COMBI

Calculating and Operationalising the Multiple Benefits of Energy Efficiency in Europe

WP5 Social welfare

Methodology for quantification of productivity impacts

D5.2a report

Grant Agreement No. 649724

Authors

Diana Urge-Vorsatz

Souran Chatterjee

Budapest, May 25, 2016

Coordinated by

Wuppertal Institut

Project partners

ABUD Advanced Building & Urban Design

Copenhagen Economics

Universiteit Antwerpen

Manchester 1824 The University of Manchester

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

Content

List of tables

List of figures

1 Background

1.1 Project description

The COMBI project is coordinated by the Wuppertal Institute for Climate, Environment and Energy and implemented together with the research partners University of Antwerp, University of Manchester, Copenhagen Economics and ABUD/Advanced Buildings and Urban Design. It aims at quantifying the multiple non-energy benefits of energy efficiency. It. These multiple non-energy benefits of energy efficiency are gaining relevance in the research and the current policy discourse, but scientific evidence is yet scarce and scattered. Therefore, this projects will gather existing approaches and evidence on benefits from energy efficiency from the EU countries, develop modelling approaches in order to come up with consolidated data on different benefits such as effect on: emissions (with related effects on health, ecosystems, crops, built environment), resources (related biotic/abiotic, energy/non-energy effects), social welfare (related effects on disposable income, comfort, health), macroeconomy (with effects on labor market, public finance, GDP), and the energy system (which affects grid, supply-side, energy security). All project outcomes will be available at an open-source online database. It will be also analysable via a graphic online-visualisation tool enabling personalising the findings to in regard to the geographic location and selected benefits. To emphasise is that the development of an aggregation methodology is of central importance in order to avoid double-counting and for presenting the various benefits and how they are inter-related. Finally, recommendations with policy relevance will be derived and elaborated to facilitate the communication and application of the non-energy benefits in the relevant policy areas. In addition, the project is taking into consideration on-going processes of how to include multiple energy efficiency benefits into policies.

1.2 Aim of this report

Based on the literature reviews conducted for individual multiple impacts (MI), the second main step of the COMBI project is to develop a methodology to quantify and monetise MIs. Monetisation of single (sub-)MI is conducted where possible. For the set of defined EEI actions (see D2.2 report), energy saving potentials in the year 2030 are being developed reflecting official EU PRIMES scenarios (energy efficiency vs. baseline scenario) (see D2.1 report). The general COMBI approach follows the additionality principle: only additional effects (both energy and non-energy impacts) relative to an action baseline are considered *(will be adapted for final version.)*

Productivity impact is one of the most important co-benefits in COMBI. In this report, the methodology to quantify productivity is discussed. We distinguish between five main types of human/workplace productivity:

1. ***Amount of active time available** for productive work. This can be affected, for instance, by being sick, which reduces the amount of active time available for workers.*
2. ***Workforce productivity within a certain time frame**. For instance, due to improved building envelopes in commercial building entire workforce can achieve more productive time.*
3. ***Productivity (earning ability/value added) per unit of time worked.** This can be affected, for instance, through education that increases productivity/earning ability per unit time worked; or*

impacts that affect the ability to concentrate/focus, such as comfort, physical and mental well-being.

4. ***Productivity per unit of resource investment.*** *This applies only for workplace/public productivity.This can be captured by input-output ratio.*
5. **Agricultural productivity, i.e.** % change of crop yields in a certain time frame. Crop production can be affected through concentration of few air pollutants such as PM, ozone, CO_2 etc.

2 Scope of investigation

2.1 Definition of impacts, end-points and metrics/indicators

Improving 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. There are many literatures which shows a strong correlation between productivity impact and indoor temperature (see (Fisk, 2000, (Worrell et al 2003), (Chapman et al., 2009), (de Dear et al (2013)).

For example, Witterseh et al (2004) found that participants who felt too warm made 56% more errors during a mathematical addition task. Seppanen et al (2004) find that an average of 2% decrease in work performance per degree Celsius has been established when the temperature is above 25°C.

However, in COMBI productivity research, we are not only capturing how temperature influence productivity but several other impact which interacts with productivity, also captures here. Table 1 shows all the key possible impacts which can influence productivity.

Table 1: Impacts and their influence on productivity

Impacts	Influence on productivity
Comfort	This impact is mainly relevant to the building sector. Due to retrofitting, comfort level increases, which has a direct impact on human productivity. There is a strong link between productivity and thermal comfort (Federspiel,et al., 2002, Lovins, 2005).However in COMBI, comfort includes visual and noise comfort as well.
Indoor air quality	Indoor air quality improves by installing improved ventilation and filtering system. Potential productivity gains can be achieved by avoiding transmittable respiratory diseases, sick building syndrome (SBS) (Redlich, Sparer, & Cullen, 1997, Kolokotsa & Santamouris, 2015), allergies and asthma.
Outdoor air quality	Outdoor air quality affects human health and health affects productivity. For example, less air pollution results in less emission of air pollutants (like PMx,NOx SOx etc.). Less emission of air pollutants results in less burden of diseases like heart disease, lung cancer, and respiratory diseases (HEI, 2010). Thus, by avoiding these diseases, the amount of productive days increase.
Pollution (waste, water, soil)	Soil or water pollution affects human health and waste actually affects soil and water. Thus, this type of pollution is affecting human productivity through health.

