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Consumer Footprint

Basket of Products indicator on Housing

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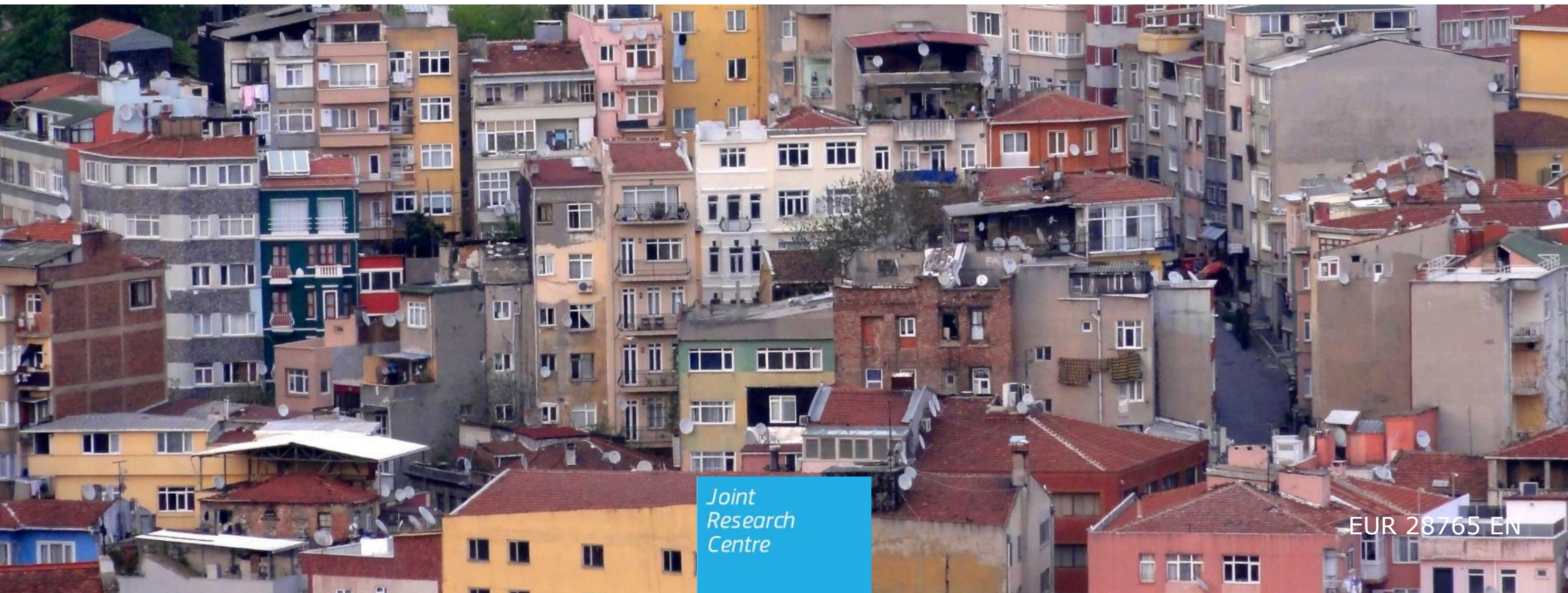

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Disclaimer
The calculation of life cycle indicators (in this case the Consumer Footprint indicators) is subject to periodical refinement, improvement and evolution. The present report describes the main methodological elements and results. For the latest versions (including updates, improvements or errata corrige), please refer to the dedicated webpage of the EPLCA website: http://eplca.jrc.ec.europa.eu/?page_id=1517.
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Contents

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Abstract

The EU Consumer Footprint aims at assessing the potential environmental impacts due to consumption. The calculation of the Consumer footprint is based on the life cycle assessment (LCA) of representative products (or services) purchased and used in one year by an EU citizen. This report is about the consumer footprint indicators of the basket of product (BoP) on housing. In order to assess the environmental impact of EU housing consumption, a LCA-based methodology has been applied to twenty-four representative dwellings (basket of products), modelled on the basis of the type of building (single or multifamily houses), the year of construction (four timeframes), and the climate zone (three zones) in which they are located. One of the main novelty of this work is the definition of twenty-four archetypes of buildings, changing the construction materials and the building specific features affecting the inventory for each archetype.

The resulting baseline inventory model, referring to the year 2010, was assessed for 15 different impact categories, using the ILCD LCIA method. A sensitivity analysis has been run for some impact categories, with a selection of recent impact assessment models and factors. Results allows a wide array of considerations, as this study reports overall impact in Europe, average impact per citizen, share of impact due to dwelling typology and climate areas, as well as impact of each dwelling type per climate zone per year of construction. Single-family houses are responsible for the highest share of impacts. The same type of building has different impacts in different climatic zones, especially because cold climate requires higher input of resources for space heating.

The overall results reveal that the use phase (energy and water consumption) dominates the impacts, followed by the production of construction materials. In general, electricity use and space heating are the activities that contribute the most to the overall impacts. Depending on the normalisation reference used (European or global) the most important impact category present a different relative share. However, human toxicity, respiratory inorganics, resource depletion (metals, fossils, and water), climate change and ionising radiations show the highest impacts for all the normalization references. Since many LCA study on housing are limited to the assessment of climate change related emissions, the BoP housing baseline aims at helping understanding the wider array of impacts associated to the housing system and the potential areas of ecoinnovation improvement for reducing the burden.

To assess potential benefits stemming from selected ecoinnovation, the Consumer Footprint BoP housing baseline has been assessed against nine scenarios, referring to improvement options related to the main drivers of impact. The nine scenarios covers both technological improvements and changes in consumers behaviour, entailing: 1. night attenuation of setting temperature for space heating; 2. external wall insulation with an increased thickness; 3. external wall insulation comparing conventional or bio-based materials; 4. use of a solar collector to heat sanitary water; 5. floor finishing with timber instead of ceramic tiles; 6. a building structure in timber compared with concrete frame; 7. implementation of smart windows for improved energy efficiency; 8. a combination of selected above mentioned energy-related scenarios; 9. production of electricity through a photovoltaic system installed on the roof.

The assessment of the selected scenarios, acting on energy efficiency, resource efficiency, renewable energy and bio-based material (scenarios 1 to 7) revealed that the potential reduction in impact for each of the eco-innovation assessed is relatively limited and that a combination of actions is needed to achieve significant improvements. Moreover, in the case of scenarios acting on the substitution of specific components of the building, the potential improvement is proportional to the relative importance of the substituted component in the baseline scenario. However, a preliminary modelling of combination of energy-related measures (scenario 8) proved to be a good way to enlarge the potential benefits coming from the selected improvements of the building stock.

The results highlight as well that LCA is fundamental for unveiling trade-off between benefits associated to eco-innovation and burden arising from their implementation.

1 The European Union (EU) Consumer Footprint

Assessing the environmental impact due to consumption of goods and services is a crucial step towards achieving the sustainable development goal related to responsible production and consumption (SDG 12). As part of its commitment towards more sustainable production and consumption, the European Commission has developed an assessment framework to monitor the evolution of environmental impacts associated to the European consumption adopting LCA as reference methodology (EC-JRC, 2012a; EC-JRC, 2012b). The present study is expanding the initial assessment framework to ensure a more complete and robust evaluation of the impacts, addressing SDG 12, partially SDG11 (on sustainable cities and communities) and assessing impact on a number of environmental impact categories related to other SDGs, mainly the ones addressing ecosystems and human health. Assessing environmental impact of consumption is primarily linked with SDG 12, and it implies the evaluation of the level of decoupling of environmental impact from economic growth, and related consumption patterns. However, assessing impact of production and consumption means, as well, understanding to which extent production and consumption may have an impact on other SDGs (Box 1).

Box 1 Overview of the link between SDGs, assessing the environmental impact of consumption and calculating this impact with Life Cycle Assessment

The assessment framework aims to support a wide array of policies, such as those related to circular economy, resource efficiency and ecoinnovation. The environmental impact of EU consumption is assessed adopting two sets of life cycle-based indicators: the Consumption footprint and the Consumer footprint, which have a complementary role in assessing impacts (Box 2).

The Consumer footprint adopts a bottom-up approach, aiming at assessing the potential environmental impact of EU consumption in relation to the impacts of representative products. In fact, the Consumer footprint is based on the results of the life cycle assessment (LCA) of more than 100 representative products purchased and used in one year by an EU citizen. The Consumer footprint allow assessing environmental impacts along each step of the products life cycle (raw material extraction, production, use phase, re-use/recycling and disposal).

For the calculation of the Consumer footprint, the consumption of European citizens is split into five key areas (food, housing, mobility, household goods and appliances). For each area, a respective Basket of representative Products (BoP) has been built based on statistics on consumption and stock of products. For each of the five BoPs, a baseline scenario has been calculated, taking as reference the consumption of an average EU citizen.

This report focuses on the BoP housing, which is one of the 5 key areas of consumption identified for calculating the consumer footprint.

The developed LCAs are in line with the International Life Cycle Data system (ILCD) guidelines and follow, to the extent it is possible and relevant, the environmental footprint methods as published in the Communication "Building the Single Market for Green Products" (EC, 2013). The quality of the models has been ensured by periodical consistency checks and model refinements. In order to allow for periodical updates, the models has been built with a parametric approach. Hence, for example, the amount and structure of consumption could be updated to more recent reference years using data on apparent consumption (i.e. BoP composition and relative relevance of representative products) taken from Eurostat.

The baseline models allow identifying the environmental hotspots along the products lifecycle and within the consumption area of each specific BoP. The results of the hotspot analysis are, then, used as a basis for the selection of actions towards environmental burden reduction, covering shifts in consumption patterns, behavioural changes, implementation of eco-solutions, or a combination of the previous ones. For each of the actions, a scenario has been developed, by acting on the baseline model and simulating the changes associated to the specific intervention. The LCA results of each scenario are then compared to the results of the baseline, to identify potential benefits or impacts coming from the implementation of the solution tested, as well as to unveil possible trade-offs.

Complementary to the Consumer Footprint is also developed by JRC the Consumption footprint indicator. The consumption footprint is basically a top-down approach, aiming at assessing the potential environmental impact of EU apparent consumption, accounting for both domestic impacts (production and consumption at country level with a territorial approach) and trade- related impacts. The impacts are assigned to the country where the final consumer is located. An overview of the two developed indicators (Consumer and Consumption footprint) is presented in box1. As mentioned above this report focuses on the Consumer footprint indicator and in particular to the Consumer footprint Basket-of-product indicator for housing.

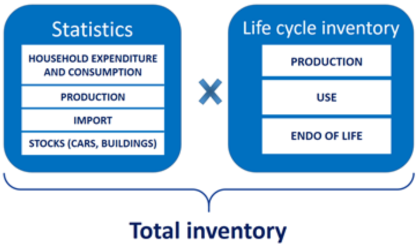
Box 2 Overview of the life cycle-based indicators for assessing the impacts of EU consumption

The life cycle-based indicators for assessing the impact of EU consumption

The Consumer footprint (BOTTOM UP)

LCA of products representative of the consumption of an average EU citizen

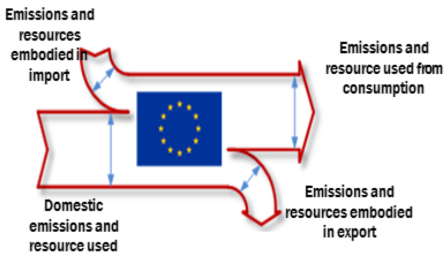
- Focusing on resources used and emissions due to production and consumption during the all life cycle of a product in selected areas of consumption (food, mobility, housing, household products, appliances)
- Combining life cycle data (environmental profiles of products) with consumption statistics



The Consumption footprint (TOP DOWN)

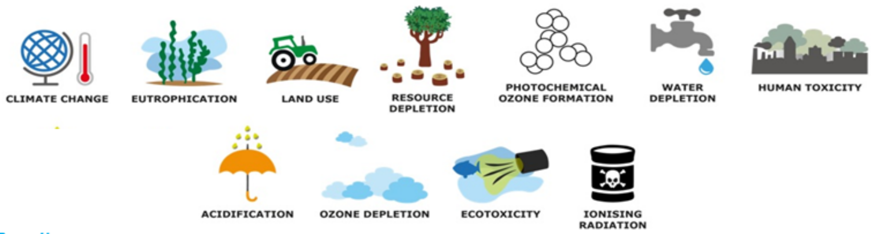
Economy wide assessment of apparent consumption in Europe

- Focusing on resources used and emissions due to production and consumption in one year in all sectors
- Combination of environmental statistics and life cycle inventories of representative products according to trade statistics
- Alternatively though the use of a the Environmentally Extended Input-Output Approach



Life Cycle Impact Assessment

Each emission in the environment and resource used are then characterized in term of potential environmental impacts in the life cycle impact assessment phase, covering the 15 impact categories recommended for the Product Environmental Footprint, including:



Results

Environmental impacts associated to households in Europe. Identification of hotspots in the Life Cycle of the consumed products considering five product categories: Food, Mobility, Housing, Household goods and Appliances. Results could be analysed for different types of consumer behaviours –e.g. average vs pro-environmental.

Each BoP represents a baseline for assessing ecoinnovations scenarios at all life cycle stages, from raw material, production, up to use phase and end of life. This help assessing benefits of sustainable lifestyles.

Environmental impacts of consumption in Europe and for each Member State, including the distinction of impacts in the three categories:

- Direct impacts, that occur because of the use of products and services.
- Indirect domestic impacts, that occur because of the life cycle impacts of products that are produced in the same country where they are consumed .
- Indirect imported impacts that occur because of the life cycle impacts of products that are produced in different countries where they are consumed.

2 Environmental impacts of housing

Housing is amongst the main drivers of environmental impacts in Europe. The building sector generates relevant impacts in terms of resource consumption (both as materials and as energy carriers) and of generation of waste. It is estimated that, in Europe, the construction and use of buildings account for about half of all extracted materials and energy consumption and about a third of water consumption. The sector is also responsible for about one third of waste generated in Europe (EC, 2014). The environmental pressures and impacts arise at different stages of a building life cycle, including the manufacturing of construction products, the phases of construction, use, renovation, and the management of construction waste.

The housing need depends on population size and household composition. The population growth pushes housing demand, so as the household composition, which has become smaller across the European Union (EU) because of older population, fewer children and more single persons. However, the quality profile of the dwelling stock changes gradually and only if the new constructions (and the refurbishments) differ substantially from the existing stock. People live in different types of buildings, and have at their disposal a given number of square meters in different types of dwelling, thus leading to different impacts depending on the type of dwelling and the climate zone in which the buildings are located. Statistics show that new houses in general have more space in terms of square meters (and rooms) than the existing dwelling stock, so from this perspective the quality of dwellings is gradually increasing (Delft University of Technology, 2010).

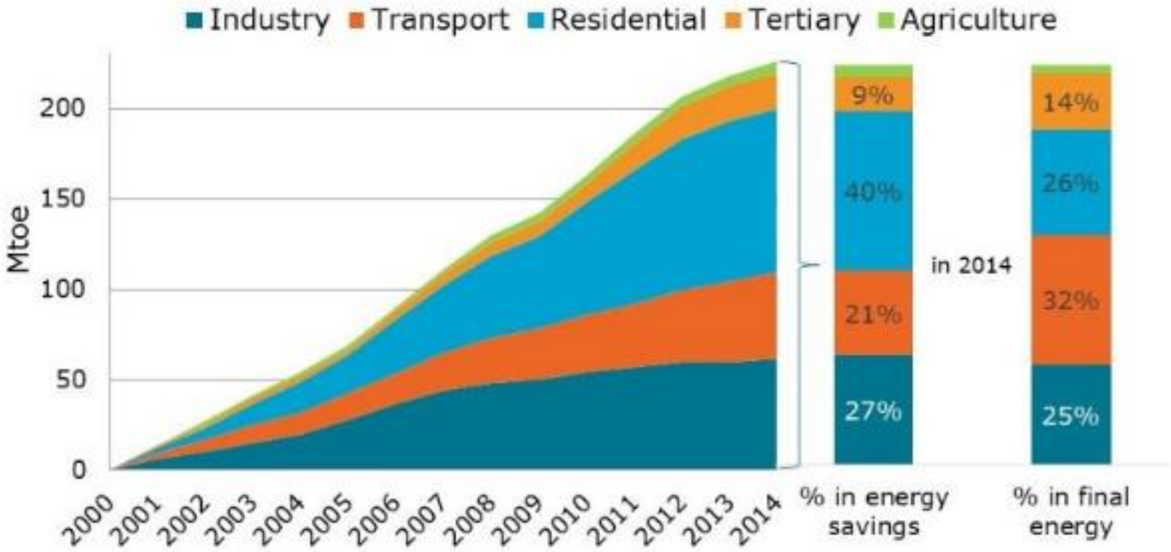
The construction sector has been identified as one of the key areas for the European policies initiatives, as Europe 2020 strategy and the Resource-efficient Europe flagship, because of its great potential for reducing environmental impacts. As a result, there are many guidelines and European directives that are affecting the construction sector, in particular those related to the reduction of the energy consumption in the use phase of buildings (it represents 41% of final energy consumption at EU level in 2010). The Energy Performance of Buildings Directive (EC, 2010), and the Energy Efficiency Directive (EC, 2012) are the EU's main legislation when it comes to reducing the energy consumption of buildings.

Construction and Demolition Waste (CDW) is one of the heaviest and most voluminous waste streams generated in the EU, since it accounts for approximately 25-30% of the total waste in EU. The Waste Framework Directive (EC, 2008) states that "Member States shall take the necessary measures designed to achieve that by 2020 a minimum of 70% (by weight) of non-hazardous construction and demolition waste […] shall be prepared for re-use, recycled or undergo other material recovery".

According to Sebi and Lapillone (2017), energy savings due to energy efficiency improvements (in all sectors) in EU from 2000 to 2014 are equal to 226 Mtoe and most of the savings were in the residential sector (40% of total EU savings) (Figure 1).

As for other sectors, also in the building sector the final reduction in energy consumption is the result of opposite trends. The increase in energy savings might be compensated by other factors like the demographic trends and the change in lifestyle (which may lead to an increase in energy needs and energy use). Therefore, improvement measures should take into account all the possible factors that may influence the overall environmental performance of the housing sector.

Figure 1. Energy savings in 2014 compared to 2000 and related final consumption by sector in Europe



Source: ODYSSEE, in Sebi and Lapillone (2017)

The communication on "Resource efficiency opportunities in the building sector" by the European Commission (EC, 2014) highlighted that the entire life cycle of a building must be considered in the selection of improvement options, to ensure that the environmental impacts are tackled effectively and to avoid burden shifting among life cycle stages. LCA is recognized as a valuable methodology to assess the environmental impact of buildings as well of eco-innovation options along the entire life cycle, unveiling trade-offs and possible burden shifting among categories of impact and over time (Anand and Amor, 2017). The European standard on Sustainability of construction works (EN 15978:2011) recommends LCA as reference tool for the assessment of the environmental performance of buildings. However, the application of LCA to the building stock is considered particularly challenging.

LCA research and applications spans over different areas ranging from building materials and components level to whole building analysis. The areas of embodied energy and building certification systems have seen the maximum growth in the most recent years (Anand and Amor, 2017). The main challenges entail: comparison issues of LCA studies; difference in calculated and actual impacts; system boundary selection procedure; standard data collection procedure and data availability, etc. Generally, to support policy related to the building sector, the assessment should be able to take into account the major sources of variability existing within the building stock (e.g. materials used, differences in energy demand due to climatic variations, differences in insulation level of the existing stock) as well as occupants' behaviour.

As reported by some of the most complete review papers found in the literature (Anand and Amor, 2017; Mastrucci et al.2017; Cabeza et al., 2014; Sharma et al., 2011; Sartori and Hestnes, 2007), a number of 'bottom up' product-oriented LCAs, have been carried out to specifically assess single case studies. The scope of most of those studies consists in the evaluation of the environmental impact of specific buildings, often focusing on energy related impacts only. The buildings are entirely modelled according to the choices made regarding construction materials, components and technological systems and construction methods. Some studies focus on analysing the contribution of different life cycle phases of the building, while others focus on evaluating different housing concepts (e.g. passive house, low energy house), or the environmental impact of dwellings located in different places (e.g. different Member States, developed and developing countries) or in different populated areas (e.g. high and low residential density). Generally, the results are difficult to compare since each project has its own specific features (e.g. building type, climate, comfort requirements, and local regulations), and different studies may apply different forms of analysis, e.g. different boundary settings (Chau, 2015).

Although a great number of studies have been carried out on the LCA of residential buildings, it is still difficult to compare the results of these studies. To make progress, the methodology needs to be harmonised and the availability of a framework scenario for evaluating single case studies needs to be implemented. Mastrucci and colleagues (2017) reviewed LCA studies of building stocks from urban to transnational scales. They report some studies in which LCA is used for the evaluation of policies on the transformation of large building stocks in order to improve their environmental performance (e.g. Wang et al., 2015; Stephan et al., 2013). Nemry et al. (2010) performed a LCA of the EU-25 building stock for a selection of impact categories (namely primary energy, acidification potential, eutrophication potential, global warming potential, ozone layer depletion potential, and photochemical ozone creation potential), using CML's Impact Assessment Methods and Characterisation Factors (Guinée, 2001).

Following this line, the Consumer footprint for the housing sector, namely the Basket of Products indicator on housing, reflects the impact of the European housing stock. The model of the European building stock in Europe in a reference year and the related impacts are taken as the baseline scenario upon which to compare scenarios of technological improvement or behavioural changes. The modelling of the entire building stock in EU (using archetypes of buildings) allows assessing the expected impact that measures taken at the building level can have at transnational scale (i.e. taking into account the expected penetration rate of each measure and the effect on different types of buildings).

3 Basket of Products model for housing

In order to comprehensively assess the impact of consumption at EU level, in 2012 the European Commission's Joint Research Centre developed a lifecycle-based methodology that focuses on specific representative products which are then up-scaled to overall EU consumption figures, named the Basket of Products (BoP) indicators (EC-JRC, 2012b). The project (called LC-IND) focused on indicators that measure the environmental impact of the consumption of products by the average European citizen, focusing on housing, food and transport, via the identification and environmental assessment of the most representative products of each category (basket of products). The initial BoPs developed in the LC-IND projects were revised extensively in the context of the LC-IND2 project, to improve the quality of the models and to allow for a better assessment of the scenarios based on circular economy principles.

The present report is focusing on the BoP housing. This section, specifically, present the scope and the structure of the BoP Housing, including a description of the key components of the Life Cycle Inventory (LCI). Aim of this section is to describe how the BoP is modelled, in order to better interpret the results and, ultimately, to replicate the exercise.

3.1 Description of the BoP housing

Housing is one of the main drivers of environmental impacts in Europe. In order to assess the environmental impacts associated to housing in Europe, a life cycle assessment (LCA)-based methodology was applied to a selection of representative dwellings (basket of products). The representative dwellings are archetypes reflecting the differences in the building stocks, namely considering the relative importance of the housing types in terms of number of dwellings per year of construction, reference materials, and climate zone.

The original baseline (developed in EC-JRC 2012 and EC-JRC 2014a) was extensively revised in the context of the current (LCIND2) project, to improve the quality of the models and to allow for a better assessment of the ecoinnovation scenarios related to energy efficiency, bioeconomy and circular economy.

The BoP housing is focused on residential building to assess the impact associated to housing in Europe. The basket is composed by twenty-four reference dwellings, representative of the EU-27[1] housing stock in the year 2010.

The system boundaries include the production, construction, use (energy and water consumption), maintenance/replacement and end-of-life phases of each dwelling. A highly disaggregated inventory model was developed for each product in the basket, based on a modular approach and build on statistical data. The environmental lifecycle impact assessment was carried out using the International Reference Life Cycle Data System (ILCD) methodology (EC-JRC, 2011). EU average annual environmental impact per person, per dwelling and per square meter were calculated.

3.1.1 The scope of the BoP Housing

Although a great number of studies have been carried out on the LCA of residential buildings, it is still difficult to compare the results of these studies. To make progress, the methodology needs to be harmonized and the availability of a framework scenario for evaluating single case studies needs to be implemented.

Moreover, the existing studies provide insights on the effects of energy efficiency measures and eco-innovation solutions applied to a specific building in specific conditions. The potential impact of these solutions at the European scale is not known because we cannot simply assume that the results would be the same in every climatic condition or type of building (e.g. with different ages of construction or technical features). A representative

[1] The orginal model refers to 2010 as reference year and, hence, to EU 27

model of the existing building stock in Europe is needed to assess this kind of scenarios, as it has been done in some EU projects for simulating the effects of energy efficiency measures.

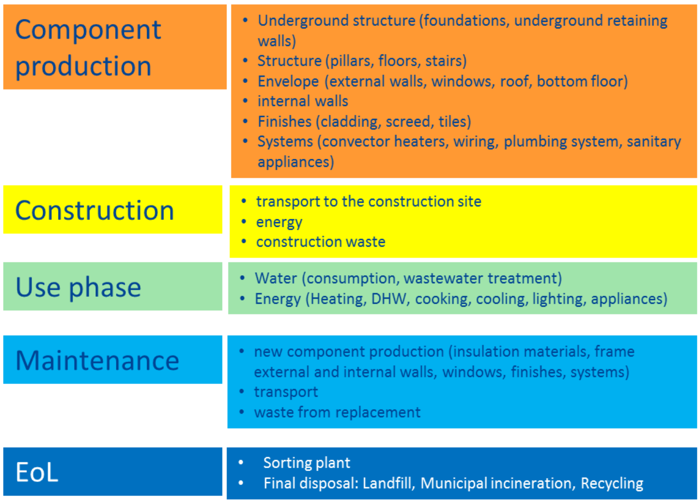
3.1.2 The functional unit

The functional unit (F.U.) is the use of one dwelling by an EU-27 citizen during one year. The results on the average impact related to housing are also presented per dwelling and per square meter. 2010 has been selected as reference year.

