small number of variable factors and see the resulting impacts.

In terms of monetisation, overall investment in new capacity needed and capital intensity of energy system investments are by definition monetary indicators and a straightforward output of the LEAP energy system modelling. It is also possible to express import shares, with various disaggregations with regard to fuels and regions, in monetary terms. To evaluate the value of lost load, we use literature values for the different EU Member States.

Interactions between multiple impacts and approach for synthesis/aggregation

In the context of climate change-related decision making, multiple impacts are often cited as factors that can significantly change the results of direct cost-benefit evaluations. However, these impacts rarely enter the quantitative decision-making frameworks applied. They often remain at the rhetorical or discourse levels, even though their inclusion would substantially influence the outcomes of decision processes (Ürge-Vorsatz, Herrero, Dubash & Lecocq 2014). Several studies (cf. Ürge-Vorsatz et al. 2009; Ryan & Campbell 2012; Ürge-Vorsatz et al. 2014) on co-benefits/non-climatic benefits indicate that some categories overlap among each other. In such cases special care needs to be taken to avoid double counting. Hence, a detailed impact map can be created to understand the impact pathway from the starting point, i.e. from the energy efficiency action to the end point (where impacts are not any more transferred into other impacts). Figure 2 can be considered as an example illustrating the interdependencies among impacts and suggesting a framework for identifying the impact pathways, endpoints, and thus key interactions as well as potential double counting. Within the COMBI project, such cause-impact interrelations will be analysed, identified and included in the quantification approaches.

Figure 2. Interrelations of multiple benefits of energy efficiency



Source: Ürge-Vorsatz et al. 2014

Methodology

In a first step, an impact map will be created as per relevant energy efficiency actions. Then, single impacts will be identified and quantified using the most convenient methods and indicators (see previous sections). Physical metrics of each significant end-point will be proposed and where possible monetised using an appropriate methodology. After monetisation, impacts are aggregated. Several impacts are quite complex and controversial to monetise like health. In that case, COMBI will quantify both the physical unit to assess the impact as well as the monetized value. Another issue of monetisation and aggregation is dependency among impacts and as a result, complexity may arise for a rigorous assessment of individual impacts as well as for their aggregation. For example, some impacts are directly dependent on the amount of energy savings (e.g. climate change mitigation, energy cost savings) while others can be derived from these values and depend on rather complex cause-impact-chains across different socio-economic and environmental fields (e.g. social welfare, health impacts, GDP and employment effects). Consequently, direct energy-dependent and indirect benefits differ in their complexity of modelling. Other benefits include different aspects and have wide ranges, e.g. welfare covers aspects like health and disposable income. Since some benefits can actually be negative for some stakeholders (such as lost employment in the energy supply sector due to less energy demand, foregone tax revenues from energy sales, etc.), the project will focus on net co-impacts rather than only benefits in order to consider the multiple impacts in an objective framework.

Challenges

1. *Context dependency*: Multiple impacts are extremely context dependent. The impact of policy design in many cases determines the types and size of multiple benefits. For example, Ürge-Vorsatz et al. (2010) found in a study on energy efficiency policy impacts on employment in Hungary that the mode of financing and not only the level of ambition of the energy efficiency action impacted the level of employment benefits, because the mode of financing influences the amount of disposable income that is available to different economic agents at different points in time (Ürge-Vorsatz et al. 2010), which in turn influences consumption and investment patterns and consequently demand for goods and thus employment in different sectors.
2. *Scale*: In terms of the geographic scope of whose benefits should matter, in general, the appropriate scale of analysis depends on the type of multiple impacts assessed. Also the unit of analysis plays a crucial role for quantification, as e.g. an analysis at national level will not capture distributional effects. Different impacts are also relevant at different scales. For example, some air pollutants (e.g. PM10) have more local impacts, while others (e.g. SO2) can have trans-boundary impacts. However, the preferences of the policymaker can override this consideration. Thus, it may be appropriate to take the boundary of the impact as the boundary for the assessment in order to avoid ignoring some impacts.
3. *Baseline and Additionality*: It is important to investigate the share of the impact is actually resulting from energy efficiency action and thus is additional compared to the baseline. Additionality thus depends on the appropriate choice of a baseline.
4. *Evaluation perspective:* When assessing multiple impacts, the perspective of the assessment needs to be established in terms of which groups of stakeholders to take into account in the assessment (e.g. society or investors/end-users)