Physical activity	More physical activity due to shift in active transportation, will result in less diseases and by improving the health condition will result in more productive days.
Congestion	Less traffic congestion would result in more productive work time. Many studies monetise the intensity of productivity loss due to congestion (Lewis, D. 2008),(Litman, 2011).
Input savings/ Raw material savings	Mainly in the industrial sector, due to improved energy efficiency actions less amount of input/ raw material is required to produce the same level of output. Here, raw material does not only include energy, but other inputs as well. This results in increased productivity in the industrial sector. (Porter & Linde, 1995), (Worrell et al 2003). Infact labout input can also be improved from energy efficiency measures which is also an input savings
Disposable income	Productivity improvement will result in increase in disposable income. (IEA,2014)
Public Budget	Productivity improvement can influence public budget as well through increase in taxation or by avoiding subsidy. To be precise, more disposable income by achieving more productivity will result in more taxation. (IEA,2014)
Energy Poverty	Energy poor people are within our research scope. Due to retrofitting, energy poor people can gain additional active days to work and it also has an impact on their earning ability.(Birol,2007)
Health	Health is affected through air pollutants, physical activity, etc. Health is the key source through which productivity influenced largely. Health improvements can influence the pace of income growth via worker productivity. (Bloom and Canning, 2008)

From table 1, we will identify the key impacts considering COMBI time frame and data availability which can influence productivity significantly. To identify the key impacts, the causal chain from energy efficiency action implementation to productivity impact needs to be understood.

Thus, for the relevant efficiency actions for this work package, the impact pathways are created in order to accurately quantify productivity impacts, avoiding double counting error (Urge-Vorsatz et al, 2014).These impact pathway or impact map will start from implementing an energy efficiency action implementation and it will lead towards the 'end-point'.

Productivity is itself considered to be an impact end-point. For the methodology, the definition of an impact 'end-point' is therefore crucial. In COMBI, end-point is the last impact which is not transferring to any other impact or policy makers can consider this impact to be a separate policy target.Due to the impotance of productivity, it can definitely can be considered as a policy target.Thus productivity is an end-point in COMBI.

2.2 EEI actions relevant for productivity (WP5)

Most of the actions which are studied in COMBI, are leading to productivity gains indirectly or directly.

Table 2 includes a detailed list of relevant actions of productivity with explanation.

Table 2: Relevance of COMBI EEI actions for productivity impacts

#	EEI actions	Considered	Reason for inclusion/exclusion
1	Residential existing buildings – improvements of building envelopes content	*Yes*	*Improvement of building envelopes has a positive influence on thermal comfort and health (through reduction of indoor and outdoor air pollutants like pollen, particulate etc. by installing proper thermal insulation, ventilation etc.) which ultimately improves the productivity.*
2	New residential buildings – PassivHaus standards for heating and cooling demands	*Yes*	*It has a positive effect on thermal comfort, health (through reduction of indoor and outdoor air pollutants like pollen, particulate etc. by installing proper thermal insulation, ventilation etc.) which ultimately improves the productivity.*
3	Existing residential buildings – improvements of heating systems	*Yes*	*It has a positive impact on thermal comfort, health (through reduction of indoor and outdoor air pollutants like pollen, particulate etc. by installing proper thermal insulation, ventilation etc.) which ultimately improves the productivity.*
4	Residential – improvements of domestic hot water systems	*No*	No significant effect on productivity.
5	Existing residential buildings – improvements of (room) air-conditioning systems	*Yes*	*It has an effect on thermal comfort which would affect productivity.*
6	Residential – improvements of lighting systems	*Yes*	Visual comfort may improve productivity.
7	Residential appliances – improvements of refrigerators / freezers	*Yes*	An improved refrigerator would consume less energy which results in less air pollutants. Air pollutants affect productivity via health.
8	Tertiary existing buildings – improvements of building envelopes	*Yes*	*Improvement of building envelopes has a positive influence on thermal comfort and health (through reduction of indoor and outdoor air pollutants like pollen, particulate etc. by installing proper thermal insulation, ventilation etc.) which ultimately improves the productivity.*
9	New tertiary buildings – PassivHaus standards for heating and cooling demands	*Yes*	*It has a positive impact on thermal comfort, health (through reduction of indoor and outdoor air pollutants like pollen, particulate etc. by installing proper thermal insulation, ventilation etc.) which ultimately improves the productivity.*
10	Existing tertiary buildings – improvements of heating systems	*Yes*	*It has a positive impact on thermal comfort, health (through reduction of indoor and outdoor air pollutants like pollen, particulate etc. by installing proper thermal insulation, ventilation etc.) which ultimately improves the productivity.*
11	Tertiary – improvements of domestic hot water systems	*No*	No significant effect on productivity.
12	Tertiary existing buildings – improvements of air-conditioning systems and fans	*Yes*	*It has a positive impact on thermal comfort, health (through reduction of indoor and outdoor air pollutants like pollen, particulate etc. by installing proper thermal insulation, ventilation etc.) which ultimately improves the productivity.*
13	Tertiary – improvements of lighting systems (including street lighting)	*No*	No significant effect on productivity.
14	Tertiary – improvements of commercial refrigeration and freezing	*Yes*	Improved refrigeration would consume less energy and that results in less air pollutants. Air pollutants affect productivity via health.
15	Passenger transport – improved efficiency of road vehicles (cars)	*Yes*	Road safety increases and fuel consumption reduces due to which productivity increases via improvement of health (due to less emission of pollutants)
16	Freight transport – improved efficiency of light and heavy duty trucks	*No*	No significant effect on productivity.
17	Passengers and freight transport – improved efficiency of rail transport vehicle	*No*	No significant effect on productivity.
18	Passenger transport – modal shift	*Yes*	Physical activity would impact health condition which implies more productive work days. Also, it would reduce the congestion and outdoor air pollution which would affect productivity through different pathways.
19	Freight transport – modal shift	*Yes*	Congestion reduction would cause more productive time and also it