3.1.3 The system boundaries

The system boundaries encompass a cradle-to-grave approach, from the production stage to the end of life stage (Figure 2), according to the European Standard EN 15978: 2011. It allows showing the results in a modular view (per life cycle stages).

Figure 2. System boundaries of the BoP housing



The modular structure of the EN 15978 includes production phase, construction phase (transport, energy and waste), use phase (energy, water), maintenance, and end-of-life phase. However, in this study the benefits from the recycling processes and energy recovery are included in the system boundaries whereas the above-mentioned standards require to have them outside of the system boundaries.

As defined by the European Standard EN 15804: 2012, the end-of-life stage of a construction product starts when it is replaced, dismantled or deconstructed from the building or construction works and does not provide any further functionality. We assumed that all the materials leaving the building are wastes that need to be sorted. In the sorting phase of the construction wastes the landfill treatment of residual wastes in the sorting plant is also included as well as the transportation of the inert waste from the sorting plant to the landfill. An average distance of 50 km has been assumed, based on data from literature: we found out that the maximum distance for making inert recovery economically convenient is 50 km between extractive site and construction site (Wilson, 2007). After the sorting phase there are three different options for the sorted materials: landfill, incineration and recycling. Details on how the EoL stage of the BoP Housing is modelled are provided in the following sections.

3.1.4 Structure of the BoP and selection of the representative products

To define the "representative products" (dwellings) of the BoP-housing a quantitative and qualitative analysis of the structure of the EU housing was carried out for the years 2000-2010. Since the ultimate goal of the study was to assess the environmental impacts of the housing of EU-27 citizens, the study focused on analysing the stock of permanently occupied dwellings, i.e. the main residence of each citizen. A dwelling is defined as a unit of accommodation, such as a building (for example a single-family house) or a part of a building (for example an apartment in a multi-family house).

It is very hard to define the aggregate categories of buildings in order to classify them as product groups from which a "representative product" can be chosen. Even if materials, components and processes in the building sector can be standardised, a building is not a standardised (repeatable) product (each building is unique). A building is a complex product, made up of quite a number of (sub)products combined in different ways in each building, so each building has different characteristics. Moreover, buildings are site-specific, e.g. their use changes in relation to the climate (i.e. the energy consumption of the same object varies depending on where it is located).

Many different physical characteristics can be used to classify buildings, each of which can vary widely, e.g. the building's typology (e.g. detached house, terraced house, multi-family house, high-rise building), the surface-area-to-volume ratio (S/V), and the construction technology. These physical characteristics are related to other aspects, such as the number of inhabitants, the period of construction, the climate and Heating Degree Days. All these characteristics affect the environmental impacts of a dwelling, and in particular the heating/cooling energy consumption of the use phase.

All of these factors imply that in the building sector there is no standard way to cluster the buildings by types. There are also different interpretations of the categories used in statistics.

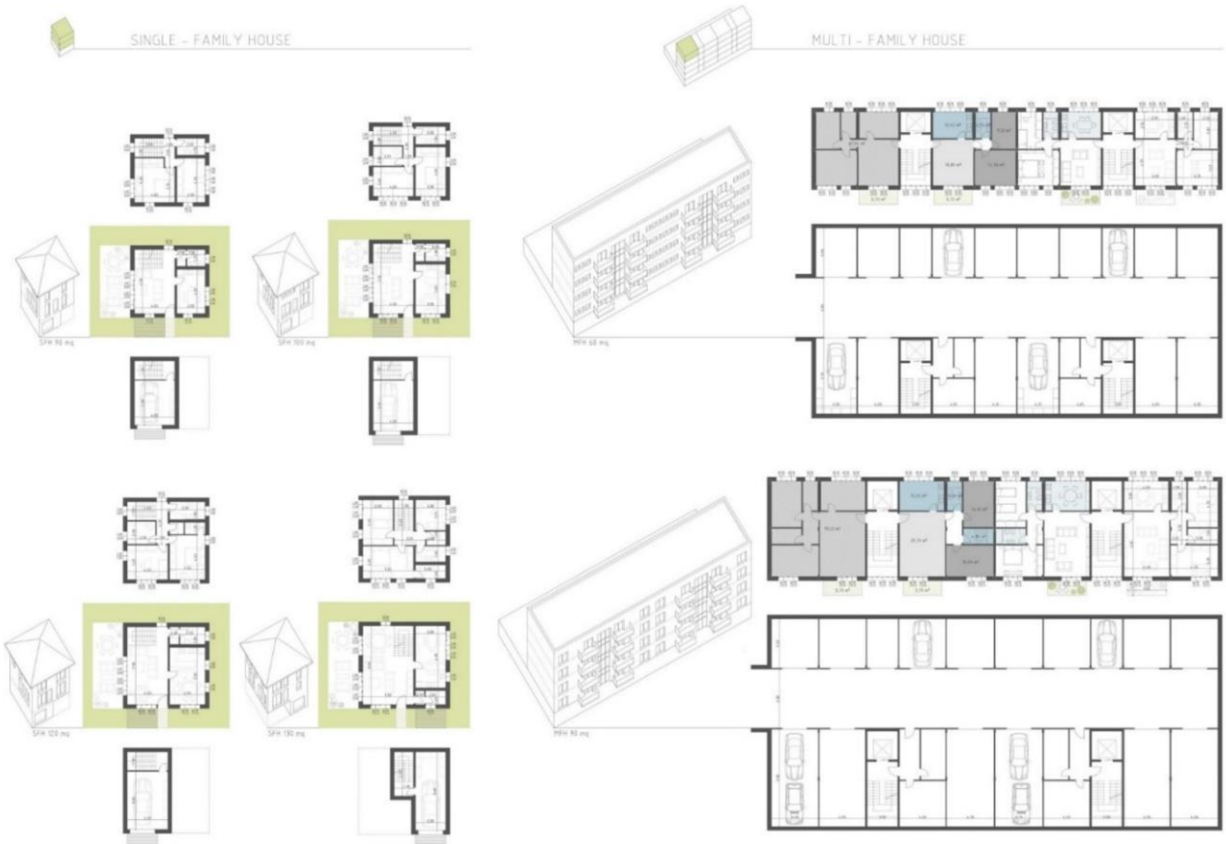
As it is practically impossible to model all of the above-mentioned variables, the models of building archetypes are based on those for which it is possible to find data in the housing stock statistics. The features chosen to define the representative dwellings in the BoP-housing are: the dwelling type, the climate of the area in which the building is located, and the period of construction.

Regarding the selection of "product groups" according to the dwelling type, the first step consisted in the classification of residential buildings according to their typology. Since statistical data were available regarding the number of dwellings for Single-Family House (SFH) and apartments for Multi-Family House (MFH) in the EU-27 in 2010, this classification was used to define the "product groups".

The "representative product" for each "product group" was chosen on the basis of its occurrence:

- a dwelling in a Detached House (Figure 3) has been chosen as a "representative product" for the "dwelling in SFH" product group, given that 34.4% of the EU-27 population live in detached houses (Eurostat, 2014a);
- an apartment in a low-rise MFH with more than 10 dwellings (Figure 3) was chosen as a "representative product" for the "dwelling in a MFH" product group (this type of building is widely diffuse, especially in urban areas, even if the exact quantification is not supported by statistical data).

Figure 3. Technical drawings of the "Representative products" in the Basket of Products housing.



As regards the classification based on the climate, Europe was divided into three climate zones in relation to the average Heating Degree Days (HDD) of each country (Figure 4):

- climate zone 1, warm climate, 500 - 2300 HDD (Malta, Cyprus, Portugal, Greece, Spain, Italy);
- climate zone 2, moderate climate, 2301 - 4,000 HDD (France, Slovenia, Hungary, Romania, Bulgaria, Ireland, Netherlands, Belgium, Luxembourg, United Kingdom, Slovakia, Germany, Austria, Czech Republic, Poland, Denmark);
- climate zone 3, cold climate, 4001 - 6000 HDD (Lithuania, Latvia, Estonia, Sweden, Finland).

The models of the representative buildings in the BoP housing are differentiated according to the most important technical features (construction materials, technical systems, floor area, etc.) of buildings in the Member States belonging to each climate zone. The subdivision into three climate zone has already been adopted by other studies (Ecofys, 2007; EC-JRC, 2008), to reflect the changes in the number of HDD related to latitude (35°-45°; 45°-55° and 55°-70°). However, this subdivision does not fully catch the climatic differences of each climate zone since both the macroclimate (regional) and the microclimate (local) influence the energy consumption of the building. Therefore, in this study the energy consumption during the use phase is allocated to the representative buildings on the basis of energy consumption data (for each Member State) available from statistics. Consumption data per Member State are then aggregated according to the climate zones defined before.

As regards the classification based on the building's period of construction, four periods were chosen, depending on the availability of statistical data on the distribution of the housing stock by period of construction (

Figure **5**). These groups were obtained by aggregating the years of construction according to the technological shifts/innovations (single or double-glazing, thickness of insulating materials, radiators, underfloor heating, etc.) and to the increased attention being paid to energy consumption. The periods are defined as: before 1945, 1945-1969, 1970-1989, and 1990-2010. Specific details on the architectural characteristics of the dwelling are reported in Lavagna et al. (2016).

Figure 4. Definition of three climatic zones

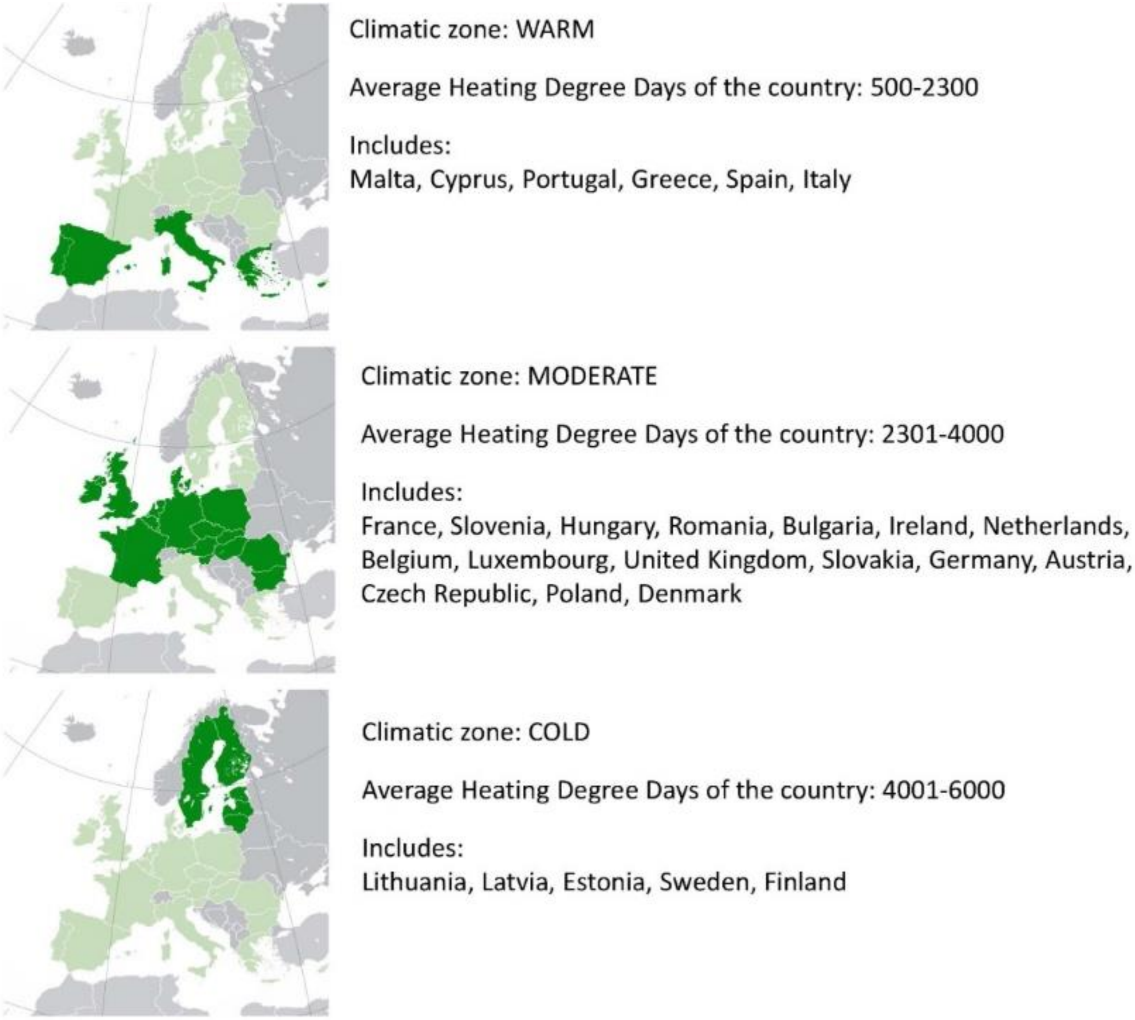
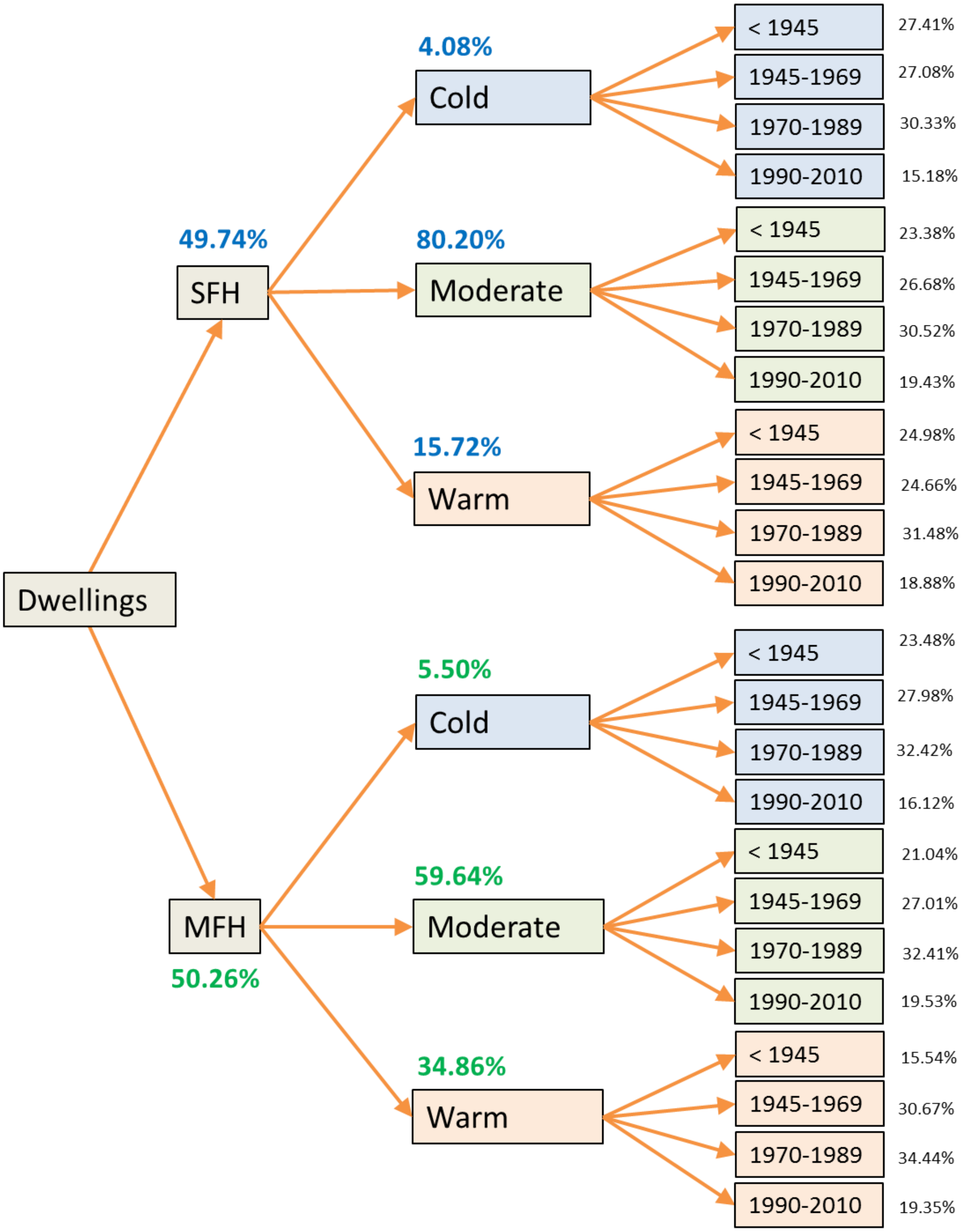


Figure 5. Distribution of the housing stock by period of construction



3.1.5 List of products in the BoP and related quantities

From the combination of the categories described above, 24 building models ("representative products") which cover 100% of the dwelling stock, have been derived. Based on available statistic data, useful parameters have been calculated for each model (Table 1) (see section 4 for details):

– The average floor area (Source: ENTRANZE)
– Total number of dwellings (Source: ENTRANZE, ODYSSEE, “Housing Statistics in the European Union 2010”)
– The total floor area;
– Number of people per dwelling (Source: ENTRANZE, Eurostat).

Table 1. Parameters used in the modelling of the 24 representative dwellings

			Average floor area/dwelling (m^2)	Number of dwellings	Total floor area (m^2)	Number of dwellers	Number of people/dwelling
SFH	WARM	<1945	110	3,990,078	438,572,767	54,801,521	3.43
		1945-1969	98	3,940,268	385,068,743		
		1970-1989	100	5,029,842	503,148,433		
		1990-2010	129	3,015,954	389,057,577		
	MODERATE	<1945	90	19,053,376	1,711,741,291	221,050,717	2.71
		1945-1969	91	21,741,474	1,982,558,495		
		1970-1989	96	24,874,549	2,382,941,441		
		1990-2010	102	15,835,402	1,607,729,281		
	COLD	<1945	102	1,137,005	116,026,371	11,733,022	2.83
		1945-1969	100	1,123,212	112,244,819		
		1970-1989	117	1,258,137	147,100,642		
		1990-2010	125	629,666	78,594,642		
MFH	WARM	<1945	90	5,563,385	499,143,406	72,640,110	2.03
		1945-1969	86	10,977,814	940,693,714		
		1970-1989	90	12,326,198	1,109,540,823		
		1990-2010	95	6,923,950	658,989,337		
	MODERATE	<1945	59	12,883,862	754,201,316	125,289,263	2.05
		1945-1969	61	16,543,072	1,008,822,797		
		1970-1989	57	19,849,947	1,132,752,151		
		1990-2010	60	11,961,082	717,265,397		
	COLD	<1945	55	1,326,949	73,606,419	9,463,779	1.67
		1945-1969	60	1,580,981	94,247,693		
		1970-1989	60	1,831,828	110,359,837		
		1990-2010	64	910,548	58,601,272		

4 Life Cycle Inventory of the BoP housing

Once the "representative products" (dwellings) were defined, the corresponding process-based LCI models were developed for each stage of the life cycle. Ecoinvent 3.2 was used as the main source of secondary data. The curtilage (the land immediately surrounding the dwelling) was omitted. No cut-off was considered.

The total lifetime of the buildings was assumed to be 100 years (considering that a relevant share of the building stock had been constructed before 1945, i.e. more than 70 years ago). Even if in the literature the lifespan of the building is stated as being between 50 (Sartori and Hestnes, 2007) to 100 years (Lewandowska et al., 2013; Dodoo et al., 2014), according to Méquignon and Haddou (2014), buildings often span centuries, at least as regards their structures. Typically, the building is at risk of demolition only when the reliability of its structure (foundations, load-bearing structures and floors) is in doubt.

4.1 Main data sources used to build the inventory

A first screening for statistical data was conducted using the Eurostat database (Eurostat, 2014) and the report "Housing Statistics in the European Union 2010" (Delft University of Technology, 2010).

The most detailed information available for housing is derived from the results of several European projects such as the Intelligent Energy Europe (IEE) Projects: ENTRANZE, ODYSSEE, TABULA and EPISCOPE. The aim of these projects was to quantify the building stock and classify it by period of construction and physical characteristics, relating these characteristics to the energy consumption in the use phase. All data collected in these studies were from national statistics.

For the scope of this study, the most useful data were found in the Data Hub elaborated by the Buildings Performance Institute Europe (BPIE), a not-for-profit think tank that supported several IEE and FP7 European Projects. The BPIE collects data related to the quantity and quality of the building stock and the energy performance of buildings, from national statistics and studies.

It should be noted that the different data sources, including the official statistics, are heterogeneous. Very few reports cover all information needed, so different sources have been combined. The analysis of the available statistical data uncovered different ways of aggregating data from country to country. This is partly explained by different national building classification rules.

It was not always possible to find data related to the subject of investigation of this study, namely the reference year 2010 and the Member States of EU-27. It should, however, be noted that the average values of statistical data (e.g. square meters of a dwelling) fluctuate very little from year to year and among countries. Hence, data related to whole Europe and the year 2008 have been used where there were no data available for EU-27 in 2010.

The main inputs used for building the inventory are i) the number of dwellings ii) the average floor area of dwelling, iii) the number of dwellers for dwelling, iv) the energy consumption. Here below it is explained, for each input, where data have been taken and how have been reworked for the scope of BoP Housing. More in detail:

1. The number of dwellings has been taken from ENTRANZE. Data are provided at Member State (MS) level and for dwelling type; in addition, a % of dwellings for age of construction is provided at MS level, allowing the accounting of dwellings, in each MS, for each dwelling type and age (e.g. number of dwellings of single family house type, built before the 1945, in Italy). Data reported in ENTRANZE allowed the calculation of the total number of dwellings for each model and in turn, for each zone (Table 2 reports the number of dwelling in zone 1- warm, as an example). The total number of dwelling reported in ENTRANZE has been cross-checked with ODYSSEE which reports a total number of dwellings, at 2010, slightly higher (1.56%); the discrepancy is due to the use, by ENTRANZE, of different census years, always before the 2010. A second cross-

check has been done with the "Housing Statistics in the European Union 2010" which provides the % of dwellings per age per MS; this data has been multiplied by the total number of dwellings per MS by ENTRANZE, providing the same trend. Finally, the number of dwellings has been retrieved from ENTRANZE.

2. The average floor area of dwellings (m^2/dwelling) has been calculated based on data reported in ENTRANZE. The source reports data about the average floor area of a dwelling, the average floor area of a dwelling per dwelling type and the average floor area of a dwelling per dwelling type and age, at MS level. These data were reworked to obtain the average floor area of dwellings for each model (Table 3). The calculation has been done taking into account, for all countries in each zone, the number of dwellings per dwelling type and age (see previous point) and the related size. Also, by combining results with the number of dwellings, calculated as explained in the first point, it was possible to calculate the total m^2 of dwellings for each model (Table 4).
3. The number of dwellers has been taken from Eurostat database, which reports the total number of dwellers at MS level for the 2010. This allowed for the calculation of the total number of dwellers in each zone (Source: reworking by authors (aggregated data) from ENTRANZE.
4. **Table 5**). Moreover, by dividing this value by the total number of dwellings per zone, the average number of dwellers per dwelling type has been calculated for each zone (Table 6).
5. The average heating consumption for space heating (kWh/m^2), for each dwelling type in each zone has been derived combining data from ODYSSEE, BPIE and ENTRANZE. ODYSSEE database reports the heating consumption from the residential sector (total stock of dwellings) at MS level. From these, consumption per zone can be derived (e.g. total kWh for heating by residential stock in zone 1). A different heating consumption value has been calculated by using BPIE and ENTRANZE data. Namely, BPIE provides for the average heating consumption per m^2, per each dwelling type in each age, at MS level; however, for some MSs data were missing and for this reason a weighted average heating consumption per m^2 of dwelling, per dwelling type and age, was calculated at zone level. The weighting has been done considering the MSs, in the zones, for which data were available and based on the total floor area of dwellings. Obtained value were multiplied for the total m^2 of dwellings (point 3) for each model to obtain total kWh for heating consumption, at zone level, each dwelling type in each age class (point 3) to obtain the total heating consumption for model (e.g. total kWh for heating a single family house dwelling, built before 1945, in zone 1). At this point, as the data from ODYSSEE were in principle more populated and thus, more reliable, they have been allocated to the different dwelling types and age proportionally to the heating consumption obtained through BPIE and ENTRANZE (Source: Allocation of total number of dwellers (Reworking by authors from Eurostat) to total number of dwellings (Reworking by authors of ENTRANZE).
6. **Table 7**). In addition, the allocated consumption were divided by the total area (m^2) of each model to obtain the average heating consumption per m^2 (Table 8).
7. The average energy consumption for Domestic Hot Water (DHW), cooling, appliances and lighting was also derived by ODYSSEE database, which reports the total energy consumption (kWh) for the above-mentioned functions, for each MS. Energy use for Domestic Hot Water (DHW), cooling, appliances and lighting were calculated per person (table 10 for lighting) by aggregating all country values (for each climate zone) and by dividing for the total number of dwellers in each zone.

Table 2. Total number of dwellings per type and age (extract for zone 1 – warm).