Conclusion

Energy efficiency improvements hold numerous wider impacts for the economy, society and end-users than 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 a consideration of complex causal chains, the context-dependency of multiple impacts, data limitations and ethical concerns in regard to monetisation. In addition, significant overlaps and interactions between these impacts exist, which 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 specific multiple impacts of energy efficiency improvement actions and pointed out which methods will be used in the European Horizon 2020-project COMBI. This project is aimed at calculating and operationalising the most important multiple impacts of the 30 most relevant energy efficiency improvement actions in Europe.

Although the field of research on multiple impacts has grown rapidly in the past years, there are several needs of further investigation 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 may need further adaptation in order to be able to assess the complex causal chains in more detail.

References

Alcamo, Joseph, Petra Mayerhofer, Ramon Guardans, Toon van Harmelen, Jelle van Minnen, Janina Onigkeit, Maximilian Posch, and Bert de Vries. 2002. An Integrated Assessment of Regional Air Pollution and Climate Change in Europe: Findings of the AIR-CLIM Project. Environmental Science & Policy 5 (4): 257–72. doi:10.1016/S1462-9011(02)00037-0.

Amann, M., C. Heyes, G. Kiesewetter, W. Schoepp, and F. Wagner. 2014. Air Quality. Complementary Impact Assessment on Interactions Between EU Air Quality Policy and Climate and Energy Policy. International Institute for Applied Systems Analysis (IIASA). http://www.europarl.europa.eu/thinktank/de/document.html?reference=EPRS_STU%282014%2952880.

Amann, Markus, Imrich Bertok, Jens Borken-Kleefeld, Janusz Cofala, Chris Heyes, Lena Höglund-Isaksson, Zbigniew Klimont, et al. 2011. Cost-Effective Control of Air Quality and Greenhouse Gases in Europe: Modeling and Policy Applications. Environmental Modelling & Software 26 (12): 1489–1501. doi:10.1016/j.envsoft.2011.07.012.

Arnold S. & Hunt A. 2009. National and EU-Level Estimates of Energy Supply Externalities, CEPS Policy Brief, No. 186, April 2009

Bickel, P., R. Friedrich, A. Burgess, P. Fagiani, A. Hunt, G. de Jong, J. Laird, et al. 2006. Developing Harmonised European Approaches for Transport Costing and Project Assessment. http://www.transport-research.info/sites/default/files/project/documents/20090918_161442_29356_HEATCO%20-%20Final%20Report.pdf.

Bouzarovski S., Petrova S. 2015. A global perspective on domestic energy deprivation: Overcoming the energy poverty–fuel poverty binary. Energy Research & Social Science 10, 31-40.

Braubach, Matthias, David E Jacobs, David Ormandy, World Health Organization, and Regional Office for Europe. 2011. Environmental Burden of Disease Associated with Inadequate Housing a Method Guide to the Quantification of Health Effects of Selected Housing Risks in the WHO European Region. Copenhagen: World Health Organization Regional Office for Europe. http://www.euro.who.int/__data/assets/pdf_file/0017/145511/e95004sum.pdf.

Brophy, Vivenne, Dublin University College, Energy Research Group, Dublin University College, and Environmental Institute. 1999. Homes for the 21st Century: The Costs & Benefits of Comfortable Housing for Ireland. [Place of publication not identified]: Energy Action.

Canadian Environmental Law Association. 2011. Healthy Retrofits the Case for Better Integration of Children's Environmental Health Protection into Energy Efficiency Programs. Toronto, Ont.: Canadian Environmental Law Association. http://site.ebrary.com/id/10456484.