#	EEI actions	Considered	Reason for inclusion/exclusion
			has an effect on outdoor air quality which increases the productivity by gaining more active days.
20	Process heating high temperature: iron – more efficient furnaces (BF and BOF)	*Yes*	
21	Process heating high temperature: steel – more efficient Electric Arc Furnaces (EAF)	*Yes*	
22	Process heating high temperature: cement –more efficient kilns	*Yes*	
23	Process heating high temperature: glass – more efficient (glass melting) furnaces	*Yes*	
24	Process heating high temperature: olefins – more efficient steam crackers	*Yes*	Energy consumption goes down which would result in less air pollutants (like, PM,SO,NO etc.) and lower morbidity rate. As a result more work days can be gained.
25	Process heating high temperature: paper – more efficient driers	*Yes*	
26	Electrochemical processes - more efficient primary aluminium production	*Yes*	
27	Electrochemical processes - more efficient chlor-alkali production	*Yes*	
28	Process heating – more efficient steam systems, including CHP	*Yes*	
29	Machine drive – more efficient fan and pump systems	*Yes*	
30	Industrial facilities – more efficient space heating	*Yes*	

2.3 Definition of system boundaries and distributional aspects

In COMBI, it is a big challenge to find the appropriate system boundaries and to tackle the spill over effect because the evaluation of impacts very much depends on the scale and unit of analysis. For productivity impacts, it is important to know whether the productivity varies from rural to urban or whether some of the productivity impacts goes beyond country boundaries. Also the additional income due to productivity improvement will vary across different income groups. It is especially relevant for the energy poor people.

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

2.4 Context Dependency

The focus in the COMBI project on actions rather than on policies or measures means that the wider policy context of how the actions are implemented is ignored. However, there is evidence that the impact of policy design may matter for the types and size of impacts. For example, congestion. Traffic congestion is very much context dependent. It will vary city to city i.e. for a less crowded country, congestion is not an issue but in a populated country willingness to pay to avoid traffic congestion will be higher. Also, industrial processes even for the same line of production can vary from advanced export-oriented economies like Germany to post-industrial countries of Eastern Europe.

Thus, in COMBI, we need to be careful while monetising theses impacts. One of the biggest advantage here is that the analysis is done country by country. Hence, this context dependency can be dealt with our methodological approach.

3 Evaluation perspectives

Table 3 shows specific aspects of productivity aspects from different evaluation perspectives.

Table 3: Evaluation perspectives for productivity impacts

Productivity aspects	Evaluation perspective
Active work days	Societal and end user/investor
Earning ability	societal and end user/investor
Input/raw material saving	Societal and end user/investor
Workforce productivity	End use/investor
Agricultural productivity	Societal and end user/investor

4 MI interactions and side effects

4.1 Impact pathways

As discussed in section 2.1, in order to avoid double counting and to understand the pathways to productivity, an impact map needs to be created. The Impact map represents the causal chains starting from implementing energy efficiency actions and ending at an impact end-point. Such an impact map creates the conceptual framework for mapping different impacts and impact end points, and for identifying the relationships to each other.

The first impact map (see figure 1) represents the impacts from building sector (both residential and commercial) and second impact map (figure 2) shows the impacts from industry and transport sector. Figure 1 and 2 both depict the pathways towards productivity, but different actions in different sectors have a different pathway towards productivity. Both figures examine the diversity of multiple impacts of energy efficiency measures and this refers to a range of end points that are used for the quantification of the overall welfare effects of energy efficiency actions.

For simplification purposes, two separate figures for the buildings and the transport/industry sector are created. The impact chains start from the implementation of energy efficiency actions and ultimately affect different aspects of productivity, the latter which is the 'end point'.

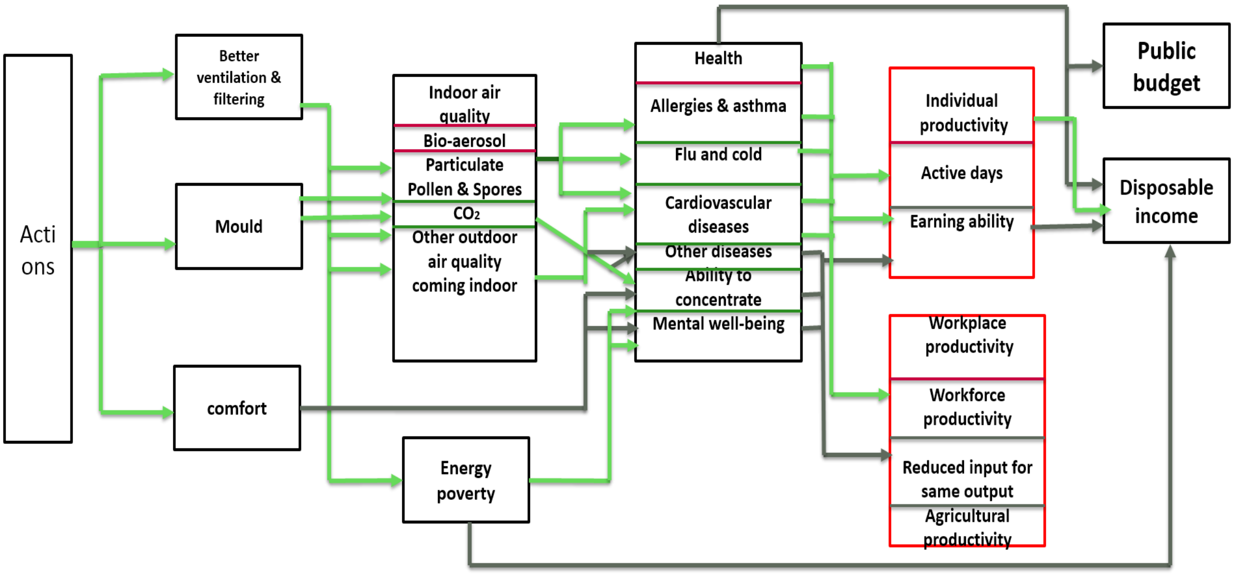

Figure 1: Impact pathway for productivity in the building sector

In figure 1, it can be seen that productivity are categorized into two types, i.e. individual productivity and productivity at the workplace. These two are broader productivity category under which specific productivity aspect is mentioned. For instance, under individual productivity, active work days and earning ability are captured and under workplace productivity, workforce productivity, input/raw material saving and agricultural productivity is captured. Both of these broader productivity category are affected through different health diseases. For example, due to improved ventilation and filtering, indoor air quality improves through which additional active days can be gained. In other words, due to improved ventilation and filtering, the indoor pollutants (mainly bio-aerosol like particulate, spores etc.) are less present inside the building, which improves human health by avoiding various diseases like transmittable and respiratory diseases (Jones, 1999), implying higher productivity (Bloom et al, 2004). Productivity can be affected both at the individual and workplace level. In section 3.2 and section 4, it is discussed how various impacts like health, energy poverty ultimately transferring to productivity.