	NUMBER OF DWELLINGS								
		SFH				MFH			
	unit	*<1945*	*1945-1969*	*1970-1989*	*1990-2010*	*<1945*	*1945-1969*	*1970-1989*	*1990-2010*
Malta	1000 dw	27.35	23.79	34.95	20.37	3.61	8.67	10.88	12.21
Cyprus	1000 dw	9.96	28.90	70.54	105.74	0.15	3.47	28.92	51.59
Portugal	1000 dw	378.00	446.44	806.38	607.47	136.26	249.22	639.60	530.34
Greece	1000 dw	132.37	481.72	677.67	264.76	187.89	683.81	961.97	457.08
Spain	1000 dw	1,087.67	1,039.33	1,371.71	1,462.01	1,098.21	2,846.36	3,869.17	3,966.92
Italy	1000 dw	2,354.73	1,920.09	2,068.58	555.60	4,137.27	7,186.28	6,815.65	1,905.80
total by period	1000 dw	3,990.08	3,940.27	5,029.84	3,015.95	5,563.38	10,977.81	12,326.20	6,923.95
total by climate zone	dw	15,976,141.93				35,791,347.06			

Source: Reworking of ENTRANZE data by authors, to obtain total number of dwellings at zone level (dw = dwelling)

Table 3. Average floor area per dwelling, by dwelling type, by climate zone and by period of construction in EU-27.

	AVERAGE FLOOR AREA OF DWELLING											
	SFH						MFH					
	Unit	*<1945*	*1945-1969*	*1970-1989*	*1990-2010*	*average floor*	*unit*	*<1945*	*1945-1969*	*1970-1989*	*1990-2010*	*avg floor*
Malta		99.00	99.00	99.00	99.00			85.00	85.00	85.00	85.00	
Cyprus		n.a.	n.a.	n.a.	n.a.			n.a.	n.a.	n.a.	n.a.	
Portugal	m^2/ dwelling	86.58	89.57	119.18	149.71		m^2/ dwelling	77.50	86.72	95.77	107.32	
Greece		61.22	64.21	76.27	86.50			88.37	83.78	93.46	100.23	
Spain		94.72	95.16	108.16	136.93			87.41	73.16	86.84	95.10	
Italy		123.54	109.40	94.98	106.85			90.80	90.80	90.80	90.80	
Average by period	m^2/dw	109.92	97.73	100.03	129.00	107.40	m^2/dw	89.72	85.69	90.01	95.18	89.64
tot. by climate z.	m^2/dw	1,715,847,520.19					m^2/dw	3,208,367,279.95				
France		58.79	111.62	104.36	86.41			54.04	65.92	63.83	n.a	
Slovenia		89.02	90.21	100.38	104.41			56.06	46.85	61.26	64.42	
Hungary		93.15	93.15	93.15	93.15			46.73	46.73	46.73	46.73	
Romania		72.58	72.58	71.46	72.58			55.36	45.68	46.53	74.46	
Bulgaria		64.78	63.16	64.91	60.63			64.48	64.48	64.48	64.48	
Ireland		99.03	97.52	114.23	135.89			50.00	50.00	69.24	71.26	
Netherlands		129.34	111.14	107.29	113.13			41.72	32.86	30.92	32.40	
Belgium		73.00	73.00	73.00	73.00			113.91	113.91	114.00	114.00	
Luxembourg	m^2/dw	80.45	83.01	97.09	95.89		m^2/dw	83.18	86.08	86.94	86.08	
U. Kingdom		101.09	77.24	73.31	82.04			55.20	51.67	48.45	45.47	
Slovakia		86.40	91.22	102.32	112.45			64.07	58.66	48.85	53.96	
Germany		100.24	100.15	111.15	119.12			n.a.	66.04	58.80	64.05	
Austria		111.27	111.37	126.03	131.88			70.96	65.72	77.58	73.83	
Czech Rep.		86.56	94.65	104.10	129.12			64.07	58.66	61.25	62.61	
Poland		76.32	79.16	113.10	111.61			52.24	43.78	51.85	59.34	
Denmark		136.35	124.07	137.84	151.36			82.04	89.10	59.80	57.20	
Average by period	m^2/dw	89.84	91.19	95.80	101.53	94.29	m^2/dw	58.54	60.98	57.07	59.97	59.00
total by climate z.	m^2/dw	7,684,970,507.84					m^2/dw	3,613,041,661.08				
Lithuania		72.43	84.58	104.06	178.09			18.60	49.17	62.68	85.06	
Latvia		96.00	96.00	96.00	96.00			52.00	52.00	52.00	52.00	
Estonia	m^2/dw	86.11	86.11	86.11	80.10		m^2/dw	47.80	47.80	47.80	47.80	
Sweden		125.00	125.00	125.00	125.00			67.00	67.00	67.00	67.00	
Finland		70.68	73.88	113.70	118.62			56.00	56.00	56.00	56.00	
Average by period	m^2/dw	102.05	99.93	116.92	124.82	108.34	m^2/dw	55.47	59.61	60.25	64.36	58.65
total by climate z.	m^2/dw	449,404,127.87					m^2/dw	331,407,734.50				
TOTAL EU	m^2	9,850,222,155.90					m^2	7,152,816,675.53				

Source: reworking of authors (aggregated data) from ENTRANZE.

Table 4. Total area (m^2) for each model.

m^2 tot								
	SFH				MFH			
	<1945	***1945-1969***	***1970-1989***	***1990-2010***	***<1945***	***1945-1969***	***1970-1989***	***1990-2010***
total by period -1	438,572,767.40	385,068,742.86	503,148,433.19	389,057,576.76	499,143,405.99	940,693,713.56	1,109,540,823.04	658,989,337.37
total - zone 1	4,924,214,800.15							
total by period - 2	1,708,002,916	1,979,763,189	2,380,059,283	1,605,937,508	753,521,406	1,007,706,782	1,131,787,827	715,994,950
total - zone 2	11,282,773,860							
total by period -3	108,230,084	104,610,016	138,167,996	69,058,432	64,140,282	84,074,541	100,078,779	47,618,413
total - zone 3	715,978,542							

Source: reworking by authors (aggregated data) from ENTRANZE.

Table 5. Total number of dwellers for zone (extract for zone 1 – warm).

	Number of dwellers 2010
Malta	414,027
Cyprus	819,140
Portugal	10,573,479
Greece	11,183,516
Spain	46,486,619
Italy	59,190,143
total zone 1	**128,666,924**

Source: Reworking by authors from Eurostat (2014).

Table 6. Total number of dwellers for each model.

	Dwellers/dwelling							
	SFH				MFH			
	<1945	***1945-1969***	***1970-1989***	***1990-2010***	***<1945***	***1945-1969***	***1970-1989***	***1990-2010***
zone 1	3.43	3.43	3.43	3.43	2.03	2.03	2.03	2.03
zone 2	2.71	2.71	2.71	2.71	2.05	2.05	2.05	2.05
zone 3	2.83	2.83	2.83	2.83	1.67	1.67	1.67	1.67

Source: Allocation of total number of dwellers (Reworking by authors from Eurostat) to total number of dwellings (Reworking by authors of ENTRANZE).

Table 7. Total heating consumption for each model (from top to bottom: zone 1, zone 2, zone 3).

Total heating consumption by each model (kWh)							
SFH				MFH			
<1945	***1945-1969***	***1970-1989***	***1990-2010***	***<1945***	***1945-1969***	***1970-1989***	***1990-2010***
47,296,423,624.80	39,303,891,216	38,463,166,383	23,989,119,247	50,393,346,096	92,075,501,536	70,191,820,502	34,148,627,080
375,490,136,862.6	364,652,589,468	359,720,933,317	161,371,959,978	137,478,496,788	183,007,224,436	150,362,169,253	70,419,955,617
20,525,693,363.32	18,312,780,586	20,702,976,142	7,960,124,599	10,145,321,690	14,094,687,991	14,813,563,266	6,142,336,582

Source: Allocation of total heating consumption for zone (reworked statistical data from ODYSSEE) to total heating consumption for each model (combination of reworked data from BPIE and ENTRANZE).

Table 8. Heating consumption for each model (kWh/m^2)

	Heating consumption by each model - kWh/m^2							
	SFH				MFH			
	<1945	***1945-1969***	***1970-1989***	***1990-2010***	***<1945***	***1945-1969***	***1970-1989***	***1990-2010***
zone 1	108	102	76	62	101	98	63	52
zone 2	220	184	151	100	182	182	133	98
zone 3	190	175	150	115	158	168	148	129

Table 9. Lighting consumption for each model (kWh/person). Allocation of total lighting consumption for zone (reworking of statistical data from ODYSSEE) to total number of dwellers for zone (reworking of EUROSTAT data - Eurostat, 2014).

	Consumption for lighting - kWh/person							
	SFH				**MFH**			
	<1945	***1945-1969***	***1970-1989***	***1990-2010***	***<1945***	***1945-1969***	***1970-1989***	***1990-2010***
zone 1	193	193	193	193	193	193	193	193
zone 2	156	156	156	156	156	156	156	156
zone 3	447	447	447	447	447	447	447	447

4.2 LCI of the production stage

With regard to building technology, typical construction systems were selected considering the period of construction of the buildings and the different climate zones. The same technological features were assumed for both the period before 1945 and 1945-1969, under the assumption that the changes that occurred in the building materials and components were negligible. This assumption could be considered valid for the stock in the period group 1900-1945, whereas it is very difficult to define a representative technology for the period before 1900 because this stock is too heterogeneous and it includes historical buildings. All of the technical solutions of the envelope (walls, windows, roofs, etc.) of the representative buildings have been modelled (size and choice of materials), taking into account the typical thermal transmittance (U-value), and combining data from Project TABULA (Ballarini et al., 2014) and the BPIE and expert judgments on the characteristics of the regional construction materials. The massive building envelope system is assumed to be representative of all EU-27 dwellings in warm and moderate climates. For cold climates, the massive building envelope system is assumed only for MFH, whereas the lightweight construction system is assumed to be representative of the SFH building type. The insulation material chosen for all of the "representative products" is rock wool, which (together with glass wool) accounts for 60% of the market of insulating materials. Organic foamy materials, expanded and extruded polystyrene and polyurethane, account only for 27% of the market (Papadopoulos, 2005).

With regard to the heating system, it has been assumed that radiators were used up to 1990 in warm and moderate climates, and that the transition from radiators to underfloor heating was made after 1990. Between 1945 and 1970, the amount of steel pipes in the heating system increased because of the change from radiators close to the hallway (to reduce pipes' length) to the below-window radiators (designed to improve heat distribution and comfort). Convector heaters were chosen heating systems in cold climates (Lavagna 2014).

The system boundaries of material production include: the extraction of raw materials or the use of recycled materials (as available in ecoinvent 3.2 datasets, referring to the EU-27 average when possible); the transport to the manufacturing plant; and the production processes. The elements of the buildings included in the inventory are: the supporting structure (foundations, underground retaining walls, load-bearing elements, floors, stairs), the envelope (external walls, windows, roof, lower floor), the internal walls, the finishes, and the systems (heating, wiring, plumbing, sanitary appliances).

Since each dwelling type is also characterised by other building features (such as the number of floors, the internal height, the window-to-wall ratio, U-value of the building components, the construction technologies, and the expected lifespan of the building) assumptions on these parameters have been made when defining the "representative product" to be included in the basket. The key features assumed for each of the twenty-four models are shown in Table 10 (for SFH) and Table 11 (for MFH).

Table 10. Main features of the "representative products" chosen for the SFH group

Dwelling type	Single Family House											
	SFH_warm_<1945	SFH_warm_1945-69	SFH_warm_1970-89	SFH_warm_1990-2010	SFH_moderate_<1945	SFH_moderate_1945-69	SFH_moderate_1970-89	SFH_moderate_1990-2010	SFH_cold_<1945	SFH_cold_1945-69	SFH_cold_1970-89	SFH_cold_1990-2010
Building typology	Detached House											
Number of dwelling	1											
Number of floors	2											
Lifetime of the building	100 years											
Climate	warm				moderate				cold			
HeatingDegreeDays	500-2300				2301-4000				4001-6000			
Year of construction	1945-1969	1945-1969	1970-1989	1990-2010	1945-1969	1945-1969	1970-1989	1990-2010	1945-1969	1945-1969	1970-1989	1990-2010
Model dwelling size (m^2)	100			130	90		100		100		120	
Number of inhabitants	3.43				2.71				2.83			
Internal height (m)	2.7				2.5				2.5			
Surface/Volume	0.92			0.85	0.98			0.95	0.92		0.87	
Window-to-wall ratio	0.29			0.31	0.30		0.32	0.32	0.30		0.28	
Constructive technology	heavy				heavy				light, dry assembly			
Foundations	reinforced concrete curb											
Underground retaining walls	reinforced concrete											
Load bearing elements	masonry in brick				masonry in brick				timber frame			
Floors (structure)	reinforced concrete/bricks				reinforced concrete				timber frame + board			
Stairs	reinforced concrete				reinforced concrete				timber frame			
External walls Insulation	masonry brick (25 cm) no insulation			masonry brick (25 cm) insulation (2 cm)	masonry brick (32 cm) no insulation	masonry brick (38 cm) no insulation	masonry brick (30 cm) no insulation	masonry brick (32 cm) insulation (5 cm)	timber frame insulation (4 cm)		timber frame insulation (5 cm)	timber frame insulation (6 cm)
External walls finishes	plaster				plaster				wood			
Windows	wood frame single glass				wood frame single glass			PVC frame double glass	wood frame single glass		wood frame double glass	wood frame triple glass
Roof Insulation	pitched no insulation			flat insulation (2 cm)	pitched insulation (2 cm)		pitched insulation (5 cm)	pitched insulation (10 cm)	pitched insulation (4 cm)			pitched insulation (7 cm)
Bottom floor	no insulation		insulation (1 cm)	insulation (1 cm)	insulation (1 cm)		insulation (2 cm)	insulation (8 cm)	insulation (7 cm)		insulation (8 cm)	insulation (11 cm)
Roof finishes	brick tiles				brick tiles				cement tiles			
Internal walls	hollow brciks				wood frame				wood frame			
Internal walls finishes	plaster				plasterboard				plasterboard			
Flooring	ceramic tiles				ceramic tiles				wood			
U-value walls	1.71		1.47	0.82	1.54		0.98	0.5	0.64		0.52	0.39
U-value roof	2.32		2.19	1.18	1.38		0.72	0.35	0.75		0.71	0.47
U-value windows	4.00		3.45	3.00	3.65		2.65	1.84	2.30		2.01	1.87
U-value bottom floor	1.76		1.71	1.48	1.63		1.16	0.49	0.49		0.43	0.33
Heating energy consumption	108	102	76	62	220	184	151	100	190	175	150	115
Heating systems	boiler				boiler				electricity			
Heating terminal unit	radiators			radiant floor	radiators			radiant floor	convector heaters			
Tot nr. of dwellings in EU-27	3,990,078	3,940,268	5,029,842	3,015,954	19,053,376	21,741,474	24,874,549	15,835,402	1,137,005	1,123,212	1,258,137	629,666
Tot nr. of people living in the dwelling EU-27	54,801,521				221,050,717				11,733,022			

Table 11. Main features of the “representative products” chosen for the MFH group

Dwelling type	Multi-Family House											
	MFH_warm_<1945	MFH_warm_1945-69	MFH_warm_1970-89	MFH_warm_1990-2010	MFH_moderate_<1945	MFH_moderate_1945-69	MFH_moderate_1970-89	MFH_moderate_1990-2010	MFH_cold_<1945	MFH_cold_1945-69	MFH_cold_1970-89	MFH_cold_1990-2010
Building typology	Low-rise > 10 apartment											
Number of dwelling	16											
Number of floors	4											
Lifetime of the building	100 years											
Climate	warm				moderate				cold			
HeatingDegreeDays	500-2300				2301-4000				4001-6000			
Year of construction	1945-1969	1945-1969	1970-1989	1990-2010	1945-1969	1945-1969	1970-1989	1990-2010	1945-1969	1945-1969	1970-1989	1990-2010
Model dwelling size (m^2)	90				60				60			
Number of inhabitants	2.03				2.05				1.67			
Internal height (m)	2.7				2.5				2.5			
Surface/Volume	0.55				0.65				0.65			
Window-to-wall ratio	0.22				0.26				0.26			
Constructive technology	heavy				heavy				light, dry assembly			
Foundations	reinforced concrete curb											
Underground retaining walls	reinforced concrete											
Load bearing elements	reinforced concrete frame											
Floors (structure)	reinforced concrete/bricks				reinforced concrete				reinforced concrete			
Stairs	reinforced concrete											
External walls	hollow bricks (30 cm)			hollow bricks (30 cm)	hollow bricks (30 cm)		hollow bricks (20 cm)		hollow bricks 8 cm			
Insulation	no insulation			insulation (2 cm)	no insulation		insulation (2 cm)	insulation (4 cm)	insulation (3 cm)			
External walls finishes	plaster				plaster				facing bricks (12 cm)			
Windows	wood frame single glass		aluminium frame double glass		wood frame double glass		PVC frame double glass		wood frame single glass		wood frame double glass	alum frame double glass
Roof	flat			flat	flat		flat	flat	pitched		pitched	pitched
Insulation	no insulation			insulation (2 cm)	insulation (2 cm)		insulation (4 cm)	insulation (10 cm)	insulation (4 cm)		insulation (5 cm)	insulation (8 cm)
Bottom floor	no insulation	no insulation	insulation (1 cm)		insulation (1 cm)		insulation (2 cm)	insulation (7 cm)	insulation (5 cm)		insulation (6 cm)	insulation (9 cm)
Roof finishes	bitumen				bitumen				cement tiles			
Internal walls	bricks				wood frame				wood frame			
Internal walls finishes	plaster				plasterboard				plasterboard			
Flooring	ceramic tiles				ceramic tile				wood			
Uvalue walls	1.76		1.47	0.81	1.55		0.98	0.54	0.71		0.54	0.58
Uvalue roof	2.25		2.11	1.16	1.42		0.75	0.39	0.79		0.73	0.48
Uvalue windows	4.80		4.90	3.75	3.81		2.90	1.93	2.20		2.04	1.97
Uvalue bottom floor	1.81		1.73	1.52	1.67		1.16	0.51	0.57		0.51	0.38
Heating energy consumption	101	98	63	52	182		133	98	158	168	148	129
Heating systems	boiler				boiler				electricity			
Heating terminal unit	radiators			radiant floor	radiators			radiant floor	convector heaters			
tot nr. of dwellings in EU-27	5,563,385	10,977,814	12,326,198	6,923,950	12,883,862	16,543,072	19,849,947	11,961,082	1,326,949	1,580,981	1,831,829	910,548
Tot nr. of people living in the dwelling EU-27	72,640,110				125,289,263				9,463,779			

4.3 LCI of the construction stage

The impact of transport from the manufacturing plant to the building site is calculated based on an average distance of 50 km (Asdrubali et al., 2013) for massive materials and 100 km (Bribián et al., 2011) for other materials. Data on energy consumption of the construction stage are usually not available. Therefore, as suggested in the literature (e.g. Scheuer et al., 2003; Beccali et al., 2013; Asdrubali et al., 2013), the impact of the assembly phase is assumed to be equal to 4% of the impact of the production of the construction materials used. The same assumption is made to estimate the amount of waste generated in this stage (4% of the total construction materials).

4.4 LCI of the use stage (household consumption)

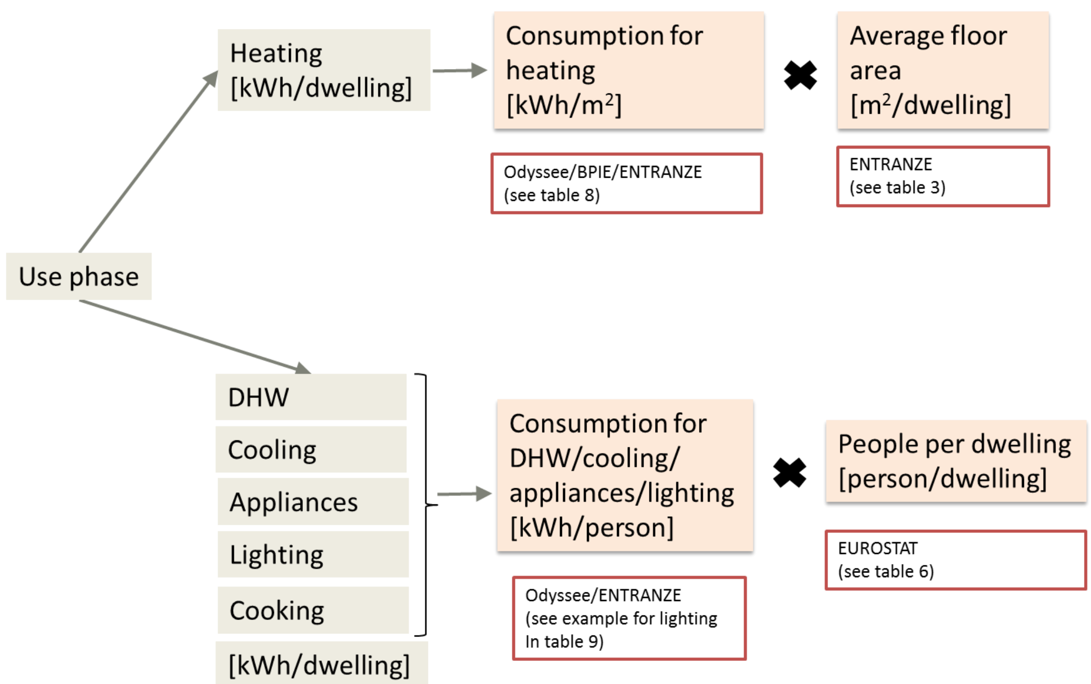
The use stage includes two main systems:

– the use of the dwelling by its inhabitants, modelling electricity and water use, and
– the maintenance of the building and the replacement of components that deteriorates by ageing (presented in the next paragraph).

Rather than calculating the energy consumption of each representative dwelling from its characteristics and through energy simulation tools, which could lead to consumption levels that are peculiar to a single building, a top-down approach was adopted. The apparent energy consumption for each representative dwelling was derived from EU-27 energy statistics.

In particular, Figure 6 shows that the average heating consumption for each model was calculated by multiplying the heating consumption per square meter by the average floor area for each model. For the other types of energy consumption, i.e. water heating, space cooling, lighting, cooking and appliances, a European average value per person for each energy consumption type was considered, and then multiplied by the number of people per dwelling (Figure 6).

Figure 6. Method and sources used to calculate the energy consumption in the use phase



As far as concerns the heating consumptions, the values has been calculated merging annual statistical data about the heating consumption of a dwelling type, by period of construction and by Member State from the BPIE with the total apparent heating consumption given for each Member State from ODYSSEE (as explained in section 4.1). Data on the energy consumption for DHW, cooling, appliances, lighting of each model are based on ODYSSEE data (as explained in section 4.1).

Since the energy consumption for cooling occurs mainly in warm climates and there are no data available on cooling for the Member States included in the cold climatic zone, it has been assumed that the total cooling consumption in Europe is related to warm and moderate climates only.

To define the environmental impacts related to energy consumption, it was also necessary to know which energy carrier was used in each country. According to the ODYSSEE data, the energy consumption for heating, cooking and DHW has been split in six sources: electricity, oil, coal, gas, heat (from district heating) and wood, with different proportions in each zone (Table 12).

Table 12. Heat sources in different zones (%)

Heat source	Warm, %	Moderate, %	Cold, %
Coal	0.4	6.6	0.6
Oil	20.2	16.8	5.2
Gas	44.7	47.6	2.2
District heating	0.5	8.8	39.8
Wood	30.6	14.1	33.3
Electricity	3.5	6.0	18.8

For modelling electricity consumption, the European electricity mix was used (ecoinvent dataset "Electricity, low voltage {Europe without Switzerland}| market group for | Alloc Def, U"- Version 3.2). With regard to water consumption, a European average value of 150 litres per person per day was assumed (Bio Intelligence Service, 2009). The same value was considered for modelling the amount of wastewater. Finally, the impact of solid waste produced during the use stage was disregarded as they are considered to be outside the building system boundaries.

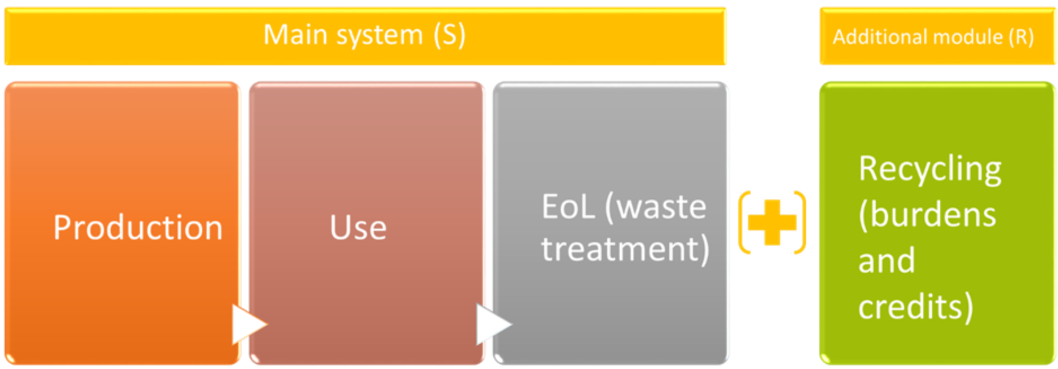
4.5 LCI of the use stage (maintenance and replacement of components)

The system boundary for replacement of building components includes the production of the components to be replaced, their transportation (50 km), and the end-of-life of the removed components (burdens and benefits from recycling and energy recovery). Data on average replacement intervals were found in the literature (Anderson et al., 2009; Schweiz, 2005): 30 years for mineral insulation; 30 years for windows; 50 years for external walls in wood frame (light construction); 30 years for internal walls in wood frame (light construction); 20 years for waterproofing; 50 years for finishes (replacement of 50% of the finishes every 25 years); and 50 years for the systems (replacement of 50% of the systems every 25 years).

4.6 LCI of the end of life stage

The end of life stage in the BoP is modelled in a way that allows separating the burdens and benefits of recycling from the rest of the system, in order to provide a clearer picture of their contributions to the total impact. Two systems are identified: "S", referring to the system excluding recycling activities, and "R" including recycling. Figure 7 illustrates the approach followed for the BoPs' models.