Chapman, R., Howden-Chapman, P., Viggers, H., O'Dea, D., & Kennedy, M. 2009. Retrofitting houses with insulation: a cost-benefit analysis of a randomised community trial. Journal of Epidemiology & Community Health, 63(4), 271–277. http://doi.org/10.1136/jech.2007.070037

Chen, P. C., Lai, Y., Wang, J. D., Yang, C. Y., Hwang, J. S., Kuo, H. W., Huang, S., Chan, C. 1998. Adverse effect of air pollution on respiratory health of primary school children in Taiwan. Environ Health Perspect. 331–335.

Clinch, J.P., and J. D Healy. 2003. Valuing Improvements in Comfort from Domestic Energy-Efficiency Retrofits Using a Trade-off Simulation Model. Energy Economics 25 (5): 565–83. doi:10.1016/S0140-9883(03)00051-3.

de Hartog, Jeroen Johan, Hanna Boogaard, Hans Nijland, and Gerard Hoek. 2010. Do the Health Benefits of Cycling Outweigh the Risks? Environmental Health Perspectives 118 (8): 1109–16. doi:10.1289/ehp.0901747.

Department for Environment, Food and Rural Affaris (DEFRA). 2013. Abatement Cost Guidance for Valuing Changes in Air Quality. London, UK. www.gov.uk/air-quality-economic-analysis.

Diamant, R. M. E. 1986. Thermal and acoustic insulation. London ; Boston: Butterworths.

Ecofys 2009. Redpoint, ERAS. Analysis of impacts of climate change policies on energy security. European Commission DG Environment; 2009.

European Commission , Directorate-General for Economic and Financial Affairs 2013. Member States' Energy Dependence: An Indicator-Based Assessment, Occasional Papers 145, April 2013

European Commission, and Directorate-General for Regional Policy. 2015. Guide to Cost-Benefit Analysis of Investment Projects: Economic Appraisal Tool for Cohesion Policy 2014-2020. Luxembourg: Publications Office.

European Commission, ed. 1995. ExternE: Externalities of Energy:: [studies]. Vol. 2: Methodology: [method for Estimation of Physical Impacts and Monetary Valuation for Priority Impact Pathways]. EUR 16521. Luxembourg: Off. for Official Publ. of the Eur. Communities.

European Commission. On the review of the list of critical raw materials for the EU and the implementation of the Raw Materials Initiative, Pub. L. No. COM(2014) 297 final (2014).

Federspiel CC, Fisk WJ, Price PN, Liu G, Faulkner D, Dibartolemeo DL, Sullivan DP, Lahiff M. 2004. Worker performance and ventilation in a call center: analyses of work performance data for registered nurses. Indoor Air Journal vol 14. Supplement 8: 41-50

Fischer-Kowalski, M., Krausmann, F., Giljum, S., Lutter, S., Mayer, A., Bringezu, S., … Weisz, H. 2011. Methodology and indicators of economy-wide material flow accounting. Journal of Industrial Ecology, 15(6), 855–876.

Fraunhofer ISI 2009. Study on the Energy Savings Potentials in EU Member States, Candidate Countries and EEA Countries. Final Report (EC Service Contract Number TREN/D1/239-2006/S07.66640). Karlsruhe: Fraunhofer-Institute for Systems and Innovation Research.

Fraunhofer ISI 2012. Concrete Paths of the European Union to the 2°C Scenario: Achieving the Climate Protection Targets of the EU by 2050 through Structural Change, Energy Savings and Energy Efficiency Technologies (Scientific Support in the Preparation of Proposals for an EU Energy Roadmap Project Number 405/2010). Karlsruhe: Fraunhofer Institute for Systems and Innovation Research.