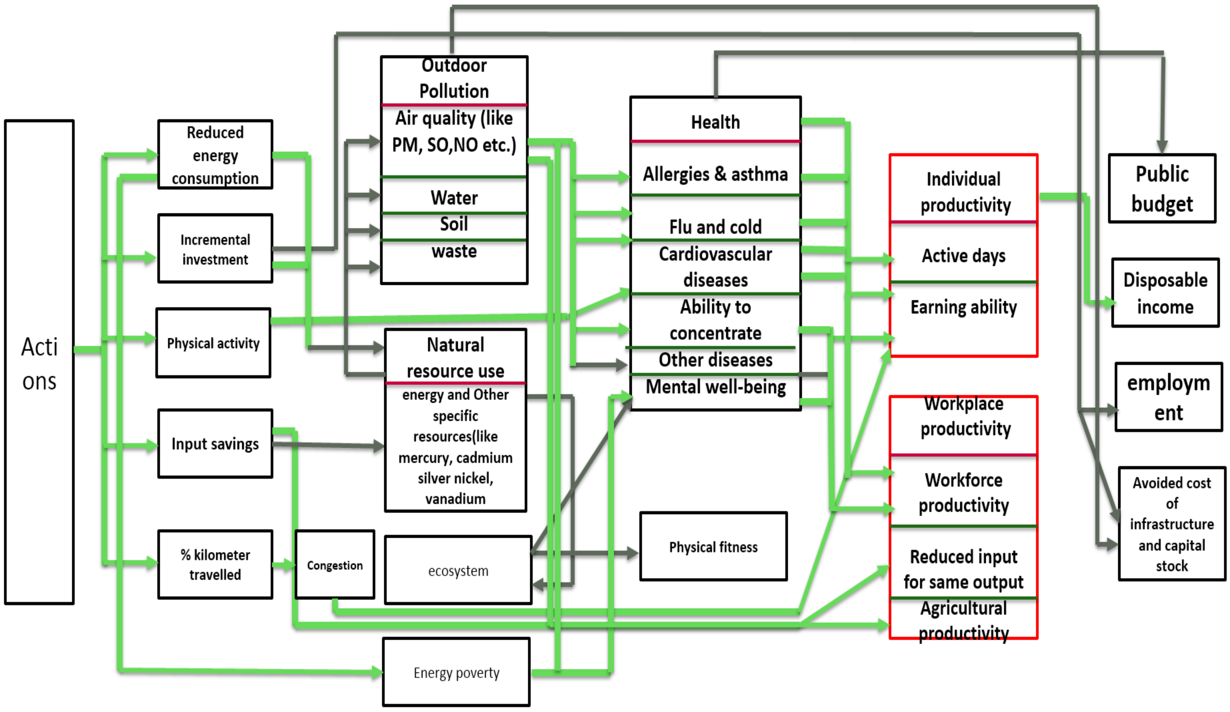

Figure 2: Impact pathway for productivity in transport and industry sector

There are various diseases which can affect health (see figure 1 and 2) and different diseases affect different aspects of productivity. For example, allergy and asthma affects active work days and poor ability to concentrate caused from excess co_2 level, may affect earning ability. Some of the impacts are directly connected to productivity such as input savings in industry or avoided congestion (due to shift in active transportation) in road (Graham, 2006).

As discussed earlier, productivity is categorised into two broader aspects and these two broader aspect i.e. individual productivity and workplace productivity can be catagorised into two and three division respectively. Each of the categories are explaned below;

4.1.1 Individual Productivity

Active days: Active days represent mainly active work days but it acknowledges the fact that a person can spend his additional time incurred from retrofitting measure in leisure rather than working. However, for simplification of the calculation, it is assumed that additional utility for work is equal to an additional utility for leisure. By gaining active days, a person can earn more by working those days or may chose leisure. In both the cases, it would be considered as a productivity improvement.

Sometimes, a person can go to work despite being sick. It is referred to as presenteeism (Mattke, Balakrishnan, Bergamo, & Newberry, 2007). Presenteeism refers to productivity loss resulting from health problems such as asthma, cardiovascular diseases, mental well-being etc. This disease affects both quantity and quality of work (Paul, 2004). For example, a person might work slowly than usual with respiratory diseases or make mistakes in work during his illness. Thus, active days can be referred as a combination of absenteeism (absent from work due to illness) and presenteeism (Caverley, Cunningham, & MacGregor, 2007).

Earning ability: Improved mental well-being and ability to concentrate has a positive impact on earning ability (Danna & Griffin, 1999). In this study, earning ability is looked at from two perspectives i.e. earning ability enhancement due to better concentration on work or mental well-being and child sickness affecting their future income earning ability. Also, if a child misses many days of school then it may impact his future earning ability.

4.1.2 Workplace productivity :

Workforce productivity: A sick person is not only losing his work days but his organisation is also losing its workforce. If employees get sick then either his work will be allocated to someone else (by providing over time or reshuffling workload) in order to meet the target production or else, the work get delayed. In both the cases, an organisation is compromising with its labor input-output ratio. Thus, indoor air quality affects a person's health which ultimately costs his workplace also. On the other hand, there exist several studies which show the effect of indoor air quality on employees' productivity at workplace (see (Seppänen, W., & Mendell., 1999), (Wargocki, Wyon, Sundell, Clausen, & Fanger., 2000), (Singh, 2005)). Thus, workforce productivity will capture the effect of indoor air quality on employee's health at workplace.