Figure 7. Illustration of the approach adopted to model waste treatment and recycling at the EoL, as systems "S" and "R"



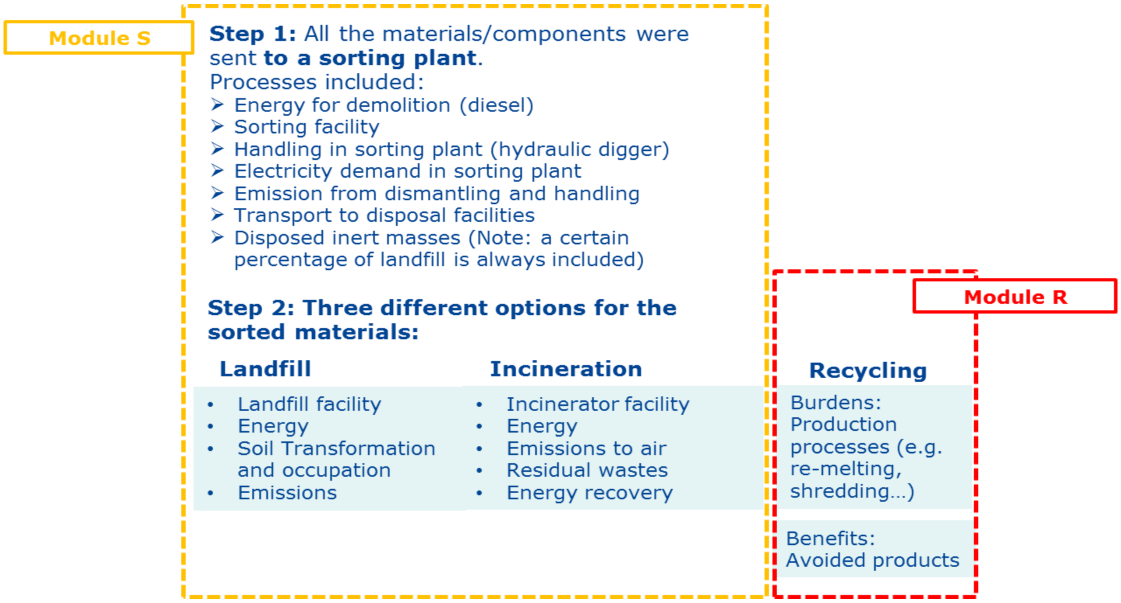
The sum of the two, named System "S+R" is the one that allows evaluating in a more comprehensive way the aspects which are of interest also in the context of circular economy. The additional module "R" quantifies burdens and benefits of activities such as recycling and reuse.

The system boundaries of the end of life stage for the BoP housing include: the demolition process (energy end emissions for dismantling), the treatment at the waste materials sorting plant (machines for handling, electricity demand, emissions from handling), the transport to disposal facilities (50 km), and the disposal of residual inert masses. After treatment, the sorted materials can be landfilled, incinerated or recycled. Both benefits from recycling materials and energy recovery (incineration) are included in the system boundaries. It must be highlighted that a certain rate of uncertainty is introduced while defining the recyclability rate of the construction materials. Data on this topic are not always available, and those that are available are characterized by a certain rate of uncertainty depending on the data source (statistics at EU level, producer associations, and case studies from the literature).

Module S includes all the activities of sorting, landfilling and incinerating. Module R includes the recycling activities only (Figure 8). In particular:

- Module S includes: deconstruction (dismantling or demolition), transportation of the discarded product to the sorting plant, handling in the sorting plant, transport of part of the waste processing from the sorting plant to landfill and physical pre-treatment and management of the disposal site, transport of part of the waste processed from the sorting plant to the incineration plant, incineration burdens and benefits from energy recovery;
- Module R includes: the burdens from recycling processes, and the benefits from avoided products and raw material extraction.

Figure 8. The end of life stage of the BoP housing for Module S and Module R



Details of the datasets used to model the two systems are provided in Annex 1.

4.7 Aggregation of dwellings into the BoP

To evaluate the contribution of the basket per person each model is multiplied by the number of dwellings then grouped according to the climate zone and divided by the number of people in that zone.

5 Results of baseline's hotspot analysis

The overall results of the study represent the potential impact coming from household final consumption in the housing sector in the EU-27. Results are presented as impact per person per year, with 2010 as reference year, according to the functional unit chosen for the study. The analysis at the level of the residential building stock in Europe and of an average EU-27 citizen derives from the integration of the bottom-up approach (process–base life cycle inventory for each representative product) with the top-down approach (statistical data).

The inventory of the BoP housing (reference flow: the impact of housing one average EU citizen in one year) has been characterised using ILCD v. 1.08 (EC-JRC, 2011), ILCD EU-27 normalisation factors (Benini et al., 2014) and ILCD Global normalization factors (Sala et al. 2016). Long-term emissions have been excluded. Results of the hotspot analysis refer to the System S+R, including burdens and credits associated to recycling activities.

In Table 13, and Table 14, a summary of the overall results (characterization and normalization) is presented for the whole basket and for an average citizen respectively. Results in Table 13 and Table 14 refer to the systems S, R and S+R, for comparison. Results of the hotspot analysis refer only to the System S+R, including burdens and credits associated to recycling activities.

Table 13. Characterized results for the whole BoP housing baseline (impacts of housing in EU in 2010).

Impact category	Unit	System S+R	System S	System R
Climate change	kg CO_2 eq	1.30E+12	1.34E+12	-3.65E+10
Ozone depletion	kg CFC-11 eq	1.65E+05	1.66E+05	-1.72E+03
Human toxicity, non-cancer effects	CTUh	1.34E+05	1.36E+05	-2.61E+03
Human toxicity, cancer effects	CTUh	1.72E+04	1.75E+04	-3.39E+02
Particulate matter	kg $PM_{2.5}$ eq	1.43E+09	1.47E+09	-3.76E+07
Ionizing radiation, effects on human health (HH)	kBq U^{235} eq	1.01E+11	1.02E+11	-5.54E+08
Photochemical ozone formation	kg NMVOC eq	3.03E+09	3.18E+09	-1.50E+08
Acidification	molc H^+ eq	6.65E+09	6.85E+09	-2.01E+08
Terrestrial eutrophication	molc N eq	9.13E+09	9.49E+09	-3.56E+08
Freshwater eutrophication	kg P eq	7.35E+07	7.53E+07	-1.84E+06
Marine eutrophication	kg N eq	8.31E+08	8.64E+08	-3.27E+07
Freshwater ecotoxicity	CTUe	5.64E+11	5.73E+11	-8.65E+09
Land use	kg C deficit	2.40E+12	2.48E+12	-8.07E+10
Water resource depletion	m^3 water eq	7.46E+10	7.51E+10	-5.11E+08
Resource depletion	kg Sb eq	5.84E+07	5.64E+07	2.07E+06

Table 14. Characterized results for the FU of the BoP housing baseline (impacts of housing by an average EU citizen in 2010).

Impact category	Unit	System S+R	System S	System R
Climate change	kg CO_2 eq	2.62E+03	2.70E+03	-7.74E+01
Ozone depletion	kg CFC-11 eq	3.33E-04	3.36E-04	-3.21E-06
Human toxicity, non-cancer effects	CTUh	2.70E-04	2.75E-04	-2.40E-04
Human toxicity, cancer effects	CTUh	3.48E-05	3.54E-05	2.35E-04
Particulate matter	kg $PM_{2.5}$ eq	2.90E+00	2.97E+00	-7.50E-02
Ionizing radiation, effects on human health (HH)	kBq U^{235} eq	2.05E+02	2.06E+02	-1.08E+00
Photochemical ozone formation	kg NMVOC eq	6.11E+00	6.42E+00	-3.08E-01
Acidification	molc H^+ eq	1.34E+01	1.38E+01	-4.36E-01
Terrestrial eutrophication	molc N eq	1.84E+01	1.92E+01	-7.66E-01
Freshwater eutrophication	kg P eq	1.48E-01	1.52E-01	-4.15E-03
Marine eutrophication	kg N eq	1.68E+00	1.74E+00	-6.47E-02
Freshwater ecotoxicity	CTUe	1.14E+03	1.16E+03	-1.75E+01
Land use	kg C deficit	4.84E+03	5.01E+03	-1.67E+02
Water resource depletion	m^3 water eq	1.51E+02	1.52E+02	-8.01E-01
Resource depletion	kg Sb eq	1.18E-01	1.14E-01	4.11E-03

Table 15. Normalized results, ILCD EU-27, BoP housing baseline

Impact category	System S+R		
	Value (tot. BoP)	Value (per person)	%
Climate change	1.43E+08	2.89E-01	4.3%
Ozone depletion	7.63E+06	1.54E-02	0.2%
Human toxicity, non-cancer effects	2.51E+08	5.06E-01	7.6%
Human toxicity, cancer effects	4.66E+08	9.42E-01	14.1%
Particulate matter	3.77E+08	7.62E-01	11.4%
Ionizing radiation HH	8.98E+07	1.81E-01	2.7%
Photochemical ozone formation	9.53E+07	1.93E-01	2.9%
Acidification	1.40E+08	2.83E-01	4.2%
Terrestrial eutrophication	5.19E+07	1.05E-01	1.6%
Freshwater eutrophication	4.97E+07	1.00E-01	1.5%
Marine eutrophication	4.92E+07	9.94E-02	1.5%
Freshwater ecotoxicity	6.43E+07	1.30E-01	1.9%
Land use	3.21E+07	6.49E-02	1.0%
Water resource depletion	9.18E+08	1.85E+00	27.7%
Resource depletion	5.79E+08	1.17E+00	17.5%
TOTAL	*3.31E+09*	*6.69E+00*	*100%*

Table 16. Normalized results, ILCD Global, BoP housing baseline

Impact category	System S+R		
	Value (tot. BoP)	Value (per person)	%
Climate change	2.47E-02	3.43E-01	9.1%
Ozone depletion	1.02E-03	1.43E-02	0.4%
Human toxicity, non-cancer effects	4.09E-02	5.69E-01	15.1%
Human toxicity, cancer effects	6.48E-02	9.04E-01	23.9%
Particulate matter	1.62E-02	2.27E-01	6.0%
Ionizing radiation HH	5.28E-02	7.39E-01	19.5%
Photochemical ozone formation	1.08E-02	1.50E-01	4.0%
Acidification	1.74E-02	2.41E-01	6.4%
Terrestrial eutrophication	7.49E-03	1.04E-01	2.8%
Freshwater eutrophication	4.18E-03	5.80E-02	1.5%
Marine eutrophication	4.25E-03	5.93E-02	1.6%
Freshwater ecotoxicity	6.92E-03	9.65E-02	2.6%
Land use	2.72E-03	3.78E-02	1.0%
Water resource depletion	9.72E-04	1.36E-02	0.4%
Resource depletion	1.58E-02	2.20E-01	5.8%
TOTAL	*2.71E-01*	3.78E+00	*100%*

The relative relevance of impact categories varies quite significantly depending on the set of normalisation references used. When applying the EU-27 set, water depletion is the most relevant impact category (27.7%), followed by resource depletion (17.5%), human toxicity cancer effects (14.1%) and particulate matter (11.4%). If the global reference is used, the most relevant contribution to the overall impact of the BoP comes from human toxicity cancer effects (23.9%), followed by ionising radiation (19.5%) and human toxicity non-cancer effects (15.1%). It is worthy to note that the contribution of toxicity-related impact categories should be further checked when improved impact assessment models for toxicity-related impacts would be available. In fact, there are some known issues related to the robustness of the impact assessment models for toxicity-related impacts. According to Zampori et al. (2017), only 50% of the elementary flows contributing to toxicity are characterised by the impact assessment models currently available. EC-JRC is looking at the improvement of the issues and that limitations of current model and the way forward are discussed in Saouter et al. (2017a and 2017b).

For the impact categories for which improved models are already available, a sensitivity analysis of the BoP housing has conducted. In the revised version of the ILCD method (called here "LCIA-LCIND2") some impact categories were updated with a selection of recent impact assessment models and factors. The updated list of impact assessment models used in the LCIA-LCIND2 method is presented in Table 17. Differences with ILCD are highlighted in green.

Results of characterization and normalization (using global references) with the LCIA-LCIND2 method are presented in Table 18 for the whole BoP housing baseline and in Table 19 for the FU of the BoP housing baseline (impacts of housing of an average EU citizen in 2010). Again, after normalization the contribution of human toxicity, cancer effect is the most relevant one (20%). However, it has to be underlined that the impact assessment models for toxicity in the LCIA-LCIND2 are the same as in the original version of ILCD. On the contrary, the splitting of ADP into fossils and other abiotic resources allows highlighting the role of energy carriers use in the housing sector.

Table 17. Impact categories, models and units of LCIA-LCIND2 impact assessment method (differences from ILCD are highlighted in green)

Impact category	Reference model	Unit
Climate change	IPCC, 2013	kg CO_2 eq
Ozone depletion	World Meteorological Organisation (WMO), 1999	kg CFC-11 eq
Human toxicity, non-cancer	USEtox (Rosenbaum et al., 2008)	CTUh
Human toxicity, cancer	USEtox (Rosenbaum et al., 2008)	CTUh
Particulate matter	Fantke et al., 2016	Deaths
Ionising radiation, human health	Frischknecht et al., 2000	kBq U^{235} eq
Photochemical ozone formation, human health	Van Zelm et al., 2008, as applied in ReCiPe, 2008	kg NMVOC eq
Acidification	Posch et al., 2008	molc H^+ eq
Eutrophication, terrestrial	Posch et al., 2008	molc N eq
Eutrophication, freshwater	Struijs et al., 2009[2]	kg P eq
Eutrophication, marine	Struijs et al., 2009	kg N eq
Ecotoxicity, freshwater	USEtox (Rosenbaum et al., 2008)	CTUe
Land use	Bos et al., 2016 (based on)	Pt
Water use	AWARE 100 (based on; UNEP, 2016)	m^3 water eq
Resource use, fossils	ADP fossils (van Oers et al., 2002)	MJ
Resource use, minerals and metals	ADP ultimate reserve (van Oers et al., 2002)	kg Sb eq

Table 18. Characterized and normalized (global) results for the whole BoP housing baseline (impacts of housing in EU in 2010) with LCIA-LCIND2 method, applied to the system S+R

Impact category	Unit	Characterization	Normalization (values)	Normalization (%)
Climate change	kg CO_2 eq	1.35E+12	2.32E-02	6.2%
Ozone depletion	kg CFC-11 eq	1.63E+05	1.01E-03	0.3%
Human toxicity, non-cancer	CTUh	1.34E+05	4.08E-02	11.0%
Human toxicity, cancer	CTUh	1.72E+04	6.48E-02	17.4%
Particulate matter	Death	1.20E+05	2.92E-02	7.8%
Ionising radiation, human health	kBq U^{235} eq	1.01E+11	5.31E-02	14.3%
Photochemical ozone formation, human health	kg NMVOC eq	3.25E+09	1.16E-02	3.1%
Acidification	molc H^+ eq	6.65E+09	1.73E-02	4.7%
Eutrophication, terrestrial	molc N eq	9.13E+09	7.49E-03	2.0%
Eutrophication, freshwater	kg P eq	6.78E+07	1.34E-02	3.6%
Eutrophication, marine	kg N eq	8.31E+08	4.25E-03	1.1%
Ecotoxicity, freshwater	CTUe	5.64E+11	6.93E-03	1.9%
Land use	Pt	2.83E+13	2.94E-03	0.8%
Water use	m^3 water eq	2.89E+12	3.65E-02	9.8%
Resource use, fossils	MJ	2.40E+13	5.35E-02	14.4%
Resource use, minerals and metals	kg Sb eq	2.54E+06	6.36E-03	1.7%

[2] CF for emissions of P to soil changed from 1 to 0.05 kg Peq/kg

Table 19. Characterized and normalized results for the F.U. of the BoP housing baseline (impacts of housing by an average EU citizen in 2010) with LCIA-LCIND2 method, applied to the system S+R

Impact category	Unit	Characterization	Normalization (values)	Normalization (%)
Climate change	kg CO_2 eq	2.72E+03	3.24E-01	6.2%
Ozone depletion	kg CFC-11 eq	3.28E-04	1.41E-02	0.3%
Human toxicity, non-cancer	CTUh	2.70E-04	5.68E-01	11.0%
Human toxicity, cancer	CTUh	3.48E-05	9.02E-01	17.4%
Particulate matter	Death	2.42E-04	4.07E-01	7.8%
Ionising radiation, human health	kBq U^{235} eq	2.05E+02	7.39E-01	14.3%
Photochemical ozone formation, human health	kg NMVOC eq	6.56E+00	1.61E-01	3.1%
Acidification	molc H^+ eq	1.34E+01	2.42E-01	4.7%
Eutrophication, terrestrial	molc N eq	1.84E+01	1.04E-01	2.0%
Eutrophication, freshwater	kg P eq	1.37E-01	1.87E-01	3.6%
Eutrophication, marine	kg N eq	1.68E+00	5.92E-02	1.1%
Ecotoxicity, freshwater	CTUe	1.14E+03	9.65E-02	1.9%
Land use	Pt	5.72E+04	4.09E-02	0.8%
Water use	m^3 water eq	5.83E+03	5.09E-01	9.8%
Resource use, fossils	MJ	4.84E+04	7.45E-01	14.4%
Resource use, minerals and metals	kg Sb eq	5.13E-03	8.86E-02	1.7%

5.1 Contribution by life cycle stages

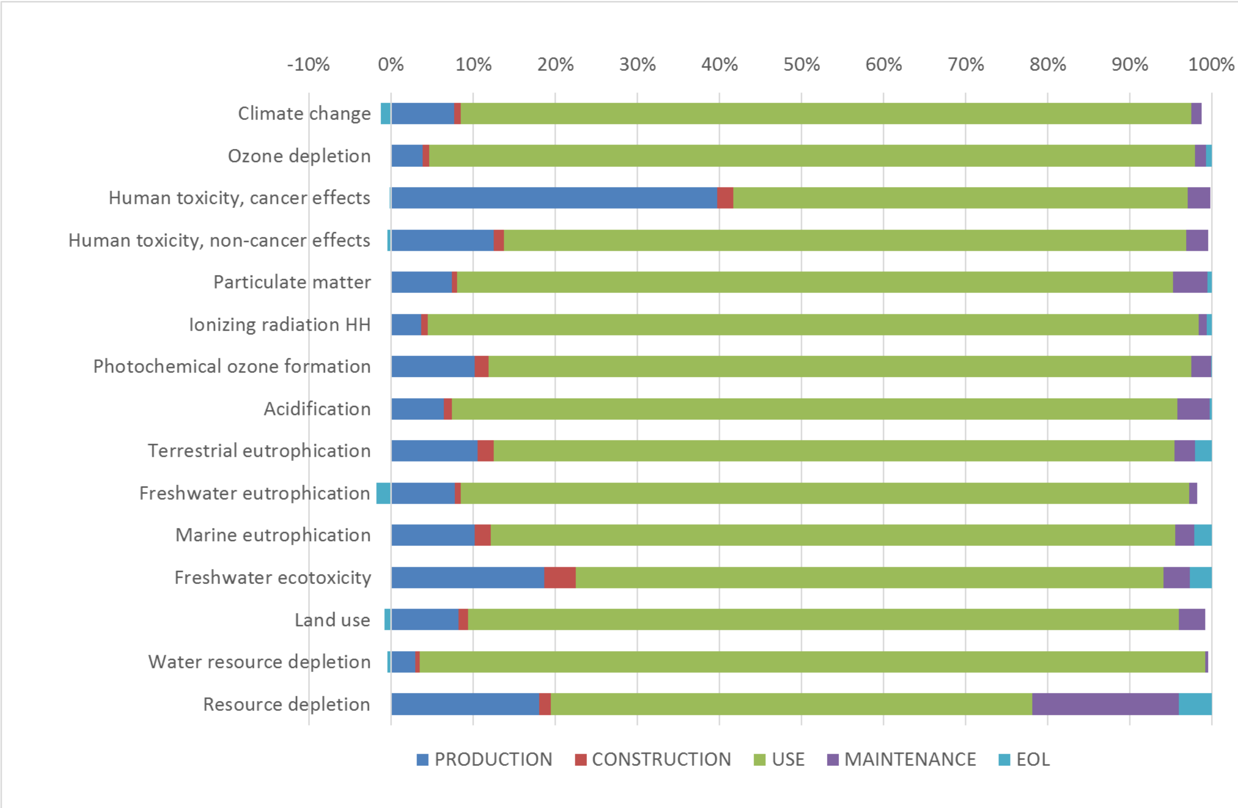
Table 20 shows the contribution of different life cycle stages to the impact categories (based on the characterised inventory results before normalisation and weighting). The life cycle stages in orange are the ones identified as "most relevant" for the impact category, as they are contributing to more than 80%.

Table 20 and Figure 9 show that there is a huge gap between the impact of the use phase (from 56% to 97%) and the impact of the other life cycle phases.

Table 20. Contribution by life cycle stages

Climate change		**Human tox, non-cancer effects**		**Particulate matter**	
Life cycle stage	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*
USE	91	USE	84	USE	87
PRODUCTION	8	PRODUCTION	13	PRODUCTION	7
MAINTENANCE	1.2	MAINTENANCE	2.7	MAINTENANCE	4.2
CONSTRUCTION	0.8	CONSTRUCTION	1.3	CONSTRUCTION	0.7
END OF LIFE	-1.3	END OF LIFE	-0.4	END OF LIFE	0.5
Ozone depletion		**Human toxicity, cancer effects**		**Ionizing radiation HH**	
Life cycle stage	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*
USE	93	USE	56	USE	94
PRODUCTION	4	PRODUCTION	40	PRODUCTION	4
MAINTENANCE	1.3	MAINTENANCE	2.8	MAINTENANCE	1.0
CONSTRUCTION	0.81	CONSTRUCTION	1.9	CONSTRUCTION	0.7
END OF LIFE	0.76	END OF LIFE	-0.1	END OF LIFE	0.6
Photochemical ozone formation		**Acidification**		**Terrestrial eutrophication**	
Life cycle stage	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*
USE	86	USE	88	USE	83
PRODUCTION	10	PRODUCTION	6	PRODUCTION	11
MAINTENANCE	2.4	MAINTENANCE	3.9	MAINTENANCE	2.5
CONSTRUCTION	1.7	CONSTRUCTION	1.0	END OF LIFE	2.1
END OF LIFE	0.1	END OF LIFE	0.3	CONSTRUCTION	2.0
Freshwater eutrophication		**Marine eutrophication**		**Freshwater ecotoxicity**	
Life cycle stage	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*
USE	92	USE	83	USE	72
PRODUCTION	8	PRODUCTION	10	PRODUCTION	19
MAINTENANCE	1.0	MAINTENANCE	2.3	CONSTRUCTION	3.9
CONSTRUCTION	0.7	END OF LIFE	2.1	MAINTENANCE	3.2
END OF LIFE	-1.9	CONSTRUCTION	2.0	END OF LIFE	2.7
Land use		**Water resource depletion**		**Resource depletion**	
Life cycle stage	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*
USE	88	USE	97	USE	59
PRODUCTION	8	PRODUCTION	3	PRODUCTION	18
MAINTENANCE	3.3	CONSTRUCTION	0.5	MAINTENANCE	17.9
CONSTRUCTION	1.1	MAINTENANCE	0.3	CONSTRUCTION	1.5
END OF LIFE	-0.8	END OF LIFE	-0.5	END OF LIFE	4.0

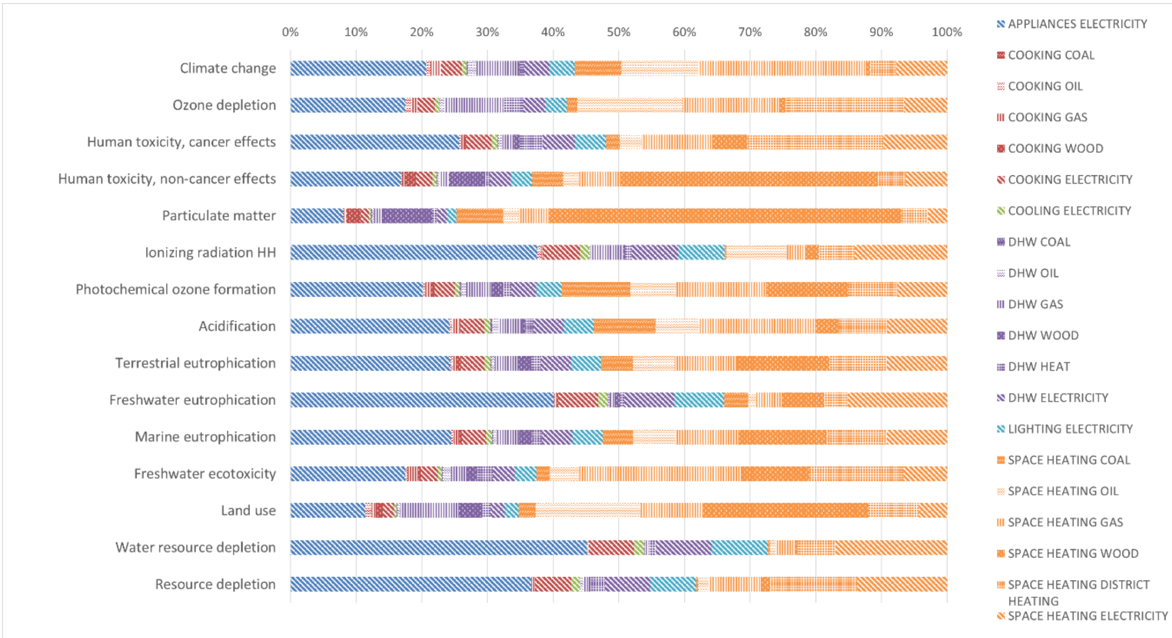
Figure 9. Contribution by life cycle phases of the BoP housing



As mentioned before, the **use phase** (energy and water consumption) dominates the impacts. In particular, Water resource depletion (97% of the impact on this category is due to the use phase) is mainly due the electricity production (85%) and around 6.3% is related to tap water consumption by users at home. The Ozone depletion (93%) is caused by the electricity consumption in the use phase of buildings, but also by light fuel oil and natural gas for heating and by incineration of municipal solid waste for district heating (due to refrigerant HCFC-22 and trichloromethane production for wastewater treatment). Ionizing radiation (94%) and Photochemical ozone formation (86%) are mainly due to the electricity use. Freshwater eutrophication (92%) is also largely due to electricity and in a smaller fraction to wood heating and district heating (incineration of municipal solid waste). Acidification (88%), Photochemical ozone formation (86%), Climate Change (91%) and Freshwater ecotoxicity (72%) are mainly due to electricity and secondarily to natural gas for heating. Land use (88%) and Human toxicity, non-cancer effects (84%) are mainly due to wood heating. Particulate matter (87%) and Terrestrial eutrophication (83%) are mainly due to fuels such as light fuel oil for heating and to electricity. Marine eutrophication (83%) is largely due to electricity and in a smaller fraction to fuels different from natural gas such as light fuel oil for heating. Human toxicity-cancer effects (56%) is mainly due to the electricity distribution network.