Giljum, S., Burger, E., Hinterberger, F., Lutter, S., & Bruckner, M. 2011. A comprehensive set of resource use indicators from the micro to the macro level. Resources, Conservation and Recycling, 55(3), 300–308. http://doi.org/10.1016/j.resconrec.2010.09.009

Goedkoop, M., Heijungs, R., Huijbregts, M., De Schryver, A., Struijs, J., & van Zelm, R. (2009). ReCiPe 2008. A Life Cycle Impact Assessment Method Which Comprises Harmonised Category Indicators at the Midpoint and the Endpoint Level, 1.

Götschi, Thomas, Marko Tainio, Neil Maizlish, Tim Schwanen, Anna Goodman, and James Woodcock. 2015. Contrasts in Active Transport Behaviour across Four Countries: How Do They Translate into Public Health Benefits? Preventive Medicine 74 (May): 42–48. doi:10.1016/j.ypmed.2015.02.009.

Gracceva F. & Zeniewski P. 2014. A systemic approach to assessing energy security in a low-carbon EU energy system. Applied Energy 123 335–348

Guinée, J. B., & Heijungs, R. 1995. A proposal for the definition of resource equivalency factors for use in product life-cycle assessment. Environmental Toxicology and Chemistry, 14(5), 917–925.

Healy, J. D. 2003. Excess winter mortality in Europe: a cross country analysis identifying key risk factors. Journal of Epidemiology & Community Health, 57(10), 784–789. http://doi.org/10.1136/jech.57.10.784

Heaps, C.G. 2012. Long-range Energy Alternatives Planning (LEAP) system. [Software version 2015.0.16] Stockholm Environment Institute. Somerville, MA, USA. www.energycommunity.org http://www.externe.info/expolwp3.pdf

Hong, Sung H., Jan Gilbertson, Tadj Oreszczyn, Geoff Green, and Ian Ridley. 2009. A Field Study of Thermal Comfort in Low-Income Dwellings in England before and after Energy Efficient Refurbishment. Building and Environment 44 (6): 1228–36. doi:10.1016/j.buildenv.2008.09.003.

Howden-Chapman, P., N. Pierse, S. Nicholls, J. Gillespie-Bennett, H. Viggers, M. Cunningham, R. Phipps, et al. 2008. Effects of Improved Home Heating on Asthma in Community Dwelling Children: Randomised Controlled Trial. BMJ 337 (sep23 1): a1411–a1411. doi:10.1136/bmj.a1411.

Hunt A.S.P. & Markandya A. 2004. Final Report on Work Package 3: The Externalities of Energy Insecurty. ExternE-Pol Reserarch Project for European Commission

IEA 2014. Capturing the Multiple Benefits of Energy Efficiency. OECD/IEA.

Intergovernmental Panel on Climate Change (IPCC) 2007. Summary for Policymakers. In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assess-ment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

International Energy Agency. 2014. Capturing the Multiple Benefits of Energy Efficiency. http://alltitles.ebrary.com/Doc?id=10961846.

Kahlmeier, Sonja, World Health Organization, and Regional Office for Europe. 2013. Health Economic Assessment Tools (HEAT) for Walking and for Cycling: Methodology and User Guide : Economic Assessment of Transport Infrastructure and Policies. Copenhagen: World Health Organisation, Regional Office for Europe.

Kats, G. 2006. Greening America's Schools: Costs and Benefits.

Kilian L. 2008. Exogenous Oil Supply Shocks: How Big Are They and How Much Do They Matter for the U.S. Economy?, Review of Economics and Statistics 90, no. 2 216–240

Kolokotsa, D., & Santamouris, M. 2015. Review of the indoor environmental quality and energy consumption studies for low income households in Europe. Science of The Total Environment, 536, 316–330. http://doi.org/10.1016/j.scitotenv.2015.07.073

Kruyt B., van Vuuren D.P., de Vries H.J.M. end Groenenberg H. 2009. Indicators for energy security. Energy Policy 2009;37(6):2166-81. http://dx.doi.org/10.1016/j.enpol.2009.02.006

Kuylenstierna, J.C.I., M.A. Ajero, D. Schindell, E. Zusman, F. Murray, G. Braathen, K. Hicks, et al. 2012. Atmosphere. In Global Environment Outlook (GEO-5): Environment for the Future We Want. United Nations Environment Programme. http://www.unep.org/geo/geo5.asp.