Reduced input for same output: Reduced input for same output is an important aspect of productivity to quantify. In industrial sector, due to improved energy efficiency actions less amount of input/ raw material is required to produce the same level of output. Here, raw material does not only include energy, but other inputs as well. This results in increased productivity in the industrial sector. (Porter & Linde, 1995), (Worrell et al 2003). In the building sector also,practically it is seen that very high-efficiency buildings have much more insulation and thus, it requires more material, but they have much less mechanical systems such as heating system i.e. less input is required to produce the same output.

Agricultural productivity: Air pollutants specially ozone have an adcerse effect on the crop production (Fuhrer, Skairby and Ashmore, 1997). Some studies show that ozone (O3), sulfur dioxide (SO2) and nitrogen dioxide (NO2) are resposibile for up to 90% of the crop losses in the U.S (Heck et al 2012).Thus, it will be very cucial to capture the impact on agricultural productivity due to energy efficiency actions studied in COMBI.

The significant impact pathways to productivity have been identified with the help of the green arrow in figure 1 and 2. The task within COMBI is to find appropriate physical indices to quantify productivity (see table 3).

4.2 Interaction with other impacts

From figure 1 and 2, it can be clearly seen that productivity impacts mainly depend on health impacts. Impacts like congestion and input/raw material savings is directly related with productivity i.e. raw material savings (due to efficient space heating) are basically a productivity.

Productivity has a definite impact on macro-economic parameters like public budget or disposable income. For example, by achieving more work days, an individual's income will increase and as a result of which an individual will pay more tax, hence it is ultimately impacting the public budget.

With the help of table4 it would be easier to explain the different interactions of all the work packages with productivity.

Table 4: Interactions with other impacts

All work packages(WP)	Productivity aspect	Types of interaction
Air pollution	Active days	Air pollutants encourage several disease (such as asthma, cardiovascular disease etc.) which affects active days of human life.
	Earning ability	Due to the presence of several air pollutants children gets sick and miss school days which has an impact on their future income.
	workplace productivity	Polluted workforce environment may cause several diseases, due to which the entire workforce productivity may get hampered.
	Reduced input for same/more output	No interaction
	Agricultural productivity	Outdoor air pollutants affects agricultural productivity
Resource	Active days	Resource has no direct relation with productivity but it has an impact on air pollution and air pollution has an effect on productivity through health.
	Earning ability	
	workplace productivity	
	Reduced input for same/more output	Resource has no direct relation with productivity. However resource can have an impact on productivity indirectly. For example, less resource use will results in less waste to produce the same level of output which a productivity improvement.
	Agricultural productivity	Resource has no direct relation with productivity but it has an effect on air pollution and air pollution and other pollution (soil, water etc) has an effect on productivity through health.
Social welfare (mainly health, comfort and energy poverty)	Active days	Most relevant impact for productivity. Mainly health directly interacts with active days.
	Earning ability	Health has a direct interaction with earning ability. It is especially crucial for children.
	workplace productivity	Health and comfort directly interacts with workforce productivity.
	Reduced input for same/more output	No interaction
	Agricultural productivity	No interaction

Economic impacts (Disposable income and public budget)	Active days	By achieving additional active days, a person's/workforce income will increase and income and GDP has high correlation.
	Earning ability	Earning ability directly interacts with disposable income and disposable income interacts with public budget.
	workplace productivity	Better workforce productivity has an effect on GDP and GDP has an effect on public budget.
	Reduced input for same/more output	Interacts with GDP and GDP has an effect on public budget.
	Agricultural productivity	Interacts with GDP.
Energy security	Productivity	No interaction

4.3 Rebound effects

Apparently, there is no direct rebound effect on productivity impacts, but there can be some indirect rebound affecting productivity. For example, by achieving more productive work days, a person's disposable income will increases which may lead to more energy consumption hence more air pollutants affecting productivity.

It has also been argued that increased energy use in energy poor households cannot be considered 'rebound effect' as traditionally understood because they weren't receiving an adequate amount of energy services in the first place (Ürge-Vorsatz and Tirado Herrero,2012).

5 Approach for impact quantification and monetization

The significant impact pathways which have an impact on productivity, have been identified in figure 1 and 2 (see the green arrows in figure 1 and 2). It can be clearly seen that diverse impacts (like congestion, different health diseases, input savings etc.) are affecting different aspects of productivity and to quantify productivity, theses aspects need to be quantified. However, there are major concerns and shortcomings related to the monetisation of certain impacts for instance health. Thus, a physical metric is a suf cient indicator for decision making (Stiglitz et al 2009) and then monetisation can be done on the basis of these physical metrics. In this section, different impacts relevant to productivity are discussed one by one.

1. **Allergies and Asthma:**

Due to poor ventilation in residential and commercial building, Allergies and Asthma may take place which affects productivity (Jones, 1999). There are various types of exposures related to building dampness, including house dust mites, moulds and bacteria and theses may be a reason for asthma and biochemical signs of inflammation (Norbäck, Björnsson, Janson, Palmgren, & Boman, 1999).

Mould exposure is a major environmental factor related to a variety of symptoms caused by indoor air conditions. The growth of mould depends on the building surface, humidity and temperature (Rylander & Lin, 2000). As per Fisk's paper, Mould or moisture problems in residences were associated with 100% increases in lower respiratory symptoms indicative of asthma (Fisk, How IEQ affects health, productivity, 2002). Thus, it is safe to conclude the significance relationship of asthma and allergy with indoor air quality.