Given the relevance of the use phase on the overall impact, Figure 10 shows the contribution of the different energy carriers to the impact. The impact due to the heating during the winter is distributed among the fuels (natural gas, oil, coal, wood), then electricity, water and wastewater treatment are also evaluated.

Figure 10. Contribution of energy consumption by sources and by use to the use phase impact.



The same colours of Figure 11 are used to identify the type of use.

An analysis to test the sensitivity of results to the choice of the European electricity mix or more detailed mixes per each climatic zone was run. Results are presented in Annex 2. They show that there is a difference between the European electricity mix and the zone electricity mix. Differences are evident for warm and cold zone, whereas are smaller for the moderate zone.

When the European electricity mix is used instead of a Warm Zone one, impacts on several impact categories are underestimated. The major underestimations are on the land use, freshwater ecotoxicity, acidification, photochemical ozone formation, marine eutrophication, particulate matter, freshwater eutrophication, for which the differences are higher than 20%. On the contrary, other impact categories are overestimated, in particular ionizing radiation HH, freshwater eutrophication, where the difference is higher than -20%. When the European electricity mix is used instead of a Cold Zone one, the major underestimations are on Ionizing radiation HH, land use, and human toxicity, non-cancer effects, for which differences are always higher than 20% and can also reach the 88%. Several other categories are overestimated, among all: water resource depletion, freshwater eutrophication and resource depletion, for which the difference is higher than 50%.

The **production phase** has a big relevance on one indicator, i.e. *Human toxicity, cancer effects* (40% of the impact on this category is due to the production phase). This is mainly due to the impact of reinforcing steel (90%). Specifically, from the process contribution, it emerges the relevance of the following processes: Slag, unalloyed electric arc furnace steel {RoW}| treatment of, residual material landfill | Alloc Def, U (42%), Basic oxygen furnace waste {RoW}| treatment of, residual material landfill | Alloc Def, U (22%), Ferrochromium, high-carbon, 68% Cr {GLO}| production | Alloc Def, U (15%), Sludge from steel rolling {RoW}| treatment of, residual material landfill | Alloc Def, U (10%).

The production phase significantly contributes to *Freshwater ecotoxicity* (19%). The impact is due to the production of reinforcing steel (77%), concrete (8%), ceramic tiles (4%, mainly due to titanium dioxide production) and clay bricks (3%). Then, the production phase contributes to *Resource depletion* (18%), due to the production of ceramic tiles (57% mainly due to zinc production), steel (28% mainly ferronickel production), concrete (6%) and clay bricks (4%).The other impact categories in which the production phase gives a relevant contribution are: *Human toxicity, non-cancer effects* (13%) due to the production of reinforcing steel and concrete; *Freshwater eutrophication* (8%) and *Water resource depletion* (3%).

The **maintenance/replacement phase** significantly contribute to *resource depletion* (17.9%). This is due to the production of ceramic tiles and aluminium scrap prepared for melting in the recycling process of aluminium. The impact of both these processes is largely due to zinc-lead mining operation. The maintenance phase contribute to a lesser extent to *Particulate matter* (4.2%) mainly due to ceramic tiles (61%) and in small percentage due to sanitary ceramics and waste gypsum plasterboard treatment in sanitary landfill; *Acidification* (3.9%) mainly due to waste gypsum plasterboard treatment (42%); *Land use* (3.3%) due to the impact of the wood components (for windows and internal walls).

The contribution of **construction phase** never exceeds 4% in all indicators. It should be highlighted that this result could be affected by the assumptions, i.e. the oversimplification done in building the inventory of this phase (i.e. simply referring to a % of impact of the production phase), because it is not well documented in literature and detailed inventory data were not available.

Small burdens come also from **end-of-life** that slightly exceeds 4% in one impact category (resource depletion); benefits from recycling also occur and they never exceed 1.9%

Table 21 shows the overall environmental impact related to housing per citizen per year in EU-27 in 2010 and its distribution on the life cycle stages included within the system boundaries. Figure 10, Figure 11 and Figure 12 represent a zoom on the use phase. In particular, they show that space heating and electricity consumption for the appliances are the major contributors to all the impact categories. When looking at the energy sources (Figure 12), electricity use has the highest share in almost all the impact categories except for *Human toxicity, non-cancer effects*, *Particulate matter* and *Land use*, where the impact of wood for space heating (see Figure 10) causes the highest impact.

Table 21. Environmental impacts related to housing per person per year in EU-27 (total and per life cycle stages). A colour scale is applied to the results in each column, from green (lowest contribution), to red (highest contribution).

Impact category	Unit	Production	%	Constr.	%	Use	%	Mainten.	%	EoL	%	Total	%
Climate change	kg CO_2 eq	2.07E+02	8	2.14E+01	0.8	2.40E+03	91	3.27E+01	1.2	-3.42E+01	-1.3	**2.62E+03**	**100**
Ozone depletion	kg CFC-11 eq	1.29E-05	4	2.70E-06	0.8	3.10E-04	93	4.42E-06	1.3	2.52E-06	0.8	**3.33E-04**	**100**
Human toxicity, cancer effects	CTUh	1.39E-05	40	6.68E-07	1.9	1.93E-05	56	9.66E-07	2.8	-4.65E-08	-0.1	**3.48E-05**	**100**
Human toxicity, non-cancer effects	CTUh	3.40E-05	13	3.56E-06	1.3	2.26E-04	84	7.37E-06	2.7	-1.10E-06	-0.4	**2.70E-04**	**100**
Particulate matter	kg $PM_{2.5}$ eq	2.15E-01	7	1.91E-02	0.7	2.53E+00	87	1.22E-01	4.2	1.43E-02	0.5	**2.90E+00**	**100**
Ionizing radiation HH	kBq U^{235} eq	7.56E+00	4	1.52E+00	0.7	1.93E+02	94	2.09E+00	1.0	1.22E+00	0.6	**2.05E+02**	**100**
Photochemical ozone formation	kg NMVOC eq	6.22E-01	10	1.07E-01	1.7	5.23E+00	86	1.45E-01	2.4	7.18E-03	0.1	**6.12E+00**	**100**
Acidification	molc H^+ eq	8.66E-01	6	1.28E-01	1.0	1.19E+01	88	5.22E-01	3.9	4.06E-02	0.3	**1.34E+01**	**100**
Terrestrial eutrophication	molc N eq	1.94E+00	11	3.75E-01	2.0	1.53E+01	83	4.54E-01	2.5	3.79E-01	2.1	**1.85E+01**	**100**
Freshwater eutrophication	kg P eq	1.20E-02	8	1.04E-03	0.7	1.37E-01	92	1.54E-03	1.0	-2.76E-03	-1.9	**1.48E-01**	**100**
Marine eutrophication	kg N eq	1.71E-01	10	3.40E-02	2.0	1.40E+00	83	3.94E-02	2.3	3.58E-02	2.1	**1.68E+00**	**100**
Freshwater ecotoxicity	CTUe	2.12E+02	19	4.40E+01	3.9	8.17E+02	72	3.62E+01	3.2	3.05E+01	2.7	**1.14E+03**	**100**
Land use	kg C deficit	4.05E+02	8	5.54E+01	1.1	4.26E+03	88	1.61E+02	3.3	-3.81E+01	-0.8	**4.85E+03**	**100**
Water resource depletion	m^3 water eq	4.50E+00	3	7.30E-01	0.5	1.46E+02	97	5.12E-01	0.3	-6.90E-01	-0.5	**1.51E+02**	**100**
Resource depletion	kg Sb eq	2.13E-02	18	1.72E-03	1.5	6.93E-02	59	2.11E-02	17.9	4.72E-03	4.0	**1.18E-01**	**100**

Figure 11. Contribution of energy uses for different applications and water consumption to the impact of the use phase

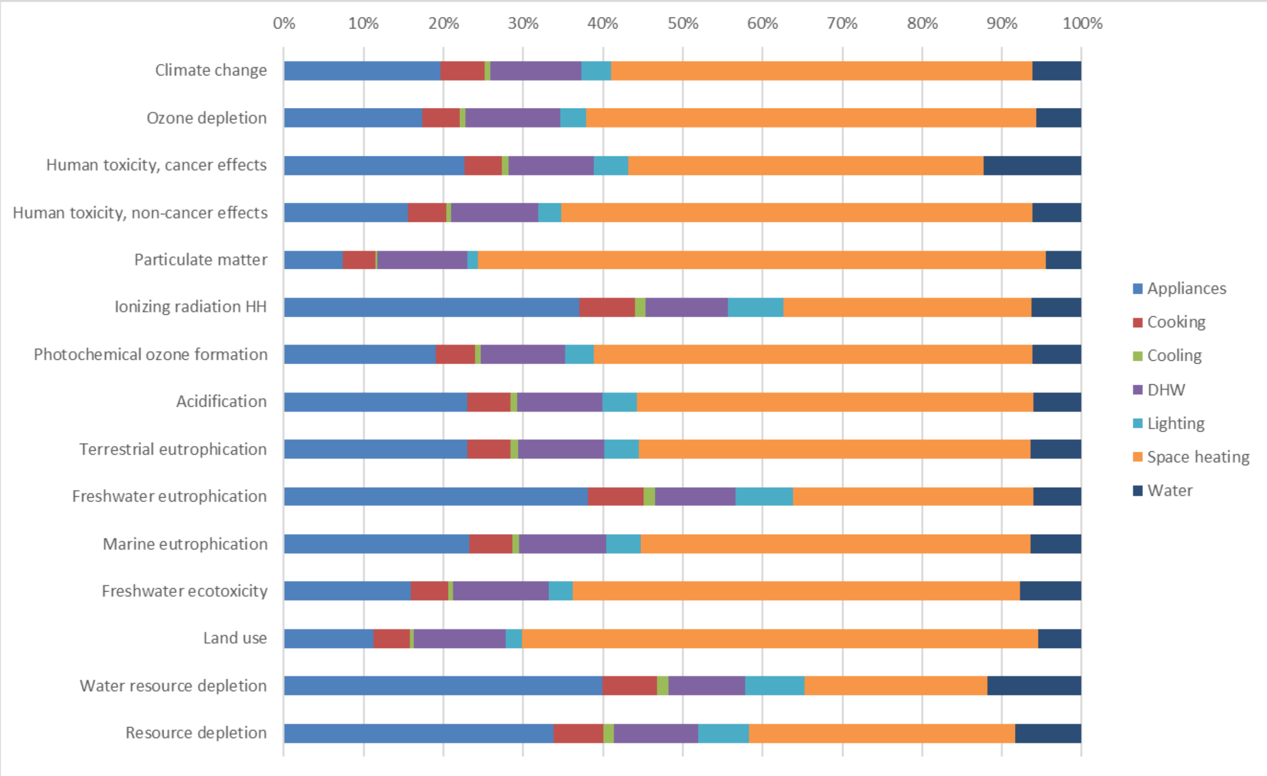
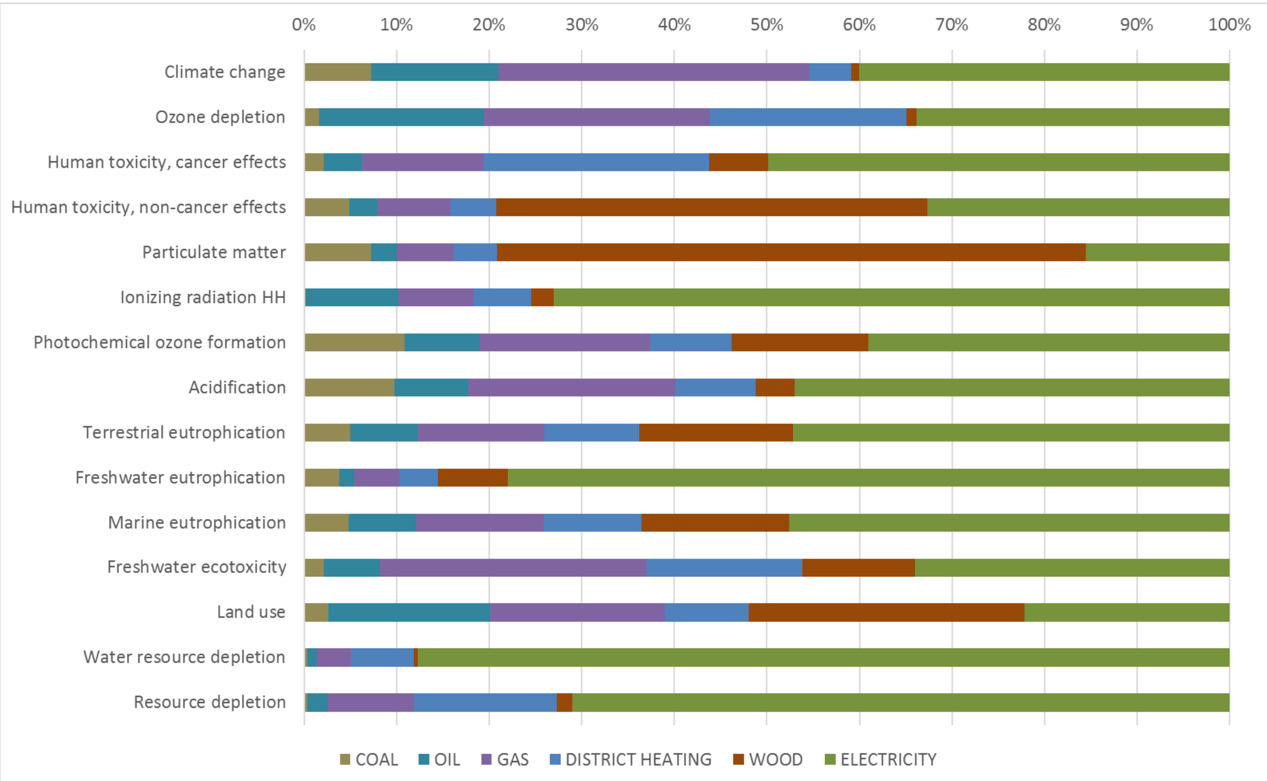


Figure 12. Contribution of energy consumption by sources to the impact of the use phase



5.2 Most relevant elementary flows

Table 22 shows a contribution analysis on the most relevant elementary flows (cut-off 5%). Within each impact category, for the flow that contributes the most, the main process from which it originates is specified (marked with *). A series of inventory network diagrams of the most important flow(s) in terms of contribution to impact categories are reported in Annex 3. They show the materials and processes for which the elementary flow is relevant.

As already mentioned before, the electricity production plays a relevant role for most of the impact categories. Also heating, and especially wood heating, is the activity from which the most relevant elementary flows come: e.g., in the case of human toxicity, the emission of zinc to soil is coming mainly from the ashes of the wood burned for space heating, which constitute about 30% of the space heating in zone 1 and 3 and around 15% in zone 2).

The inclusion of cooling as a contributor to water depletion is debated and represents one of the main differences between the model recommended in the ILCD method (Frischknecht, 2009) and the model recommended in the LCIA-LCIND2 method (Boulay et al. 2016). If the impact of cooling is excluded (not consistently with the original method) when assessing the BoP with ILCD, the most contributing elementary flow is "Water, river, Europe without Switzerland".

Moreover, it has to be specified that there is a known issue about the impact category Resource depletion. The highly relevant contribution of the elementary flow for Indium is partially due to the allocation method chosen in the ecoinvent database (economic allocation) for the dataset of zinc-lead-indium production. In addition to this, it has to be noted that the ILCD method includes the assessment of minerals and metals and of energy carriers under the same indicator. Since the use of energy resources is quite relevant for the housing sector (especially in light of the relative contribution of the use phase in the overall impact of the entire basket), a specific sensitivity analysis on the impact of resource depletion has been run, using the indicators included in LCIA-LCIND2 method. These indicators assess the impact of minerals and metals and of energy carriers separately.

The contribution by elementary flows for the indicators that are different between the ILCD method and the LCIA-LCIND2 method (namely resources, water, land use and particulate matter) is reported in Table 23.

Table 22. Most relevant elementary flows (cut-off 5%)

Climate change		**Human toxicity, non-cancer effects**		**Particulate matter**	
Elementary flow	*Contr. (%)*	*Elementary flow*	*Contr. (%)*	*Elementary flow*	*Contr. (%)*
Carbon dioxide, fossil*	92.20%	Zinc to soil*	32.40%	Particulates, < 2.5*	81.80%
Methane, fossil	6.45%	Zinc to air	23.70%	Sulfur dioxide	16.70%
		Mercury to air	23.30%		
		Lead to air	5.18%		
*Electricity production (EU mix)		*Ashes from wood heating		*Coke burning for heating	
Ozone depletion		**Human toxicity, cancer effects**		**Ionizing radiation HH**	
Elementary flow	*Contr. (%)*	*Elementary flow*	*Contr. (%)*	*Elementary flow*	*Contr. (%)*
Methane, bromotrifluoro-, Halon 1301*	42.80%	Chromium VI to water*	54.20%	Carbon-14 to air*	94.10%
Ethane, 1,2-dichloro-1,1, 2,2-tetrafluoro-, CFC-114	20.40%	Chromium VI to soil	15.10%		
Methane, bromochlorodifluoro-, Halon 1211	14.80%	Chromium to water	12.70%		
Methane, dichlorodifluoro-, CFC-12	8.64%	Chromium to air	11.80%		
Methane, chlorodifluoro-, HCFC-22	8.24%				
*Light fuel oil production		*Reinforcing steel		*Electricity production FR	
Photochemical ozone formation		**Acidification**		**Terrestrial eutrophication**	
Elementary flow	*Contr. (%)*	*Elementary flow*	*Contr. (%)*	*Elementary flow*	*Contr. (%)*
Nitrogen oxides*	67.40%	Sulfur dioxide*	75.80%	Nitrogen oxides *	95.20%
NMVOC	18.10%	Nitrogen oxides	22.70%		
Sulfur dioxide	10.30%				
*Electricity production (EU mix)		*Natural gas production		*Electricity production (EU mix)	
Freshwater eutrophication		**Marine eutrophication**		**Resource depletion**	
Elementary flow	*Contr. (%)*	*Elementary flow*	*Contr. (%)*	*Elementary flow*	*Contr. (%)*
Phosphate to water*	91.20%	Nitrogen oxides to air*	95.50%	Indium	70.90%
Phosphorus to air	8.20%			Cadmium	8.51%
				Nickel	5.94%
*Lignite mining		*Electricity production (EU mix)		*Zinc-lead mining	
Land use occupation		**Water resource depletion**		**Freshwater ecotoxicity**	
Elementary flow	*Contr. (%)*	*Elementary flow*	*Contr. (%)*	*Elementary flow*	*Contr. (%)*
Occupation, forest, extensive*	52.0%	Water, cooling, DE*	25.30%	Chromium VI to water*	16.40%
Occupation, forest, intensive	26.4%	Water, cooling, PL	15.30%	Barium to water	10.50%
Occupation, traffic area, rail/road embankment	7.4%	Water, cooling, FR	8.90%	Silver to water	9.02%
Occupation, industrial area	2.9%	Water, cooling, ES	8.03%	Vanadium to air	8.41%
Occupation, dump site	2.8%	Water, river, Europe without Switzerland	6.10%	Antimony to air	7.45%
*Wood chips (wood heating)		Water, cooling, UA	5.84%	Zinc to water	6.20%
Land use transformation		Water, cooling, BE	5.12%	Zinc to air	6.07%
From forest to mineral extraction site*	72.2%				
From pasture and meadows to industrial area	4.3%				
Unknown to industrial area	3.0				
*Onshore oil/gas production		*Electricity production (EU mix)		*Reinforcing steel	

Table 23. Most relevant elementary flows for resource depletion, water scarcity, land use and particulate matter, when applying LCIA-LCIND2 method

Resource use - minerals and metals		**Resource use - fossils**		**Particulate matter**	
Elementary flow	*Contr. (%)*	*Elementary flow*	*Contr. (%)*	*Elementary flow*	*Contr. (%)*
Cadmium*	27.6%	Gas, natural*	39.1%	Particulates, < 2.5 um*	84.7%
Lead	18.6%	Uranium	18.9%	Sulfur dioxide	13.2%
Copper	12.2%	Coal, hard	17.0%	Nitrogen oxides	1.7%
Silver	8.3%	Oil, crude	16.3%	Ammonia	0.5%
Chromium	4.8%	Coal, brown	8.2%		
Tin	4.1%				
Gold	2.9%				
* Zinc-lead mining		*Heating with natural gas		*Coke burning for heating	
Water use (contribution by country)		**Land occupation**		**Land transformation**	
Elementary flow	*Contr. (%)*	*Elementary flow*	*Contr. (%)*	*Elementary flow*	*Contr. (%)*
Net water use in Europe without Switzerland*	72.6%	Occupation, forest, extensive*	56.6%	From forest to mineral extraction site*	54.0%
Net water use in RoW	13.6%	Occupation, forest, intensive	32.8%	From arable to arable, non-irrigated, intensive	15.9%
Net water use in RER	6.6%	Occupation, traffic area, rail/road embankment	3.8%	From pasture and meadows to industrial area	3.0%
Net water use in IT	2.7%			From unknown to industrial area	2.4%
Net water use in unspecified country	1.1%			From arable, non-irrigated to arable, non-irrigated intensive	2.1%
*Tap water		*Wood chips (wood heating)		*Onshore well, oil/gas production	

5.3 Contribution by product groups

The contribution of the representative dwellings to the overall impact of housing in Europe depends on two factors: the impact of one unit of each type of dwelling and the number of dwellings of that type in the EU territory.

As shown in Figure 13, the larger contribution comes from the single-family houses in moderate climate, followed by multi-family houses, again in moderate climate. These two types of dwelling together represent about 70% of the European building stock (Table 24) and contribute to 60%-70% of the overall impact, depending on the impact category considered.

When analysing the impact per single dwelling, irrespectively of the number of dwellings of that type in the EU building stock, it emerges that the SFHs in cold climate are the ones with the highest impact per dwelling per year for all the impact categories considered, except for climate change and resource depletion. The use phase contributes for more than 50% to the overall impact of the dwellings, for most of the impact categories (Figure 15). Therefore, dwellings in cold climate, which have on average a higher energy consumption for space heating (Table 25), are the ones impacting the most.

SFH contribute more than MFH in the same climate area because SFHs have a larger surface area compared to MFHs, and this implies a higher energy demand for space heating. Similarly, more ancient dwellings (built before 1945) contribute more than dwellings in the same climate are and of the same building type (SFH or MFH) built in more recent years. The only exception is represented by SFHs in warm climate built between 1990 and 2010, which have a larger surface (130 m^2) compared to SFHs built before 1990 (100 m^2). In this case, the energy consumption per square meter is lower (76 kWh/m^2 in SFH of 1970-1989 compared to 62 kWh/m^2 in SFH of 1990-2010 (Table 8)) but this improvement in energy efficiency is offset by the increased amount of materials input, due to the larger surface of the dwelling.