Liddell, C. and Morris, C. 2010. Fuel poverty and human health: a review of evidence. Energy Policy 38: 2987-2997.

Liedtke, C., Bienge, K., Wiesen, K., Teubler, J., Greiff, K., Lettenmeier, M., & Rohn, H. 2014.

Resource Use in the Production and Consumption System—The MIPS Approach. Resources, 3(3), 544–574. http://doi.org/10.3390/resources3030544

Lovins, A. B. 2005. Energy End-Use Efficiency. Colorado, USA: Rocky Mountain Institute. Retrieved from http://www.udel.edu/igert/JournalClub/JC5.pdf

Macmillan, Alexandra, Jennie Connor, Karen Witten, Robin Kearns, David Rees, and Alistair Woodward. 2014. The Societal Costs and Benefits of Commuter Bicycling: Simulating the Effects of Specific Policies Using System Dynamics Modeling. Environmental Health Perspectives, February. doi:10.1289/ehp.1307250.

Maizlish, Neil, James Woodcock, Sean Co, Bart Ostro, Amir Fanai, and David Fairley. 2013. Health Cobenefits and Transportation-Related Reductions in Greenhouse Gas Emissions in the San Francisco Bay Area. American Journal of Public Health 103 (4): 703–9. doi:10.2105/AJPH.2012.300939.

Mansson A., Johansson B. and Nilsson L.J. 2014. Assessing energy security: An overview of commonly used methodologies, Energy 73 (2014) 1-14.

Milne, Geoffrey, and Brenda Boardman. 2000. Making Cold Homes Warmer: The Effect of Energy Efficiency Improvements in Low-Income Homes A Report to the Energy Action Grants Agency Charitable Trust. Energy Policy 28 (6-7): 411–24. doi:10.1016/S0301-4215(00)00019-7.

Mzavanadze, N. 2015. Literature Review on Avoided Air Pollution Impacts of Energy Efficiency Measures. http://combi-project.eu/wp-content/uploads/2015/09/D3.1.pdf.

Mzavanadze, N., A. Kelemen, and D. Urge-Vorsatz. 2015. Literature Review on Social Welfare Impacts of Energy Efficiency Improvement Actions. http://combi-project.eu/wp-content/uploads/2015/09/D5.1.pdf.

OECD. 2001. Measuring Productivity- measurement of aggregate and industry-level productivity growth. Organisation for economic co-operation and development. http://www.oecd.org/std/productivity-stats/2352458.pdf

Rabl, Ari, and Audrey de Nazelle. 2012. Benefits of Shift from Car to Active Transport. Transport Policy 19 (1): 121–31. doi:10.1016/j.tranpol.2011.09.008.

Redlich, C. A., Sparer, J., & Cullen, M. R. 1997. Sick-building syndrome. The Lancet, 349(9057), 1013–1016. http://doi.org/10.1016/S0140-6736(96)07220-0

Rojas-Rueda, D., A. de Nazelle, O. Teixidó, and M.J. Nieuwenhuijsen. 2012. Replacing Car Trips by Increasing Bike and Public Transport in the Greater Barcelona Metropolitan Area: A Health Impact Assessment Study. Environment International 49 (November): 100–109. doi:10.1016/j.envint.2012.08.009.

Ryan, L., & Campbell, N. 2012. Spreading the net: the multiple benefits of energy efficiency improvements. International Energy Agency https://www.iea.org/publications/insights/insightpublications/Spreading_the_Net.pdf

Saldiva P., Lichtenfels, A., Paiva, P., Barone, I., Martins, M., Massad, E., Pereira, J., Xavier, V., Singer, J., Bohm, G. 1994. Association between Air Pollution and Mortality Due to Respiratory Diseases in Children in São Paulo, Brazil: A Preliminary Report. Environmental Research. 218–225.