Asthma and allergies affects different aspects of productivity and the intensity of the impact would also vary among children and adult. For instance, if a child misses school days due asthma then it would impact on the earning ability of the parents and also the future earning ability of the child. In fact, excessive school absence disrupts learning and is a strong predictor of premature school dropout. School-aged children with asthma are absent more often compared to their healthy peers without asthma (Moonie, Sterling, Figgs, & Castro, 2006). In US, asthma affects an estimated 5% to 10% of children under 18 years of age and is the most common reason for childhood hospitalizations (Sharek, et al., 2002).On the other hand, due to asthma and allergy a person misses his work days for he is paid. For the U.S., the estimated potential annual savings and productivity gains $1 to $4 billion from reduced allergies and asthma (Fisk, 2011).

For quantification, an equation along with the physical metric is required to estimate the intensity of asthma and allergy.

Table 5: Allergies and asthma

Impact	Productivity aspects	Physical metric	Draft monetisation equation
Allergies and asthma	Active days	Health care cost, number of sick days	Value of presentism(in Euro) =(Na-Na1)*w Here Na represent days suffered from asthma and allergy. Na1 is sick days taken due to allergies and asthma spent on allergy and asthma. Value of sick days= Na1* w Here, Active lost days= presentism + value of sick days + health care cost
	Workforce productivity	Health care cost, number of sick days	WkP= ῃ *w where ῃ is % change in labour input and wkp represents workforce productivity Here, Total workforce productivity= workforce productivity+ health care cost spent on allergy and asthma.
	Earning ability	% school days lost due to asthma and allergy	Education = schooldays lost*knowledge can be taught per class hour (education and income is positively correlated)

2. **Cardiovascular Diseases:** Outdoor air pollutants such as ozone, SO_2 etc causes cardiovascular disease which ultimately affects productivity (Brunekreef & Holgate,2002). Also due to modal shift towards active transportation, there exists a positive correlation between active transportation and cardiovascular system (Ogilvie et al 2004. Time-series studies estimate that “a 10-ug/m3 increase in mean 24-hour PM2.5 concentration increases the relative risk (RR) for daily cardiovascular mortality by approximately 0.4% to 1.0%” (Brook, et al., 2010) .

However, to quantify cardiovascular disease effect on productivity, the same approach like asthma methodology will be taken.

Table 6: Cardiovascular impact

Impact	Productivity aspects	Physical metric	Draft equation
Cardiovascular Diseases	Active days	Healthcare cost, number of sick days	Value of presentism(in Euro) = (Nc-Nc1)*w w represents average wage Value of sick days (in Euro) = Nc1*w Here, Value of lost active days= value of sick days+ health care cost spent on cardiovascular diseases.
	Workforce productivity	Healthcare cost, number of sick days	WkP= ῃ *w where ῃ is % change in labour input and wkp represents workforce productivity. Total Workforce productivity= workforce productivity + health care cost spent on cardiovascular diseases.
	Earning ability	% school days lost due cardiovascular diseases	Education = %school days lost* knowledge can be taught per class hour

3. **Flu and cold:** The incidence of common respiratory infections is higher in exposure to building mould. The key cause of the infection is usually common respiratory pathogens, viruses causing common cold and flu (Husman, 1996) (Miller, 1992). Common flu and cold will lead to productivity loss by impacting active work days and earning ability.

Table 7: Flu and cold

Impact	Productivity aspects	Physical metric	Draft equation
Flu and cold	Active days	Health care cost, number sick days due to flu and cold	Value of presentism(in Euro) = (Nf-Nf1)*w w represents average wage Value of sick days (in Euro) = Nf1*w Here, Value of lost active days= value of sick days+ health care cost spent on flu and cold diseases.
	Workforce productivity	Health care cost, number of sick days	WkP= ῃ *w Here, Total workforce productivity= workforce productivity+ health care cost spent on flu and cold
	Earning ability	% lost school days due to flu and cold	Education = %school days lost* knowledge can be taught per class hour

3. Ability to concentrate: Ability to concentrate gets affected by poor ventilation and filtering at home or workplace. Ability to concentrate mainly consists eye irritation (eye tears, eye blinking etc) ,skin irritation etc. (Melhave, et al, 1985).Thus, by avoiding theses irritations an individual or a workforce will be more productive and earning ability would also increases. Ability to concentrate is related with mainly two kind of productivity aspect described in table 7.

Table 8: Ability to concentrate

Impact	Productivity aspects	Physical metric	Draft equation
Ability to concentrate	Workforce productivity	% change in labour input during work hours	WkP= ῆ *w where wkp represents workforce productivity represents % change in labour input and w is average wage
	Earning ability	% change in income per hour	-

Earning ability impacts future income. Hence, while calculating earning ability we need to account income growth of a country.

4. Mental well-being: Mental well-being can get affected through reducing comfort level and energy poor people can gain productivity by avoiding mental stress from paying high energy bills.

Table 9: Mental well-being

Impact	Productivity aspects	Physical metric	Draft equation
Mental well-being	Workforce productivity	% change in labour input during work hours	wkp= ῆ*w Here ῆ represents gain in workforce productivity
	Earning ability	% change in income per hour	-

Here, we are only looking how mental well-being is related and transferred to productivity but how mental well-being is effected through comfort or energy poverty is out of scope of this productivity work package. It will be addressed in WP 5.

5. **Input/Raw material savings:** Due to several energy efficient actions raw material can be used in lesser quantity to produce same or higher level of output. Here, raw materials not only includes energy but other materials too. For instance, very high efficiency buildings have much more insulation (thus more material), but they have much less mechanical systems such as heating system (Bribián, I et al 2010).

Input/raw material savings have a direct effect on productivity specifically to the reduced input for same output aspect of productivity. The appropriate physical indicator for this impact would be the input-output ratio and monetization can be done based on input-output ratio multiplying by product price.