Figure 13. Contribution of dwelling types (representative dwellings) to the overall impact of housing in Europe (whole BoP housing)

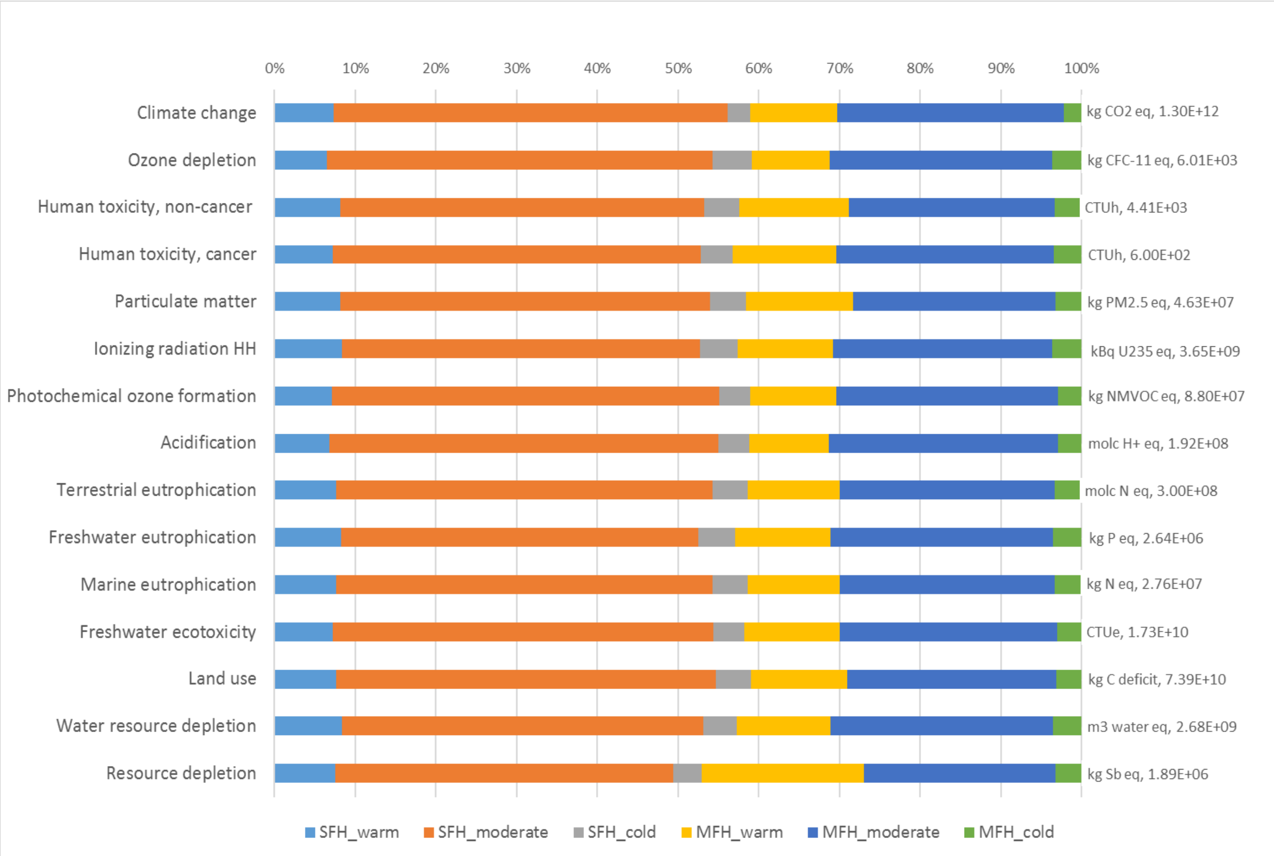


Table 24. Share of each dwelling typology in the EU building stock

Type	SFH_warm	SFH_moderate	SFH_cold	MFH_warm	MFH_moderate	MFH_cold
Share of dwelling typology in the building stock	7.8%	39.9%	2.0%	17.5%	30.0%	2.8%

Table 25. Energy consumption for space heating in the 24 representative dwellings of the BoP housing

	Energy consumption for space heating (kWh/dwelling)							
	SFH				MFH			
	<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
warm	10784	10207	7644	8016	9086	8809	5694	4664
moderate	19786	16577	15114	10048	10947	10896	7971	5901
cold	18965	17506	17981	13832	9490	10059	8881	7739

When considering the contribution to climate change, the dwellings with the highest impact are SFH and MFH in moderate climate built before 1945. The difference with the ranking obtained for the other impact categories considered (i.e. highest impact of SFHs in cold climate) is partially due to the slightly higher energy consumption for space heating. However, the main reason of the difference is the higher impact of concrete and bricks used in the moderate climate compared to the construction technology used in cold climate (timber frame), which has a lower contribution to climate change compared to concrete.

As mentioned before, the use phase (as regards the use of energy and water) is the first contributor to all the impact categories analysed, for all the types of dwellings considered (Figure 15). The production of construction materials is generally the second most important contributor, with a higher relevance for human toxicity, cancer effects, freshwater ecotoxicity and resource depletion. The construction phase has a negligible contribution to almost all the impact categories, except for freshwater ecotoxicity. However, also in this case its relevance is marginal compared to use phase and to the production of raw materials. Maintenance of buildings has generally a limited contribution to all impact categories. A notable exception is resource depletion, because of the impact coming from the production of materials that are substituted during maintenance (such as ceramic tiles, windows, etc.). This contribution is higher in MFH in cold climate, built between 1990 and 2010 and in the most recent (1970-89 and 1990-2010) MFHs in warm climate, because of the replacement of the aluminium frame of the windows (in other buildings, the window frame is made by wood or polyvinylchloride - PVC). Regarding land use, maintenance is more relevant for SFH in cold climate compared to other dwellings because of the partial replacement of the timber frame (the same activity has lower impact on the respective MFH in cold climate because the overall impact is allocated to the 16 dwellings that compose the building). A similar pattern is observed for the contribution of the production of construction materials to land use impact. On the contrary, the impact on resource depletion by construction materials (mainly wood) used in dwellings in cold climate is lower compared to the impact of other types of dwellings, because the indicator used in the assessment (ADP; van Oers, 2002) covers only abiotic resources. Similarly, the impact of construction materials on human toxicity, cancer effect, generated by dwellings in cold climate is lower than the one generated by construction materials of other types of dwellings, because part of the impact by other dwellings is coming from reinforced concrete, which is not used in buildings in cold climate.

If the impact is calculated per person, the occupancy factor of each type of dwelling (Table 26) influences the results. As shown in Figure 14 with the example of climate change, the ranking of dwelling types in terms of magnitude of impact changes when the impact is calculated per each person living in that type of dwelling. The biggest difference between the two types of ranking is observed for SFHs in warm climate, which have the highest occupancy factor (3.4 persons for dwelling, on average) among the dwelling types considered. The lowest impact per person is obtained for a citizen living in a SFH in warm climate, whereas according to the ranking per impact of single dwelling, the SFHs in warm climate generate higher impact compared to MFHs in moderate, cold and warm climate.

Figure 14. Impact on climate change calculated per dwelling and per person living in that dwelling

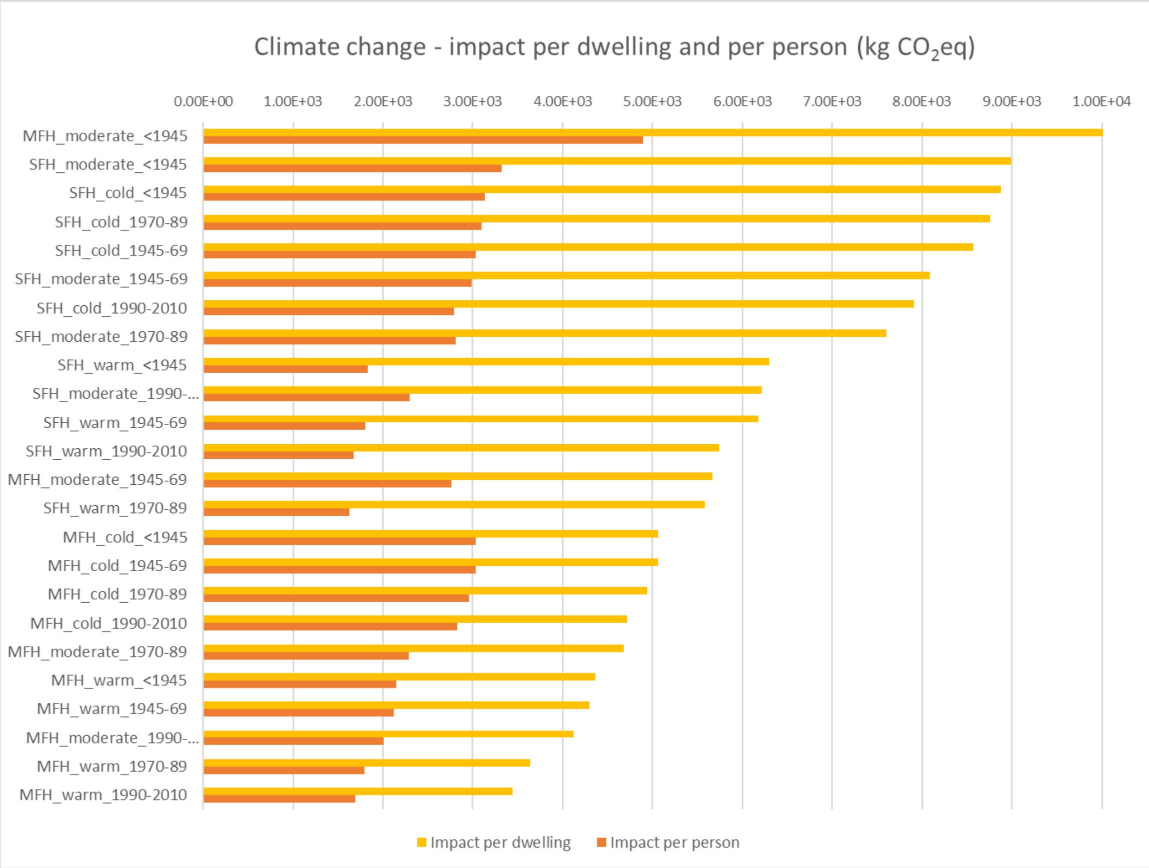


Table 26. Occupancy factor of the representative dwellings in the BoP housing

Type	SFH_warm	SFH_moderate	SFH_cold	MFH_warm	MFH_moderate	MFH_cold
Occupancy factor	3.4	2.7	2.8	2.0	2.0	1.7

Figure 15. Impact per dwelling type, with contribution by life cycle phases

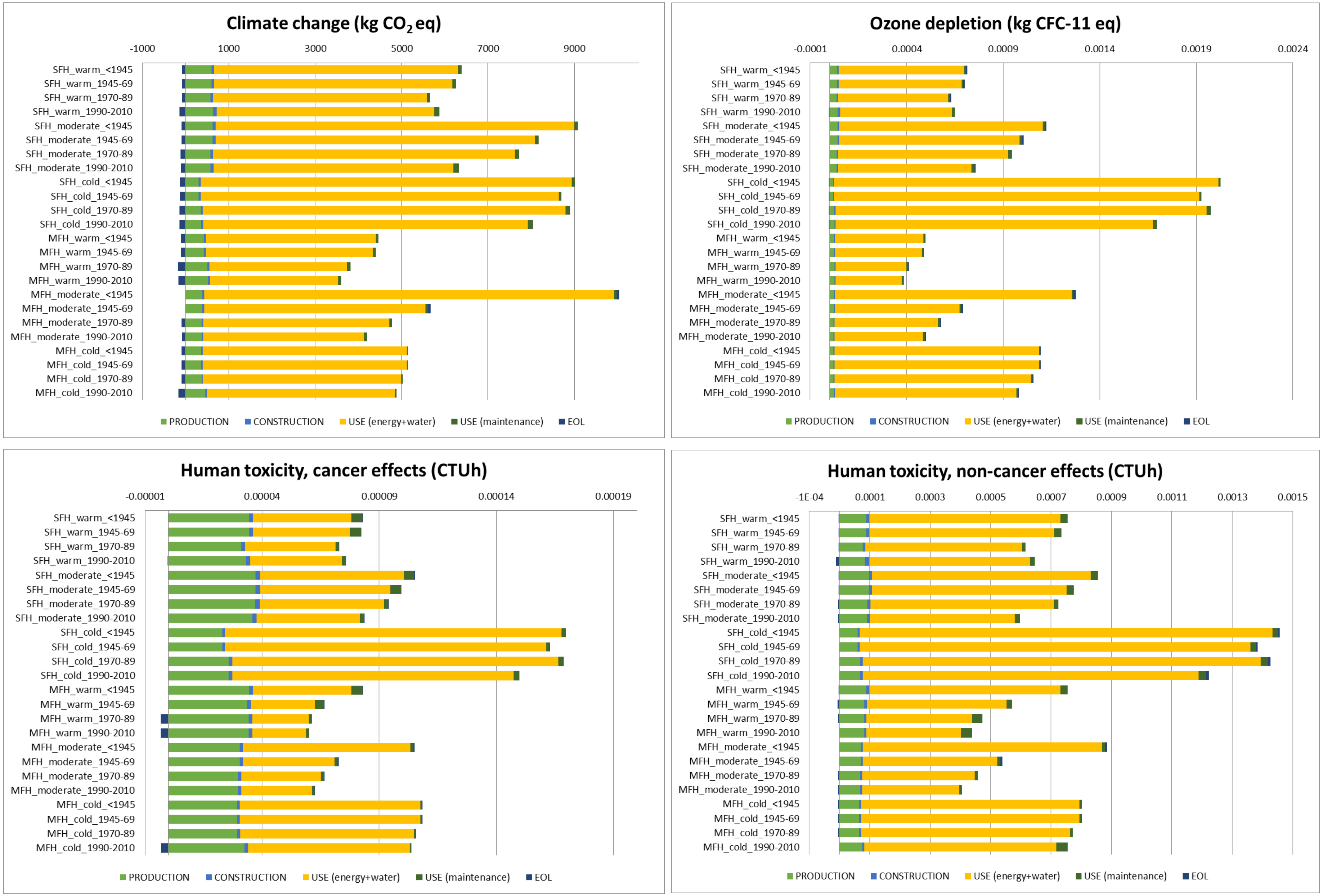


Figure 15. Impact per dwelling type, with contribution by life cycle phases (continuation)

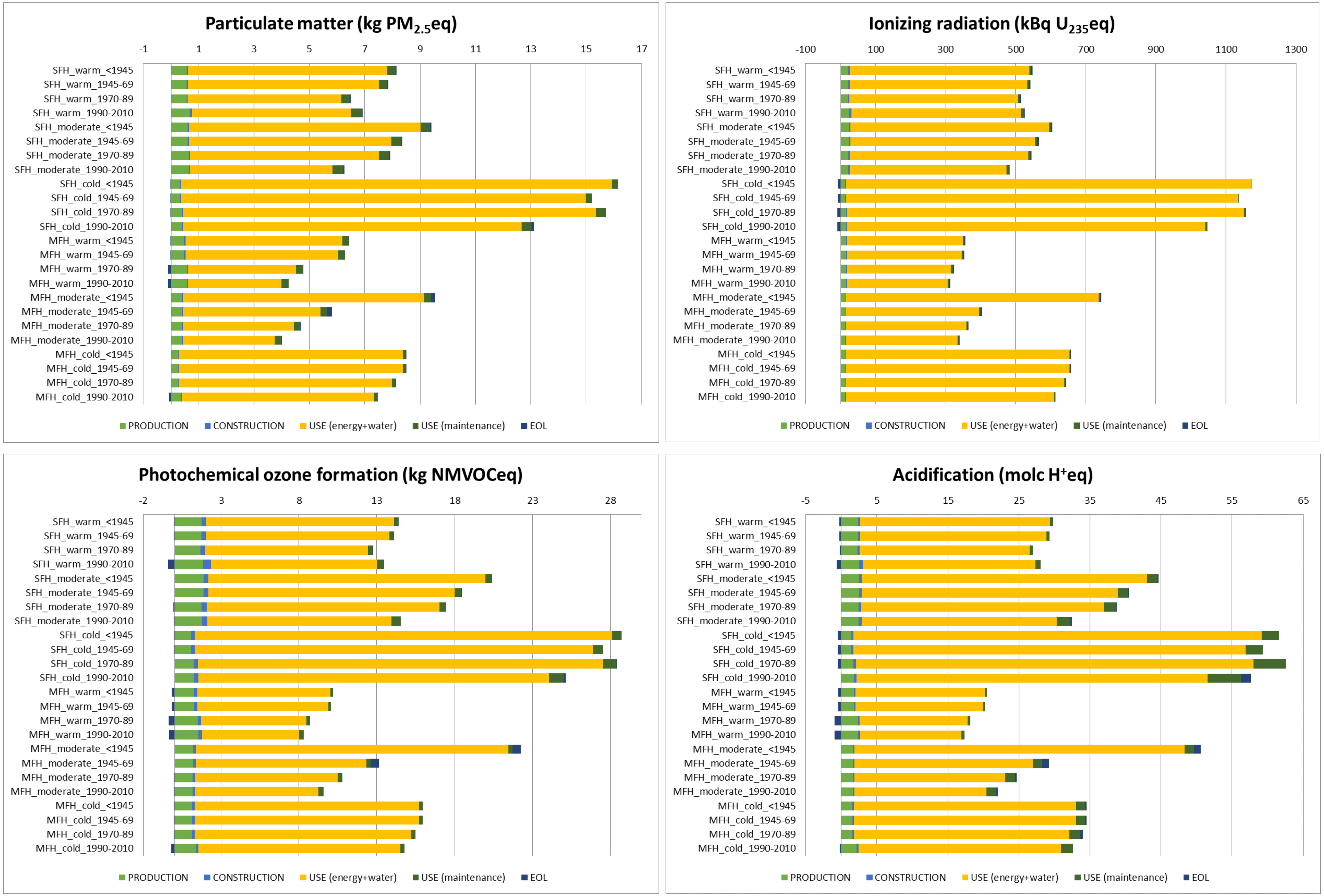


Figure 15. Impact per dwelling type, with contribution by life cycle phases (continuation)

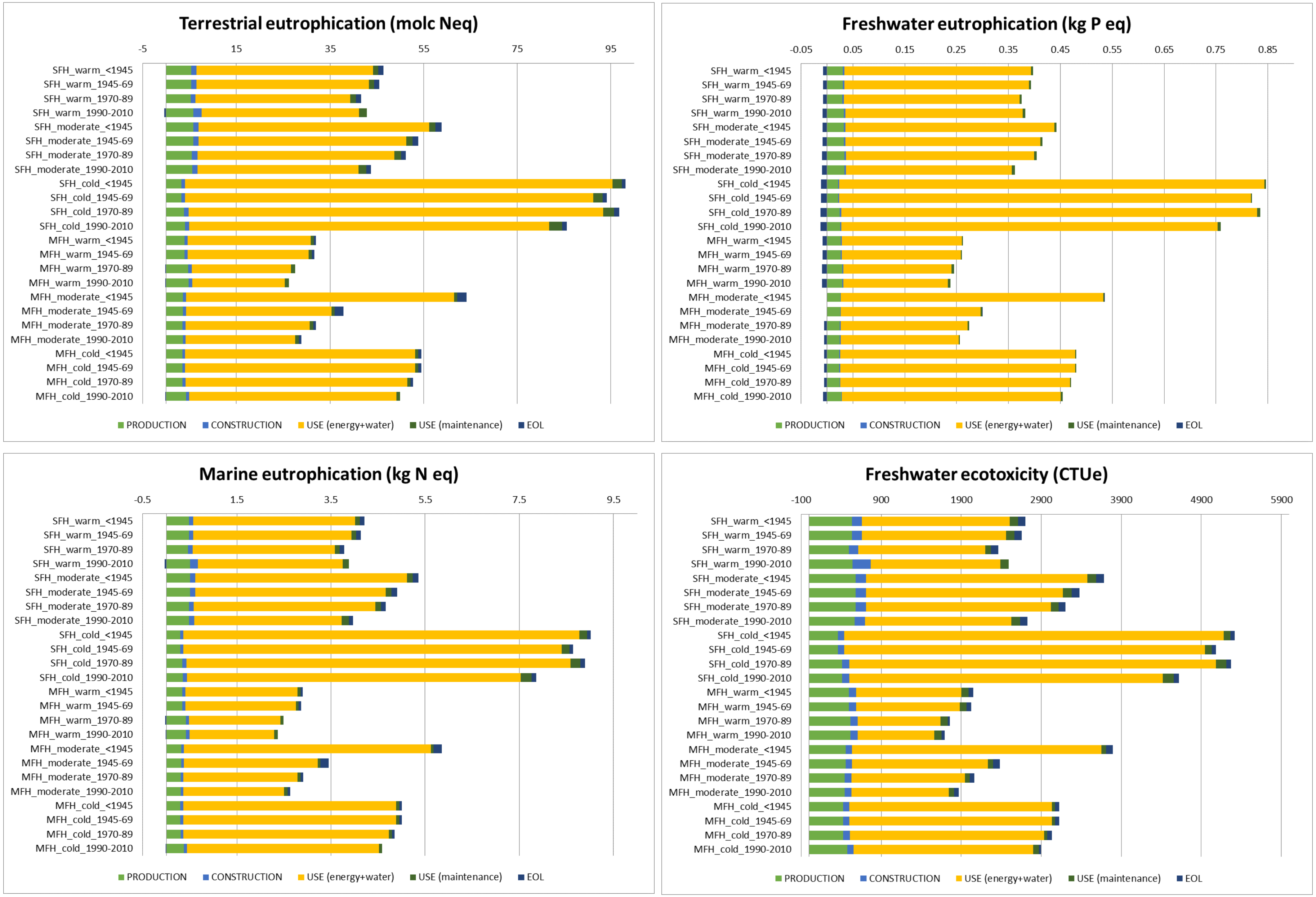
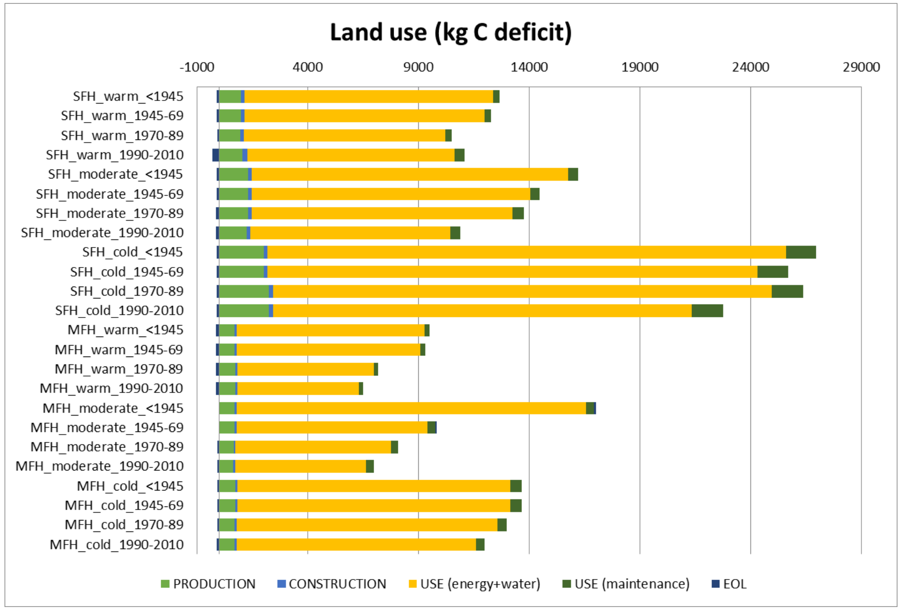
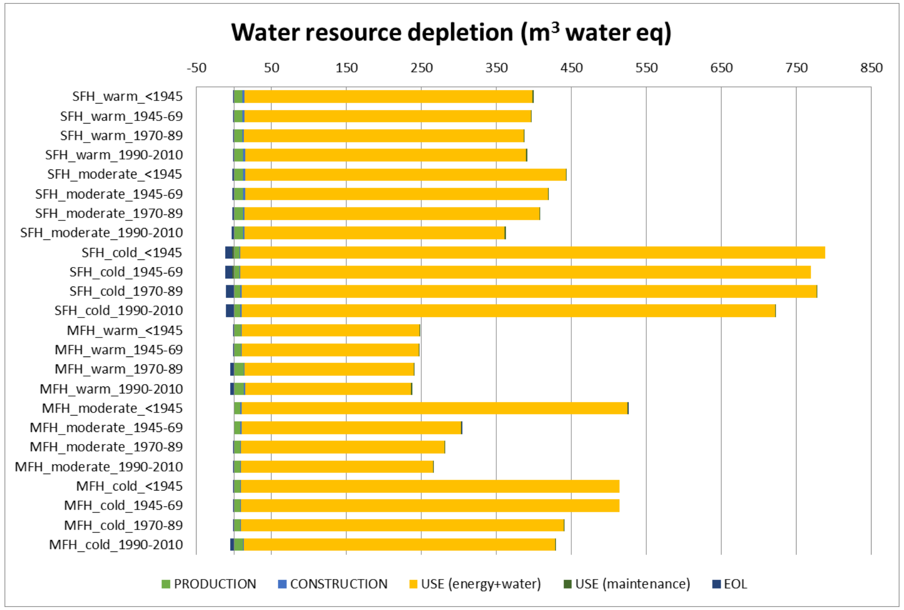
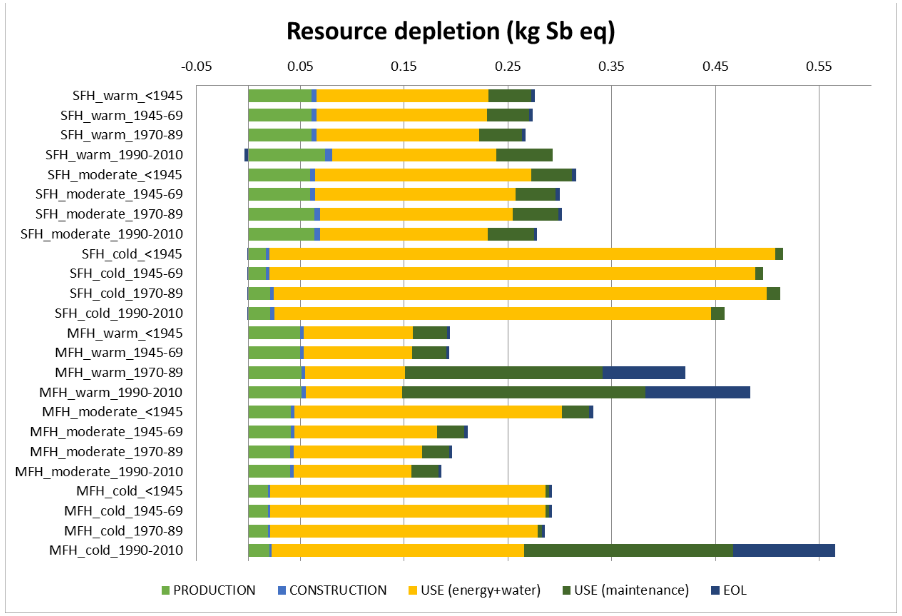


Figure 15. Impact per dwelling type, with contribution by life cycle phases (continuation)







5.4 Relevance of impact categories

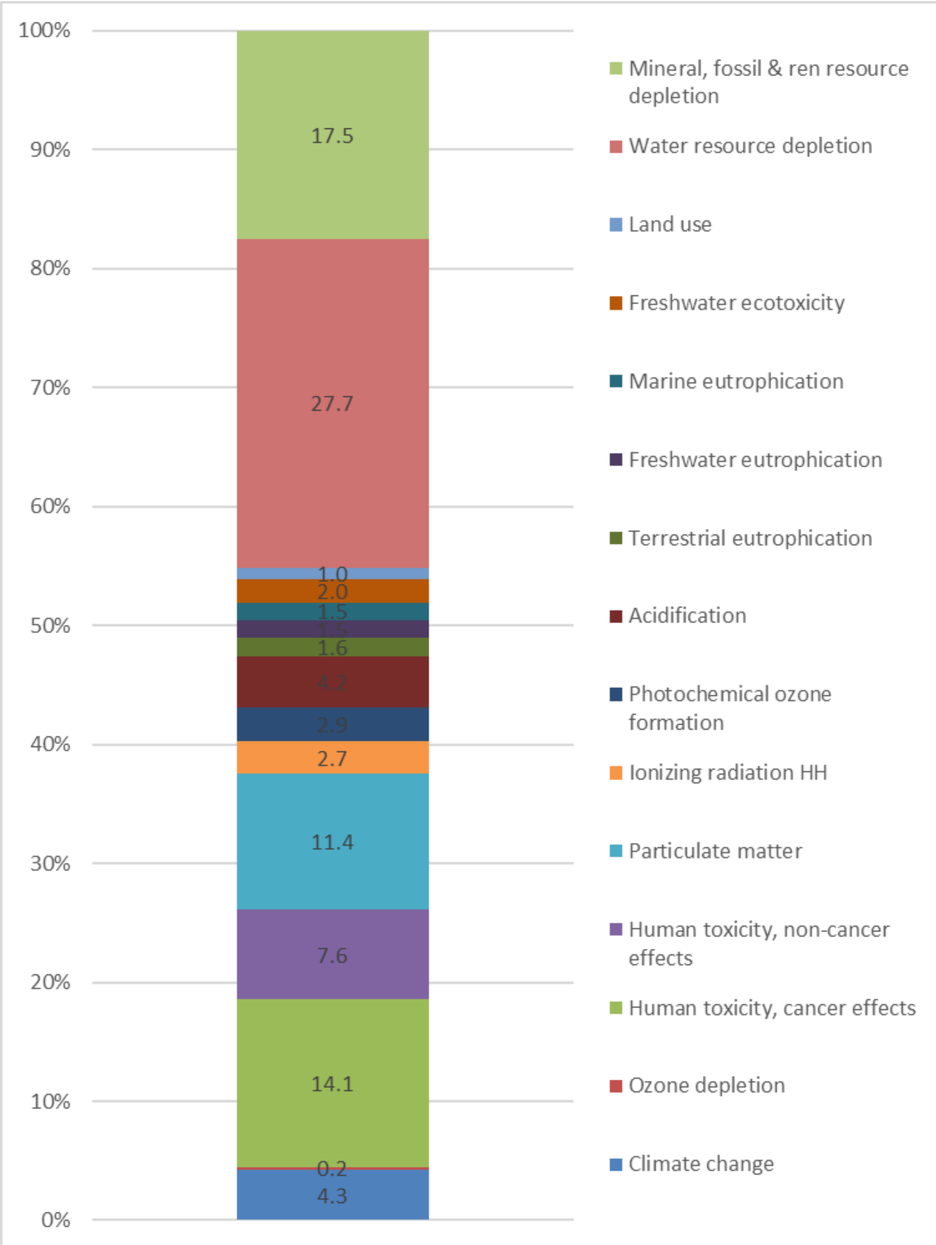
The results have been normalized referring to the average impact per person in EU-27 (Benini et al, 2014) and applying equal weighting. The results are shown in Table 27 and Figure 16.