Schneider, L., Berger, M., & Finkbeiner, M. 2011. The anthropogenic stock extended abiotic depletion potential (AADP) as a new parameterisation to model the depletion of abiotic resources. The International Journal of Life Cycle Assessment, 16(9), 929–936.

Schweitzer, M., Tonn, B. 2002. Non-energy benefits from the weatherization assistance program: A summary of findings from the recent literature. Oak Ridge National Laboratory.

Schweitzer, Martin, and Bruce Tonn. 2003. Non-Energy Benefits of the US Weatherization Assistance Program: A Summary of Their Scope and Magnitude. Applied Energy 76 (4): 321–35. doi:10.1016/S0306-2619(03)00003-5.

Smith, K., Mehta, S. 2003. The burden of disease from indoor air pollution in developing countries: comparison of estimates. International Journal of Hygiene and Environmental Health. 279–289.

Stewart, M., & Weidema, B. P. 2005. A Consistent Framework for Assessing the Impacts from Resource Use-A focus on resource functionality (8 pp). The International Journal of Life Cycle Assessment, 10(4), 240–247.

Teubler, J., Bienge, K., & Wiesen, K. 2015. WP4 Resources: Literature review on resource benefits D4. 1 report.

Ürge-Vorsatz D., Arena D., Tirado Herrero S., Butcher A., Telegdy A., Fegyverneky S., Csoknyai T., Kopataki E., Janko A. 2010. Employment Impacts of a Large-Scale Deep Building Energy Retrofit Programme in Hungary. Prepared by the Center for Climate Change and Sustainable Energy Policy of Central European University, Budapest, on behalf of the European Climate Foundation. June 8, 2010.

Ürge-Vorsatz, D., Novikova, A., Sharmina, M. 2009. Counting good: quantifying the co-benefits of improved efficiency in buildings, in proceedings of the ECEEE 2009 Summer Study. http://psb.vermont.gov/sites/psb/files/projects/EEU/screening/Urge-Vorsatz__Counting_Good.pdf

Ürge-Vorsatz, D., Tirado Herrero, S., Dubash, N.K., Lecocq, F. 2014. Measuring the co-benefits of climate change mitigation. Annual Review of Environment and Resources, 39, 1, 549-582. DOI: 10.1146/annurev-environ-031312-125456.

Ürge-Vorsatz, Diana, and Sergio Tirado Herrero. 2012. Building Synergies between Climate Change Mitigation and Energy Poverty Alleviation. Energy Policy 49 (October): 83–90. doi:10.1016/j.enpol.2011.11.093.

Van de Ven D.J. & Fouquet R. 2014. Historical Energy Price Shocks and their Changing Effects on the Economy, Centre for Climate Change Economics and Policy, April 2014

Vogtländer, J. G. 2001. The model of the Eco-costs/Value Ratio. A New LCA Based Decision Support Tool. Universidad Técnica de Delf.

Woodcock, James, Phil Edwards, Cathryn Tonne, Ben G Armstrong, Olu Ashiru, David Banister, Sean Beevers, et al. 2009. Public Health Benefits of Strategies to Reduce Greenhouse-Gas Emissions: Urban Land Transport. The Lancet 374 (9705): 1930–43. doi:10.1016/S0140-6736(09)61714-1.

Worrell, E., Laitner, J. A., Ruth, M., & Finman, H. 2003. Productivity benefits of industrial energy efficiency measures. Energy, 28(11), 1081–1098. http://doi.org/10.1016/S0360-5442(03)00091-4.

Xia, Ting, Monika Nitschke, Ying Zhang, Pushan Shah, Shona Crabb, and Alana Hansen. 2015. Traffic-Related Air Pollution and Health Co-Benefits of Alternative Transport in Adelaide, South Australia. Environment International 74 (January): 281–90. doi:10.1016/j.envint.2014.10.004.

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