6. **Congestion:** Modal shift towards active mode of transportation would cause less number of cars in the road as a result of which there will be less congestion as well. By avoiding congestion active time can be gained (Litman, 2011). Thus, Congestion has an inverse relationship with

productivity. To quantify congestion, travel time saved can be used as a physical metric and to monetised it we can use average wage earned per hour.

7. The effect of outdoor air pollutants on agricultural productivity: Outdoor air pollutants like (CO2, PM, Ozone, NO etc.) directly affects agricultural productivity (Olesen & Bindi, 2002). Agricultural productivity depends on concentration of these air pollutants (Fuhrer,et al 1997).

% crop change in crop production can be used as a physical indicator for agricultural productivity.

The methodology for entire productivity impact quantification depends on WP3/5 health impact quantification methodologies and the respective physical indicators that those allow to quantify. Productivity in COMBI is referring to active work days in reality to monetise it with average wage with the assumption of additional leisure time is equal to additional work time. In productivity report we will measure the 'shadow price' of productivity.

There are many studies (see (Saldiva et al,1994),(Chen at al 1998),(Smith & Mehta, 2003) etc) which show a relationship between lost school days and indoor air pollution and it can be stated that due to lost school days, a student's ability to earn would decrease because there exists a strong correlation between education and income (Gregorio, 2002). However, it will a definitely be a challenge in COMBI, to capture the effect of school days lost on future income.

In COMBI, productivity impacts will be quantified for each EEI action by country.

6 Data

6.1 Input data

Productivity methodology will transfer health, congestion and other impacts into productivity benefits. From implementing energy efficiency actions to health or other relevant impacts for productivity, are addressed in respective work package researches. Productivity methodology lists all kind of possible outcome but, considering the short timeframe of COMBI project and data availability, we will see how much can actually be quantified.

Table 10 shows a summary of impacts and its possible data sources for productivity;

Table 10: Summary of impacts and its data sources

Impacts	Unit	Data source
Health	1.Health care cost for EU member countries 2. Number of sick days taken due to asthma, allergy and cardiovascular diseases. 3. School days lost due to allergies and asthma 4.Concentration of ozone, CO_2, PM,NO	WP3/5,COMBI Euro found

	5. Share of building stock retrofitting	WP-2
Economic	1. Yearly energy cost savings per household in each EU member state (EUR) 2. Average wages for EU country specific 3. %change in Disposable income 4. Income per hour	WP-2 Eurostat Statistical year book
Congestion and modal spilt	Travel time saved and modal split	WP2, Eurostat
Energy poverty	1. Number of sick days taken by energy poor people due to asthma, allergy and cardiovascular diseases. 2. School days lost in energy poor house due to allergies and asthma	WP3, Eurostat
Input savings/ raw material savings	1.Input output data for industry (specific industries within the scope of COMBI) and building 2.Final output data for industry 2.Final product price	Eurostat, OECD
Productivity	1.% crop yields 2.Average hours worked per week	Eurostat

References

Bernstein,J., Alexis,N., Barnes, C., Bernstein,L., Nel, A., Peden,D., Diaz-Sanchez,D., Tarlo,s., Williams,p. (2004)- Health effects of air pollution. Journal of Allergy and Clinical Immunology.Pages-1116-11123

Birol, F. (2007). Energy economics: a place for energy poverty in the agenda?. The Energy Journal, 1-6.

Brunekreef,B., Holgate, S. (2002)- Air pollution and health. The Lancet. Pages 1233–1242

Bribián, I., Capilla,A., Usón,. (2011). Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential. Building and Environment. Pages 1133–1140

Brook, Robert D., et al. “Particulate matter air pollution and cardiovascular disease an update to the scientific statement from the American Heart Association.” Circulation 121, no. 21 (2010): 2331-2378.

Bloom D. Canning, D. (2008). Population Health and Economic Growth. Commission on Growth and Development. http://siteresources.worldbank.org/EXTPREMNET/Resources/489960-1338997241035/Growth_Commission_Working_Paper_24_Population_Health_Economic_Growth.pdf

Bloom D. Canning, D.,Sevilla, J. (2004). The Effect of Health on Economic Growth: A Production Function Approach. World Development.Pages 1–13

Caverley, Natasha, J. Barton Cunningham, and James N. MacGregor. “Sickness presenteeism, sickness absenteeism, and health following restructuring in a public service organization.” Journal of Management Studies 44, no. 2 (2007): 304-319.

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. Pages; 331–335.

Clement,S., Evans,N. (2014)- Procuring clean and efficient road vehicles. (ICLEI – Local Governments for Sustainability. http://www.clean-fleets.eu/fileadmin/files/documents/Publications/Clean_Fleets_Guide_-_Final_-_June_2014_.pdf

Cullenward, D., Koomey,J. (2015)- A critique of Saunders' ‘historical evidence for energy efficiency rebound in 30 us sectors’. Technological Forecasting & Social Change.Pages: 203–213

Dear, R. J., Akimoto, T., Arens, E. A., Brager, G., Candido, C., Cheong, K. W. D., ... & Toftum, J. (2013). Progress in thermal comfort research over the last twenty years. Indoor air, 23(6), 442-461.

Fisk, W. J. (2000). Health and productivity gains from better indoor environments and the relationship with building energy efficiency. Annual Review of Energy and the Environment, 25(1), 537–566. http://doi.org/10.1146/annurev.energy.25.1.537

Fisk, William J. “How IEQ affects health, productivity.” ASHRAE journal 44, no. 5 (2002): 56.

Fisk, William J. “Potential nationwide improvements in productivity and health from better indoor environments.” Lawrence Berkeley National Laboratory, 2011.

Fuhrer,J., Skairby, L., Ashmore,M. (1997). Critical levels for ozone effects on vegetation in Europe. Environmental Pollution. pp. 91 106

Graham,D. (2006)- Variable returns to agglomeration and the effect of road traffic congestion. Journal of Urban economics. Pages:103–120

GREGORIO, J(2002). EDUCATION AND INCOME INEQUALITY: NEW EVIDENCE FROM CROSS-COUNTRY DATA. Review of Income and Wealth.