Table 27. Normalized results per life cycle stage (ILCD EU-27). A colour scale is applied, from red (highest contributor) to green (lowest contributor), for each life cycle phase

Impact category	Production	Constr.	Use	Mainten.	EoL	TOTAL
Climate change	2.25E-02	2.33E-03	2.60E-01	3.55E-03	-3.71E-03	2.85E-01
Ozone depletion	5.97E-04	1.25E-04	1.44E-02	2.05E-04	1.16E-04	1.54E-02
Human toxicity, cancer	3.76E-01	1.81E-02	5.23E-01	2.62E-02	-1.26E-03	9.42E-01
Human toxicity, non-cancer	6.38E-02	6.68E-03	4.24E-01	1.38E-02	-2.07E-03	5.07E-01
Particulate matter	5.66E-02	5.03E-03	6.66E-01	3.21E-02	3.77E-03	7.63E-01
Ionizing radiation HH	6.69E-03	1.35E-03	1.70E-01	1.85E-03	1.08E-03	1.81E-01
Photochemical ozone formation	1.96E-02	3.36E-03	1.65E-01	4.59E-03	2.26E-04	1.93E-01
Acidification	1.83E-02	2.71E-03	2.51E-01	1.10E-02	8.58E-04	2.84E-01
Terrestrial eutrophication	1.10E-02	2.13E-03	8.70E-02	2.58E-03	2.15E-03	1.05E-01
Freshwater eutrophication	8.12E-03	7.06E-04	9.23E-02	1.04E-03	-1.87E-03	1.00E-01
Marine eutrophication	1.01E-02	2.01E-03	8.28E-02	2.33E-03	2.12E-03	9.93E-02
Freshwater ecotoxicity	2.43E-02	5.04E-03	9.35E-02	4.14E-03	3.49E-03	1.30E-01
Land use	5.42E-03	7.41E-04	5.70E-02	2.15E-03	-5.09E-04	6.48E-02
Water resource depletion	5.53E-02	8.97E-03	1.79E+00	6.29E-03	-8.47E-03	1.85E+00
Resource depletion	2.11E-01	1.71E-02	6.86E-01	2.09E-01	4.68E-02	1.17E+00

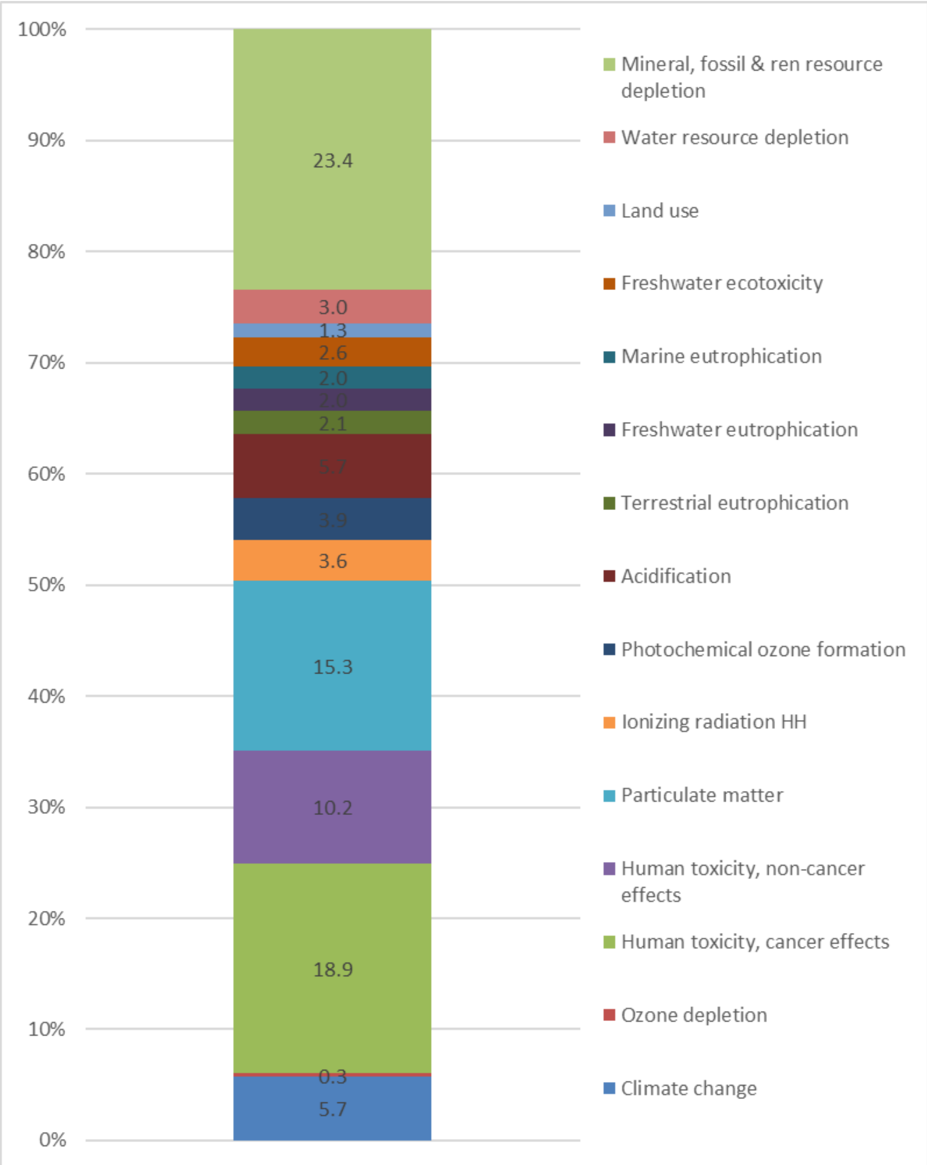
Figure 16 shows, among the other results, the high relevance of Water resource depletion (27.7%) compared to the other impact categories. This finding required a further analysis. The normalized results showed that that impact is mainly related to the use phase of and in particular to the use of water for cooling in the production of electricity. The water consumption includes different natural origins, well in ground, river, lakes, but also water used for cooling plants, whereas water in turbine for the hydroelectric power generation is excluded.

Figure 16. Results of normalisation of BoP housing for an average EU citizen, obtained using ILCD 1.08 for characterization, EC-JRC (2010) for normalisation on EU27 geographical scale and assuming equal weighting among impact categories.



Assuming that the water used for cooling being excluded from the inventory, i.e. the cooling water is assumed to be put again in the environment after purification, the total water consumption would be much lower. Figure 17 shows that in this second case the relevance of Water resource depletion drops down to 3% of the normalized impact of BoP housing for an average EU citizen.

Figure 17. Results of normalisation with ILCD EU-27 of BoP housing for an average EU citizen. In this graph, cooling (e.g. cooling of power plants) is excluded from the calculation of the impact of the BoP on "water resource depletion"



6 Main hotspots identified

In conclusion, the environmental impact assessment of the BoP housing baseline scenario provided insight in which life cycle stage and which technological solutions contribute to the highest share in impacts.

Based on the normalized results, the following conclusions were drawn:

- After excluding the water used for cooling, water resource depletion is mainly caused by the **use of tap water during the use phase** and electricity for pumping water into the house;
- The contribution of resource depletion is responsible for 19% of the impact and this is mainly due to the **production of the ceramic tiles and the electricity from the use phase**; when energy carriers are assessed separately from other abiotic resources, their relevance is the highest one after human toxicity, cancer effects.
- Human toxicity, cancer effects is responsible for 18.9% of the impacts, mainly due to: the **production of reinforcing steel, the distribution network of electricity, district heating by incineration of municipal solid waste, the wastewater treatment and to natural gas, oil, coal and wood (heating)** that have a similar contribution. As mentioned before, this contribution should be further checked when more robust impact assessment methods for toxicity would be available.

Regarding the contribution of the life cycle phases of the European building stock, as modelled in the BoP Housing, it can be concluded that:

- the **use phase** is the most dominant life cycle stage for the different impact categories, mainly due to energy and water consumption.
    - **Electricity production and the related distribution network** are the most relevant contributors to the impact of the use phase for what concerns water resource depletion, ionizing radiation, photochemical ozone formation, freshwater eutrophication, acidification, freshwater ecotoxicity and climate change.
    - **Space heating** contributes as well to a large number of impact categories, in particular, **wood heating and district heating** contribute to freshwater eutrophication, **natural gas** to acidification, photochemical ozone formation, climate change and freshwater ecotoxicity, **light fuel oil** to particulate matter, terrestrial eutrophication and marine eutrophication.
    - **Tap water consumption** contributes to water resource depletion. Its contribution varies depending on the impact assessment method used (i.e. accounting or not for cooling water).
- the **production phase** dominates only in one indicator: human toxicity, cancer effects due to the impact of reinforcing steel;
- the **production phase** contributes significantly to
    - Freshwater ecotoxicity due to the production of reinforcing steel, ceramic tiles, concrete and bricks;
    - resource depletion, due to the production of ceramic tiles, steel , concrete and clay bricks;
    - human toxicity, non-cancer effects due to the production of reinforcing steel and concrete;
- the **maintenance/replacement phase** significantly contributes to resource depletion due to the production of finishes (ceramic tiles) and recycling of aluminium;
- the **Construction phase** never exceeds 4.5% in all impact categories;
- the **End-of-Life phase** gives rise to small burdens.

Finally, the contribution of the dwelling typologies is mostly proportional to the number of European citizens living in that type of dwelling. However, the climatic zones play a role, especially because cold climate requires higher input of resources for space heating, which is one of the hotspots of the housing sector, as discussed before.

7 Ecoinnovations relevant for the BoP housing

The construction sector has been identified as one of the key areas for the European policies initiatives, as the Europe 2020 strategy and the Resource-efficient Europe flagship initiative, because of its great potential for reducing environmental impacts. Over the years, many policy actions dedicated to the construction sector have been developed, in particular focusing on the reduction of the energy consumption in the use phase of buildings (which represents 41% of final energy consumption at EU level in 2010). The Energy Performance of Buildings Directive (2010), and the Energy Efficiency Directive (2012) are the EU's main legislations referring to the reduction of energy consumption of buildings.

At the same time Construction and Demolition Waste (CDW) is one of the heaviest and most voluminous waste streams generated in the EU, since it accounts for 35% of the total waste in EU in 2010, with 860 million of ton (Eurostat, 2017). CDW generated in the BoP Housing is 516 million ton/year. This amount includes waste from construction, maintenance and end-of-life stage of buildings as modelled in the BoP and represents the 60% of the CDW quantified by Eurostat.

The European legislation is moving its focus from energy efficiency to resource efficiency. In July 2014, the European Commission adopted the Communication on Resource Efficiency Opportunities in the Building Sector (EC, 2014a). This Communication identified the need for a common European approach to assess the environmental performance of buildings throughout their lifecycle, taking into account the use of resources such as energy, materials and water. A study to develop a common EU framework of indicators for the assessment of the environmental performance of buildings is being taken forward during 2015-2017 by Environment and Growth Directorates General (DG ENV and DG GROW), with the technical support of JRC (Herczeg et al., 2014 and EC-JRC, 2015).

This section illustrates the main findings of a literature review on eco-innovation for the area of consumption covered by the BoP housing. The reviewed documents are scientific papers and technical reports about eco-innovation in the housing sector. To complement the results of the literature review, also some studies commissioned by DG ENV were considered for the identification of the areas of improvement (and the selection of the scenarios):

"Assessment of Scenarios and Options towards a Resource Efficient Europe. An Analysis for the European Built Environment" (EC, 2014b). This study aims to identify inefficient use of resources in the built environment at meso- and macro level and then quantitatively assess potentials and socio-economic and environmental effects of efficiency improvements up to 2030. The core methodology is a hybrid modelling approach: identifying improvement options, their costs and improvement potential at micro/meso level, and feeding them into a macro-model (EXIOMOD) to assess economy-wide impacts of improvement scenarios.

"Resource efficiency in the building sector" (Herczeg et al., 2014). This report supported the preparation of the European Commission's Communication on Resource Efficiency Opportunities in the Building Sector (COM(2014) 445) (EC, 2014a).

"Identifying macro-objectives for the life cycle environmental performance and resource efficiency of EU buildings" (EC-JRC, 2015). In EC-JRC, 2015 the findings of a selection of technical studies that have analysed buildings and major construction materials from both a 'top down' sectorial and 'bottom up' building typology perspective are reviewed. The studies have been selected based on their quality, scope and representativeness. Based on these findings, environmental and resource efficiency 'hot spots' for the most significant environmental impacts of residential and commercial buildings, as well as indications of practical areas of focus for improvement, are then identified.

The ongoing study on costs and benefits of working towards environmental macro-objectives in the building sector (Ecorys, 2017).

Results are summarized as a list of areas of improvement and the related information needed to drive the further selection (Table 28). Possible synergies with the ongoing work on macro-indicators are discussed below, in a dedicated paragraph.

Table 28. Results of literature review on eco-innovation for the building sector and link with possible scenarios

Areas of eco-innovation and related keywords	Specific options leading to scenarios at component level	Eco-innovation	References
Construction materials (Material efficiency)	Increase material durability	Paints (change of the composition) and flooring (warm mix asphalt)	EC, 2014b; Ardente et al., 2014
		Implementation of preventative maintenance strategies to maintain/prolong the service life of building materials, including provision of guidance/training for operators, owners and/or occupiers on maintenance requirements	
	Use of recycled materials	Thermal insulation (recycled PET fiber, recycled cotton and denim, glass foam, textile fibers, wool, paper), recycled aggregate (RA) for new concrete; Wastes-create bricks	EC, 2014b; Intini et al., 2011; Ingrao, 2014; Asdrubali et al., 2015; Ricciardi et al. 2014; Behera et al. 2104; Raut 2011; COM/2014/0445
	Increase the use of product with low impact /Decrease the use of product with high impact	Lightweight timber instead of heavyweight masonry	EC, 2014b; Monahan et al 2011
	Bio-based materials	Thermal insulation panel (paper wool and flax, hemp-based materials, kenaf-fibres, reeds, bagasse, cattail, corn cob, cotton, date palm, durian, rice, sunflower)	EC, 2014b, Schmidt et al., 2004, Zampori et al. 2013; Ardente et al, 2008; Batouli et al., 2014; Asdrubali et al., 2015
	Reduce the presence of hazardous substances	Asbestos, VOCs emission (formaldehyde from wallpaper assembly, plywood flooring assembly, and particle board)	EC, 2014b; EC-JRC, 2015; Frank, 2014; Chen, 2106
Energy and water savings (Resource efficiency)	Efficient windows	Multilayer glazing, new spacer solutions, vacuum glazing, low emissivity (low-e) coating, solar cell glazing, aerogels, glazing cavity gas fills, frame with composite materials, highly insulated windows frames, interlayer with phase change material (PCM) included, transparent conductors and electrochromic windows, gasochromic devices, liquid crystal devices, electrophoretic or suspended-particle devices, automatic solar control e.g. exterior solar shades and blinds, window attachments (e.g. cellular shades, low-e films)	EC, 2014b; IEA, 2013; Jelle et al., 2012; Gustavsen et al., 2007; Baetens et al., 2010; Granqvist et al., 2016; EC-JRC (2015)
	Energy efficient lighting	Installation of energy efficient lighting (e.g. LEDs) in new residential buildings	Ecorys, 2017

Areas of eco-innovation and related keywords	**Specific options leading to scenarios at component level**	**Eco-innovation**	**References**
	External wall insulation system (or EWIS)	Structural insulated panels (SIPs), integration of PCMs for thermal storage, ventilated claddings, ventilated double skin façade. Insulation materials and systems; e.g. mineral wool, expanded polystyrene, extruded polystyrene, polyurethane, vacuum insulation panels, gas insulation panels, aerogels, vacuum insulation materials, nano insulation materials and dynamic insulation materials.	EC, 2014b; IEA, 2013; Medina et al., 2008; De Gracia, 2015; Theodosiou et al., 2015; Anđelković, 2015; EC-JRC (2015)
	Green roof/ Painting roofs with solar-reflective white coating	Reflecting surfaces/cool roof	EC, 2014b; IEA, 2014; Niachou et al. 2001; Ascione et al 2013; Silva et al, 2016; Jaffal et al. 2012
	Greenhouses	Passive solar heating strategies	EC, 2014b; Asdrubali et al. 2012; Fernandez-Gonzalez, 2007; Bataineh et al. 2011
	Rainwater Storage	Active water source replacement, rainwater harvesting	EC, 2014b; Upshaw et al. 2016; Okoye et al., 2015
	Heating and cooling	Combined heat and power, Heat pumps, air sealing with mechanical ventilation; Evaporative cooling systems. Use of efficient heat pumps supplied by low carbon/decarbonised grid electricity for hot water, heating and/or cooling in new and existing office and residential buildings.	IEA, 2011; IEA, 2013; Guillén-Lambea et al., 2016; Cuce et al., 2016, Ecorys, 2017
		Verification of build/installation quality for new and refurbished buildings through commissioning of systems, thermographic survey, and airtightness testing	Ecorys, 2017
		Implementation of operational performance measures for new and existing residential buildings to include, where appropriate, fine-tuning and seasonal and continuous commissioning of Heating, Ventilation and Air Conditioning (HVAC) systems, post occupancy evaluation, guidance/training for operators and/or occupants on correct operation of systems and controls, implementation of preventative maintenance strategy, and regular energy audits	Ecorys, 2017
	Taps and shower	Water efficiency. Upper quartile performing European Water Label or WELL Water Efficiency Label specification for (where applicable)	García-Montoya et al.; 2016; EC-JRC (2013), Ecorys, 2017

Areas of eco-innovation and related keywords	Specific options leading to scenarios at component level	Eco-innovation	References
		taps, showers, baths, urinals and siphon WCs in new and existing buildings	
CDW (Circular Economy)	Design for deconstruction	Tactile fixing of flooring; components with embedded disassemble-able connections; prefabrication; Industrial, Flexible and Demountable (IFD) Building System	EC, 2014b; Akbarnezhad et al., 2014; Van Gassel et al., 2014; Akinade et al., 2015
		Design of buildings for ease of segregation of materials at refurbishment and end-of-life stages (i.e. design for disassembly) to allow displacement of primary materials with secondary materials through increased reuse and recycling, e.g. document materials and methods for deconstruction, minimise chemical connections and/or use bolted/screwed connections, simplicity of structure and form, etc	Ecorys, 2017
	Re-usability /recyclability /recoverability	Strategy to evaluate and support re-usability /recyclability /recoverability; Increase in recycling share of concrete, PVC, glass, carpet, plaster board… Reduce CDW (non-metallic waste, metal and wood based materials)	EC, 2014b; EC, 2014a; Maccarini Vefago et al 2013; Saghafi et al. 2011, Gao et al. 2001, Thormark, 2006; Napolano Let al., 2016
	CDW management	Development of guidelines for waste minimization	EC, 2014b; Tam, 2008; Chau et al., 2016; EC-JRC (2014b)
	Off-site prefabrication	Modular prefabricated steel, timber and conventional concrete buildings	EC, 2014b; Mao et al., 2013; Tam et al., 2007; Lu et al., 2013, Aye et al., 2012
Consumer behaviour	Improved behaviours	Role of occupants' behaviour and their energy/water/environmental attitudes on the burdens reduction	EC, 2014b; Pisello et al., 2014; Peschiera et al.,2010; Beal et al., 2013
		Provision of guidance/training for operators and occupants on correct operation of water systems and maintenance requirements, and implementation of preventative maintenance strategy for new and existing buildings	Ecorys, 2017
	Energy efficiency awareness	information campaigns, marketing campaigns, labelling, subsidies for energy efficiency and low-emission heating systems	EC, 2014b; Müller, 2014, Kikuchi-Uehara et al. 2016; Labanca et al., 2015
	Smart metering	Installation of smart water metering and real-time displays on water use. Installation of building leak detection system for new and existing apartment blocks	Ecorys, 2017

Areas of eco-innovation and related keywords	Specific options leading to scenarios at component level	Eco-innovation	References
Renewable energy	BIPV	semi-transparent thin-film PV (STPV), ventilated photovoltaic double-skin facade (PV-DSF), BIPV window	EC, 2014b; Peng et al., 2016; Yoon et al., 2013; Han et al., 2013
	Solar panel + efficient heating systems (space heater)	Active solar thermal; solar tracking systems solutions; integrated solution with absorber and storage systems; façade solar collector	EC, 2014b; IEA, 2011; Colangelo et al., 2016; Matuska et al. 2006
	Ground Source Heat Pumps		EC, 2014b; Bayer et al. 2012; Omer et al. 2008
	District heating	Joint use of cogeneration power plants with district heating networks	EC, 2014b; Colmenar-Santos et al. 2006; Colmenar -Santos et al. 2015; Directive 2012/27/EU
	Home batteries	Battery Energy Storage (BES) in off-grid systems and mini-grid systems	EC, 2014b; Directive 2006/66/EC; Commission Regulation (EU) No 493/2012 (EC, 2006); Speidel et al. 2016

7.1 Measures identified in "Identifying macro-objectives for the life cycle environmental performance and resource efficiency of EU buildings".

In the working paper "Identifying macro-objectives for the life cycle environmental performance and resource efficiency of EU Buildings" macro-environmental 'hot spots' along the life cycle of buildings have been identified based on a literature review of relevant technical studies. Based on this literature review the following areas of attention have been identified to have the greatest potential to reduce environmental impacts (EC-JRC 2015, p. 26-27) in Europe (based on a top-down analysis of the EU building stock LCA impacts):

- The production of products that are more resource efficient, based on evidence from EPDs for their embodied energy, abiotic resource depletion and water use. Examples cited include a shift from concrete/masonry to timber materials, hollow pre-cast concrete, concrete formwork with void formers and hollow blockwork;
- A reduction in the size of new housing and offices (i.e. a more efficient use of space per occupant). This is linked to an increased density of the built environment;
- A reduction in the amount of waste from construction, including upstream waste arising from extraction and processing;
- The recycling of large flows of construction and demolition waste, with a focus on closed loop recycling instead of down-cycling from the building to the road construction sector.