Heck, W. W., Taylor, O. C., Adams, R., Bingham, G., Miller, J., Preston, E., & Weinstein, L. (1982). Assessment of crop loss from ozone. Journal of the Air Pollution Control Association, 32(4), 353-361.

HEI.(2010)- Outdoor Air Pollution and Health in the Developing Countries of Asia: A Comprehensive Review-HEI International Scientific Oversight Committee

Husman, Tuula. "Health effects of indoor-air microorganisms." Scandinavian journal of work, environment & health, 1996: 5-13.

International Energy Agency. (2014). Capturing the multiple benefits of energy efficiency. Retrieved from http://allt tles.ebrary.com/Doc?id=10961846http://pubs.healtheffects.org/getfile.php?u=602

Jones A.P. (1999)- Indoor air quality and health. Atmospheric Environment. Page; 4535}4564

Kampa,M.,Castanas,E. (2008)-Human health effects of air pollution.Environmental Pollution. Pages 362–367

Künzli,N., Kaiser,R., Medina,S., Studnicka,M., Chanel,O., Filliger,P., Herry,M., Horak, F., Puybonnieux-Texier,V., Quénel,P., Schneider,J., Seethaler,R., Vergnaud,J-C., Sommer, H.(2000)- Public-health impact of outdoor and traffic-related air pollution: a European assessment. The Lancet. Pages: 795–801

Lewis, D. (2008). America's traffic congestion problem: Toward a framework for national reform. *The Brookings*, *51.* http://www.hamiltonproject.org/papers/americas_traffic_congestion_problem_toward_a_framework_for_national_re/

Litman,T. (2011)-London Congestion Pricing Implications for Other Cities.Victoria Transport Policy Institute. http://www.vtpi.org/london.pdf

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

Mattke, Soeren, Aruna Balakrishnan, Giacomo Bergamo, and Sydne J. Newberry. "A review of methods to measure health-related productivity loss." *American Journal of Managed Care* 13, no. 4 (2007): 211

Melhave,L., Bach,B., Pedersen,O. (1985). Human reactions to low concentrations of volatile organic compounds. Environment International. pp. 167-175

Miller, J. David. "Fungi as contaminants in indoor air." Atmospheric Environment Part A. General Topics 26, no. 12 (1992): 2163-2172.

Moonie, Sheniz A, David A. Sterling, Larry Figgs, and Mario Castro. "Asthma status and severity affects missed school days." Journal of School Health 76, no. 1 (2006): 18-24.

Norbäck,D., Michel,I., Widström,J.(1990)- Indoor air quality and personal factors related to the sick building syndrome. Scandinavian Journal of Work, Environment &Health.Pages: 121-128

Ogilvie,D., Egan,M., Hamilton,V., Petticrew,M. (2004)- Promoting walking and cycling as an alternative to using cars: systematic review. Pp: 329-763

Olesen, J., Bindi, M. (2002). Consequences of climate change for European agricultural productivity, land use and policy. European Journal of Agronomy. Pp; 239–262

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.Pages 218–225

Seppanen, O., Fisk, W. J., & Faulkner, D. (2004). Control of temperature for health and productivity in offices (No. LBNL - 55448). Helsinki University of Technol-ogy, Lawrence Berkeley National Laboratory. Retrieved from https://eaei.lbl.gov/sites/all/files/lbnl-55448_0.pdf

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. Pages:279–289

Stiglitz JE, Sen A, Fitoussi J-P. 2009. Report by the commission on the measurement of economic performance and social progress. Comm. Meas. Econ. Perform. Soc. Prog., Paris. http://www.stiglitz-sen- toussi. fr/en/index.htm

Sharek, Paul J., et al. “Agreement among measures of asthma status: a prospective study of low-income children with moderate to severe asthma.” Pediatrics 110, no. 4 (2002): 797-804

Paul, Hemp. “Presenteeism: at work-but out of it.” Harvard business review 82, no. 10 (2004): 49-58.

Porter,M, Linde, C (1995)- Toward a New Conception of the Environment-Competitiveness Relationship. The Journal of Economic Perspectives. pp. 97-118

Rylander, Ragnar, and Rong-Hwa Lin. “(1 3)- β -d-glucan—relationship to indoor air-related symptoms, allergy and asthma.” Toxicology 152, no. 1 (2000): 47-52.

Toman,M., Jemelkova,B. (2003)- Energy and Economic Development: An Assessment of the State of Knowledge. The Energy Journal. pp. 93-112

World Health Organization.(2009).Global Status Report on Road Safety: Time for Action. https://books.google.hu/books?hl=en&lr=&id=Ndrf6DuCQHMC&oi=fnd&pg=PP2&dq=road+safety+and+productivity&ots=tdhKLsfXVy&sig=fYZL5j2Xf2A1IHiOqrGtEbTQco4&redir_esc=y#v=onepage&q=road%20safety%20and%20productivity&f=false

Urge-Vorsatz,D., Herrero,S., Dubash,N., Lecocq,F. (2014- Measuring the Co-Benefits of Climate Change Mitigation. The Annual Review of Environment and Resources. Pages: 549–582

Ürge-Vorsatz, D., & Herrero, S. T. (2012). Building synergies between climate change mitigation and energy poverty alleviation. Energy Policy, 49, 83-90.

Witterseh T, Wyon DP, Clausen G. The effects of moderate heat stress and open-plan office noise distraction on SBS symptoms and on the performance of office work. Indoor Air 2004;14:3-40. doi: 10.1111/j.1600-0668.2004.00305.x

Worrell, E, Laitner, J, Ruth ,M, Finman ,H.(2003) - Productivity benefits of industrial energy efficiency measures.Energy.pp. 1081–1098