The same study moreover identified as well priority scenarios for long-term improvements (EC-JRC 2015, p. 27):

- *Design for repair, disassembly and recycling (deconstruction). This is described as design to re-use modules or whole elements of constructions;*
- *Ensuring a high adaptability, flexibility and functionality of design in order to extend the service life of buildings.*

The above literature review of top-down studies was accompanied by a review of bottom up LCA analyses of several building typologies. The key findings from these studies were the following (EC-JRC 2015, p. 30-31)

- *The use phase of buildings is the most important because of primary energy use for, in particular, space heating, hot water and lighting;*
- *For new buildings the construction phase becomes proportionally more important, with exterior walls, basements and floors/ceilings the most significant modelled impacts;*
- *The effect of building form and geometry is reflected in a general trend for higher energy demand for larger, single family houses.*

The most significant options for improvement identified were further design improvements to reduce the energy use of new buildings, the substitution of concrete and bricks by wood in new construction, and renovation measures to improve roofs, façades and air tightness. Moreover, the resource efficiency potential of more compact dwelling forms was also highlighted. Furthermore, a growth in household appliances and electrical equipment ownership across the EU was identified, which has led to an increase in this portion of the use phase energy use. An important measure is the use of low energy appliances and fittings. Finally, a review was made of LCA studies for the most common building materials, namely mineral-based, metallic and wood, and with a focus on building structures. The following findings can be summarised:

- Improvement potential for non-metallic minerals: mainly related to limestone, clay, gravel and sand used to produce amongst others concrete, bricks and tiles. Concrete has been identified as very significant and its impact can be reduced by:
  - substitution of cement clinker/Portland clinker by fly ash, blast furnace slag, copper slag or alternative raw materials (e.g. magnesium hydrates);
  - optimized use of concrete: use of superplasticisers, light weight and high strength concrete.
- Improvement potential for metals: steel has been identified as predominant material associated with significant environmental impacts across the construction sector. Improvement potential identified:
  - light weight design and longer life spans;
  - re-use of steel and aluminium (scrap constrained though).
- improvement potential for wood:
  - to be sourced from legal and sustainable sources (i.e. FSC and PEFC labels);
  - high quality structural timber to be replaced by lower grade and waste wood materials;
- improvement potential from material recovery and cycling:
  - recycling concrete to a quality sufficient for replacement of coarse natural aggregates in structural concrete instead of landfilling/down-cycling;
  - use of recycled construction and demolition waste;
  - reduction in the amount of waste from construction by selective deconstruction enabling the reuse of wooden, masonry and metal building elements.

Table 29 shows the list of macro-objectives proposed for the identification of indicators. It also shows a cross-check of macro-objective coverage by LC-IND project BoP housing and the LCA methodology, including specific impact categories covered. In particular, for the macro-objective that have been addressed in environmental assessment of the BoP housing, the table shows the link between the indicator and the macro-objective. The two last columns show the main drivers of the impact for each macro-objective and the available EU policy instruments.

Table 29. Coverage of macro-objectives (EC-JRC, 2015) by BoP housing in LC-IND project

		List of macro-objectives proposed by IPTS for the identification of indicators	***Addressed by LC-IND project***	***Indicators (impact categories) used in BoP housing to deal with the macro-objectives***	***Hotspots/ Drivers***	***Policy instruments***
Life cycle environmental performance macro-objectives	**Building level macro-objective**	**Low carbon building life cycle** Minimise the total GHG emissions along a buildings lifecycle, with a focus on building operational energy use emissions and embodied emissions.	✓	- **Climate change** - Acidification - Photochemical ozone formation - Human toxicity - Particulate matter - Ionising radiation - Freshwater eutrophication - Terrestrial eutrophication - Marine eutrophication	- Energy use to extract, process and manufacture products - Production of cement - Energy use during the occupation of buildings with majority of emissions from aging building stock - Private transport associated with building occupants	- Energy Efficiency Directive 2012/27/EU - Energy Performance of Buildings Directive 2010/31/EC - Renewable Energy Directive 2009/28/EC - Clean Air policy package (2013) - Industrial Emissions Directive 2010/75/EU - Clean Air Directive 2008/50/EC - National Emissions Ceiling Directive 2001/81/EC
		Resource efficient material flows Optimise building design, engineering and form in order to support lean and circular flows, extend long-term material utility and reduce significant environmental impacts.	✓	- **Resource depletion** - Human toxicity - Particulate matter	- Demand for construction materials manufactured from fossil fuels, metals, non-metallic minerals and timber - Construction and demolition waste arising that are sent to landfill or down cycled	- Landfill Directive 1999/31/EC - Waste Framework Directive 2008/98/EC - Industrial Emissions Directive 2010/75/EU - Construction Products Regulation (EU) No 305/2011
		Efficient use of water resources Make efficient use of water resources, particularly in areas of identified long-term or projected water stress.	✓	- **Water resource depletion** - Freshwater ecotoxicity - Freshwater eutrophication	- Material extraction and product manufacturing - Thermal pollution from electricity generation - Wastewater treatment and discharge - Urban run-off from hard surfaces - Water used by building occupiers	- Water Framework Directive 2000/60/EC; - Urban Wastewater Directive 91/271/EEC - Industrial Emissions Directive 2010/75/EU

	List of macro-objectives proposed by IPTS for the identification of indicators	Addressed by LC-IND project	Indicators (impact categories) used in BoP housing to deal with the macro-objectives	Hotspots/ Drivers	Policy instruments
Stock and neighbourhood level macro-objective	**Urban pressures on land and habitats** Efficient use of land in order to minimise urban sprawl, habitat fragmentation and the loss of fertile soils.	✓	- **Land use**	- Increased urban sprawl and the use of greenfield development sites with agricultural or biodiversity value - Increased use of material obtained from biotic sources	- Timber Regulation (EC) No 995/2010 - Thematic strategy for soil protection (2006) - Thematic strategy for the urban environment (2005)
	Greenhouse gas emissions from building occupier's travel patterns Minimise GHG emissions and urban air pollution associated with the travel patterns and transport modes used during the occupation of buildings and neighborhoods.	**-** *(BoP mobility)*	- **Climate change** - Photochemical ozone formation - Human toxicity - Particulate matter	- Private and public transport journeys and urban congestion - Potential for longer distance transport of high mass/large flow construction materials	- Clean Air policy package (2013) - National Emissions Ceiling Directive 2001/81/EC - Clean Air Directive 2008/50/EC
Building level macro-objective	**Healthy and comfortable spaces** Design, construction and renovation of buildings that protect human health by minimising the potential for occupier and worker exposure to health risks.	**+** *(Occupant exposure to indoor pollutant emissions not addressed)*	- Photochemical ozone formation - Human toxicity - Particulate matter	- Chemicals used in the extraction and production of building materials - Hazardous construction and demolition waste sent to landfill or down cycled - Occupant exposure to hazardous materials, chemicals and emissions	- Construction Products Regulation (EU) No 305/2011 - Industrial Emissions Directive 2010/75/EU - Waste Framework Directive 2008/98/EC - CLP Regulation (EC) No 1272/2008 - REACH Regulation (EC) No 1907/2006 - Safety and health of workers Directive 89/391/EEC - Clean Air policy package (2013) - Clean Air Directive 2008/50/EC - National Emissions Ceiling Directive 2001/81/EC - Montreal Protocol (1987)

		List of macro-objectives proposed by IPTS for the identification of indicators	Addressed by LC-IND project	Indicators (impact categories) used in BoP housing to deal with the macro-objectives	Hotspots/ Drivers	Policy instruments
						- Water Framework Directive 2000/60/EC - Urban Wastewater Directive 91/271/EEC - Industrial Emissions Directive 2010/75/EU
Quality performance and value creation" macro-objectives		**Resillience to climate change** The future proofing of building thermal performance to projected changes in the urban microclimate, in order to protect occupier health and comfort.	**-**		- Human induced climate change resulting from fossil fuel use and deforestation - Damage associated with increased GHG emissions from cooling - Changes in habitats and biodiversity - Increased extent of areas affected by flood events	- EU strategy on adaptation to climate change (2013) - Biodiversity strategy to 2020 (2011)
		Optimised life cycle cost and value Optimisation of the life cycle cost and value of buildings, inclusive of acquisition, operation, maintenance and disposal.	**-**		- Higher initial capital costs may be required to achieve lower life-cycle running costs	

Key:

✓ Fully addressed

\+ Partially addressed

\- Not currently addressed

8 Scenarios of eco-innovation for the area of consumption "Housing"

For the selection of the scenarios developed for the BoP, out of the long list coming from the literature review, priority was given to:

1. scenarios that were expected to address the most relevant hotspots identified in the baseline
2. scenarios able to simulate the effect of European policies, especially if in relation to the hotspots of the consumption sector as emerged from the assessment of the BoP baseline (e.g. scenarios related to macro-objectives for the life cycle environmental performance and resource efficiency of EU buildings, discussed before)
3. scenarios related to innovations that are at present a niche in the market but are foreseen to become relevant for one of the consumption sector, such as the insulation of walls with bio-based and recycled materials.

In addition, a dedicated study about dynamic energy simulations applied to the BoP Housing was developed (Baldinelli, 2016). The study analysed several measures to reduce the energy use of buildings in the EU by running whole building energy performance simulations in unsteady-state conditions, starting from the dwelling models developed in the BoP Housing baseline. The study focused on the effect on the energy consumption of the following interventions:

- indoor set-point change;
- increase of the building envelope insulation (both opaque and transparent surfaces);
- installation of solar panels for Domestic Hot Water (DHW) production.

Each of the interventions was simulated for a single-family and multi-family house, for three different construction periods (i.e. before 1970, between 1970-1989, between 1990-2010) and three climate zones in the EU.

Based on the results, the following measures were identified as having a high improvement potential for the BoP housing baseline scenario regarding energy use (heating and domestic hot water), in order of priority:

- indoor set point temperature has a high effect on the energy use and hence should be lowered or monitored/managed in a better way;
- increase in wall insulation and window thermal resistance;
- use of solar panels, especially in warmer climates and recent constructions.

The results of the study were used also as in input for changing parameters of energy use in the LCI models of the scenarios selected, as described in the following paragraphs and in Annex 4.

8.1 List of the scenarios tested in the BoP "housing"

Table 30 shows the result of the selection of the scenarios to be built and implemented in the model of the BoP housing, and finally evaluated against the baseline. The third column highlights the link to macro-objectives (EC-JRC 2015) described in the previous section.

Table 30. List of scenarios selected for the BoP Housing.

Area of intervention	Link to macro-objectives (EC-JRC, 2015)	Scenario analysed	Description
Construction materials (Material efficiency)	– Resource efficient material flows – Urban pressures on land and habitats – Healthy and comfortable spaces	External walls insulation – biobased and recycled materials	External wall insulation system with bio-based materials: auxiliary insulation layer that halves the U-value of the walls. Materials used: cellulose fibres (cold climate, cellulose blown in the timber frame structure), wood board (warm and moderate climate);
		Timber frame	Using a timber frame when building new houses
		Wood flooring	Ceramic tiles replaced with wood flooring
Energy and water savings (Resource efficiency)	– Low carbon building life cycle – Efficient use of water resources	External walls insulation – rock wool	External wall insulation system with rock wool: Auxiliary insulation layer that halves the U-value of the walls
		Smart windows	Replacement of existing windows with more efficient ones (smart windows)
Consumer behaviour	– Healthy and comfortable spaces – Low carbon building life cycle	Night attenuation	Night attenuation of the heating system
Renewable energy	– Low carbon building life cycle	Solar collectors	Solar panels for heating domestic hot water
		PV system	Installing a PV system on the roof for auto-production of electricity

Details of the LCI models for the scenarios selected are described in Annex 4.

8.2 Scenario 1 – Night attenuation

Description and aim:

The aim of this scenario is to assess the potential environmental benefits arising from lowering the average indoor air temperature through night attenuation of the heating system. By installing a room thermostat and outdoor air sensor, the heating system can be controlled in a more intelligent way and, on average, the indoor air temperature will be lower.

Area of intervention:

- Hotspot addressed: the energy consumption during the use phase for space heating.
- Whole basket
- Life cycle stage: production phase and use phase (energy consumption)

Policy relevance: Energy and resource efficiency in the building sector

Rationale for building the scenario:

An improved control system of the heating system in housing can reduce the energy consumption for heating in residential buildings to an important extent. This benefit is a consequence of a reduction in average daily indoor air temperature due to an improved control system of the indoor air temperature. The scenario on night attenuation investigates the potential impact reduction in terms of reduced heating demand by installing a system to allow for night attenuation of the heating system. This implies that the central heating system of the baseline scenario will need to be extended with an additional room thermostat (for the hall and bedrooms), a manifold, ducts for the heat distribution in the additional circuit and an additional circulation pump.

Parameters modified in the model:

- Production phase: room thermostat, manifold, heat distribution pipes, electricity cable to connect room thermostat with the boiler
- Construction phase: no changes except for similar assumptions as in baseline scenario (4% waste, transport)
- Use phase: calculated reduction in heating demand (from dynamic energy simulation from Baldinelli 2016) is deducted from the baseline heating demand. The calculation of the energy demand takes into account the climatic zone, building type (SFH vs MFH) and construction period.
- EoL phase: room thermostat, manifold, heat distribution pipes and electricity cables are added to the inventory.

The study of Baldinelli (2016) identified the potential reduction in heating demand of a reference single-family and multi-family house when night attenuation is assumed. For the baseline scenario, Baldinelli assumed an average indoor air temperature of 20°C, while in the eco-innovation scenario of night attenuation, Baldinelli differentiated the temperature setpoint as follows: 12 hours a day (day time) the temperature is set to normal (20°C) and the remaining 12 hours (night time) the temperature is set to attenuation (16°C). Table 31 summarises the findings related to the scenario of night attenuation.

Table 31. Summary of results in Baldinelli (2016) regarding the reduction in heating demand due to night attenuation (single-family and multi-family houses).

		Single-family house Warm zone			Single-family house Moderate zone			Single-family house Cold zone		
City		Athens			Strasbourg			Helsinki		
Years of construction		< 1970	1970-1989	1990-2010	< 1970	1970-1989	1990-2010	<1970	1970-1989	1990-2010
Size (m^2)		100	100	130	90	100	100	100	120	120
Base case	Heating energy consumption (kWh/year)	9.350	5.380	5.869	15.913	14.500	8.184	19.606	14.586	13.219
Night attenuation	Heating energy consumption (kWh/year)	5.992	3.261	3.772	12.772	11.486	6.470	16.759	12.505	11.322
	Heating savings	-36%	-39%	-36%	-20%	-21%	-21%	-15%	-14%	-14%

		Multi-family house Warm zone			Multi-family house Moderate zone			Multi-family house Cold zone		
City		Athens			Strasbourg			Helsinki		
Years of construction		< 1970	1970-1989	1990-2010	< 1970	1970-1989	1990-2010	<1970	1970-1989	1990-2010
Size (m^2)		90	90	90	60	60	60	60	60	60
Base case	Heating energy consumption (kWh/year)	4.515	2.961	1.953	9.898	6.596	3.627	9.236	6.705	6.598
Night attenuation	Heating energy consumption (kWh/year)	3.295	2.204	1.404	8.207	5.465	3.071	8.078	5.891	5.799
	Heating savings	-27%	-26%	-28%	-17%	-17%	-15%	-13%	-12%	-12%

Based on the above findings, the same percentages in heating reduction have been assumed for the baseline scenario in the BoP housing. The assumptions for the night attenuation scenario are summarized in Table 32 for the single-family houses and Table 33 for the multi-family houses.

Table 32. Single-family houses: summary of the assumptions for the baseline scenario (Lavagna 2014) and scenario 1 (night attenuation).

Heating energy consumption (kWh/m².yr)	Baseline scenario	Scenario night attenuation
SFH_warm_<1945	108	69
SFH_warm_1945-69	102	65
SFH_warm_1970-89	76	46
SFH_warm_1990-2010	62	40
SFH_mod_<1945	220	176
SFH_mod_1945-69	184	148
SFH_mod_1970-89	151	120
SFH_mod_1990-2010	100	79
SFH_cold_<1945	190	162
SFH_cold_1945-69	175	150
SFH_cold_1970-89	150	128
SFH_cold_1990-2010	115	99

Table 33. Multi-family houses: summary of the assumptions for the baseline scenario (Lavagna 2014) and scenario 1 (night attenuation).

Heating energy consumption (kWh/m².yr)	Baseline scenario	Scenario night attenuation
MFH_warm_<1945	101	74
MFH_warm_1945-69	98	71
MFH_warm_1970-89	63	47
MFH_warm_1990-2010	52	37
MFH_mod_<1945	182	151
MFH_mod_1945-69	182	151
MFH_mod_1970-89	133	110
MFH_mod_1990-2010	98	83
MFH_cold_<1945	158	138
MFH_cold_1945-69	168	147
MFH_cold_1970-89	148	130
MFH_cold_1990-2010	129	113

Results

Table 34 and Table 35 summarise respectively the characterised and normalised results for the first scenario for the whole BoP housing stock, expressed as impact per EU citizen. In the last column of the tables, the results are also shown for the baseline scenario in order to get a first idea on the effect of this first intervention analysed.

Table 34. Characterised results, BoP housing scenario night attenuation compared to baseline scenario (yearly impact by EU citizen)

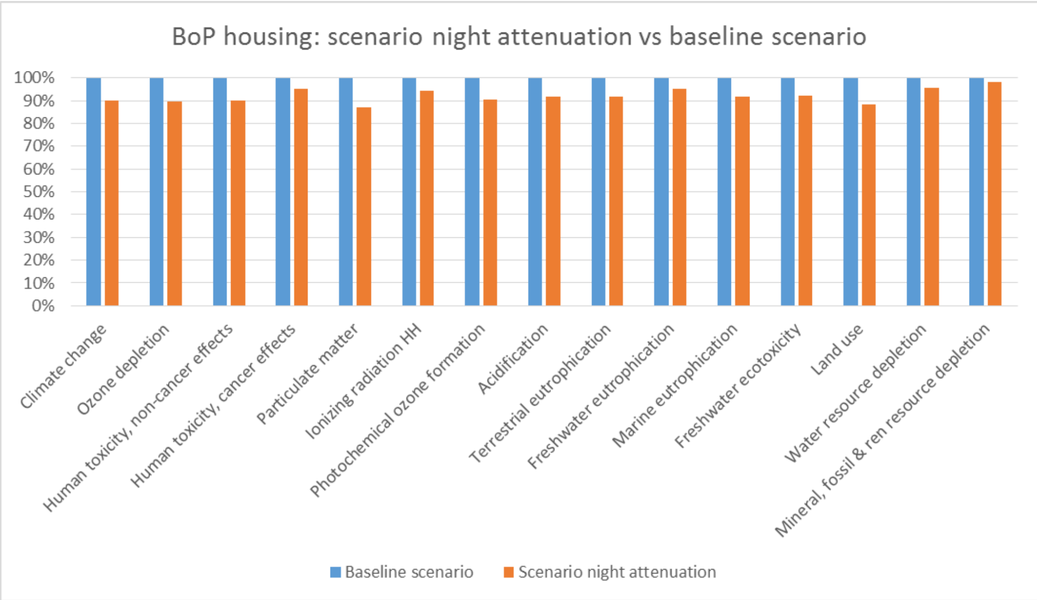
Impact category	Unit	Scenario night attenuation	Baseline scenario
Climate change	kg CO_2 eq	2.36E+03	2.62E+03
Ozone depletion	kg CFC-11 eq	2.98E-04	3.33E-04
Human toxicity, non-cancer effects	CTUh	2.43E-04	2.70E-04
Human toxicity, cancer effects	CTUh	3.31E-05	3.48E-05
Particulate matter	kg $PM_{2.5}$ eq	2.52E+00	2.90E+00
Ionizing radiation HH	kBq U^{235} eq	1.93E+02	2.05E+02
Photochemical ozone formation	kg NMVOC eq	5.53E+00	6.11E+00
Acidification	molc H^+ eq	1.23E+01	1.34E+01
Terrestrial eutrophication	molc N eq	1.69E+01	1.84E+01
Freshwater eutrophication	kg P eq	1.41E-01	1.48E-01
Marine eutrophication	kg N eq	1.54E+00	1.68E+00
Freshwater ecotoxicity	CTUe	1.05E+03	1.14E+03
Land use	kg C deficit	4.27E+03	4.84E+03
Water resource depletion	m^3 water eq	1.44E+02	1.51E+02
Resource depletion	kg Sb eq	1.16E-01	1.18E-01

Table 35. Normalised results, BoP housing scenario night attenuation compared to baseline scenario

Impact category	Scenario night attenuation	Baseline scenario
Climate change	2.60E-01	2.89E-01
Ozone depletion	1.38E-02	1.54E-02
Human toxicity, non-cancer effects	4.56E-01	5.06E-01
Human toxicity, cancer effects	8.97E-01	9.42E-01
Particulate matter	6.62E-01	7.62E-01
Ionizing radiation HH	1.71E-01	1.81E-01
Photochemical ozone formation	1.74E-01	1.93E-01
Acidification	2.58E-01	2.83E-01
Terrestrial eutrophication	9.61E-02	1.05E-01
Freshwater eutrophication	9.52E-02	1.00E-01
Marine eutrophication	9.12E-02	9.94E-02
Freshwater ecotoxicity	1.20E-01	1.30E-01
Land use	5.72E-02	6.49E-02
Water resource depletion	1.77E+00	1.85E+00
Resource depletion	1.15E+00	1.17E+00

The comparison with the baseline scenario is also graphically presented in Figure 18 for the characterised results. The environmental impact of the BoP housing has reduced for all impact categories by 2% -13% dependent on the impact category.

Figure 18. Characterised results per citizen, BoP housing scenario night attenuation compared to baseline scenario



When interpreting the results, it is worth noting that this scenario acts on space heating, which was a hotspot for the use phase of the baseline. The highest contribution of space heating was on particulate matter formation (70% of the total impact of PM in the use phase). The use phase contributed for 87% of the overall impact of the BoP housing on PM. Therefore, the contribution of space heating was 60% of the overall impact of the BoP on PM. The reduction obtained through the implementation of this scenario is proportional to this contribution.

Table 36 shows the results as annual environmental impact per person, whereas Table 37 reports the environmental impact associated to a single dwelling in each climatic zone taking into account the number of dwellings for each different age of construction and their impact (weighted average).

Compared to the baseline scenario, the environmental impact is reduced for each dwelling type in each climatic zone and for each impact category. The impact of the average EU housing has reduced for all impact categories with the highest reduction for particulate matter (13%), followed by land use (12%) and climate change, ozone depletion and human toxicity-cancer effects (all 10% reduction) and with the lowest reduction for resource depletion (1%).

Table 36. Annual environmental impact per person. Each line has a green (lower impact) to red (higher impact) colour scale.

Impact categories		SFH_warm	SFH_moderate	SFH_cold	MFH_warm	MFH_moderate	MFH_cold	Average SFH	Average MFH	EU housing average
Climate change	kg CO2 eq	1.52E+03	2.54E+03	2.86E+03	1.73E+03	2.83E+03	2.83E+03	2.36E+03	2.45E+03	2.40E+03
Ozone depletion	kg CFC-11 eq	1.70E-04	3.13E-04	6.23E-04	1.95E-04	3.51E-04	5.91E-04	2.98E-04	3.07E-04	3.02E-04
Human toxicity, non-cancer effects	CTUh	1.63E-04	2.45E-04	4.49E-04	2.18E-04	2.65E-04	4.34E-04	2.38E-04	2.56E-04	2.45E-04
Human toxicity, cancer effects	CTUh	2.18E-05	3.34E-05	5.41E-05	2.95E-05	3.66E-05	6.05E-05	3.20E-05	3.52E-05	3.34E-05
Particulate matter	kg PM2.5 eq	1.62E+00	2.59E+00	4.83E+00	2.14E+00	2.74E+00	4.46E+00	2.50E+00	2.61E+00	2.54E+00
Ionizing radiation HH	kBq U235 eq	1.45E+02	1.89E+02	3.76E+02	1.56E+02	2.21E+02	3.68E+02	1.89E+02	2.05E+02	1.96E+02
Photochemical ozone formation	kg NMVOC eq	3.45E+00	5.86E+00	9.06E+00	3.96E+00	6.46E+00	8.75E+00	5.53E+00	5.69E+00	5.60E+00
Acidification	molc H+ eq	7.34E+00	1.30E+01	1.99E+01	8.23E+00	1.48E+01	1.93E+01	1.22E+01	1.27E+01	1.24E+01
Terrestrial eutrophication	molc N eq	1.14E+01	1.75E+01	3.10E+01	1.30E+01	1.91E+01	2.99E+01	1.69E+01	1.74E+01	1.71E+01
Freshwater eutrophication	kg P eq	1.04E-01	1.38E-01	2.71E-01	1.14E-01	1.63E-01	2.68E-01	1.37E-01	1.50E-01	1.43E-01
Marine eutrophication	kg N eq	1.03E+00	1.59E+00	2.85E+00	1.18E+00	1.74E+00	2.75E+00	1.54E+00	1.59E+00	1.56E+00
Freshwater ecotoxicity	CTUe	6.62E+02	1.10E+03	1.67E+03	8.49E+02	1.18E+03	1.72E+03	1.04E+03	1.09E+03	1.06E+03
Land use	kg C deficit	2.67E+03	4.47E+03	8.29E+03	3.28E+03	4.78E+03	7.23E+03	4.29E+03	4.37E+03	4.32E+03
Water resource depletion	m3 water eq	1.11E+02	1.42E+02	2.56E+02	1.15E+02	1.65E+02	2.73E+02	1.41E+02	1.53E+02	1.46E+02
Mineral, fossil & ren resource depletion	kg Sb eq	7.98E-02	1.08E-01	1.68E-01	1.62E-01	1.14E-01	1.94E-01	1.05E-01	1.34E-01	1.17E-01

Table 37. Annual environmental impact for a dwelling in EU-27. Results per dwelling: each line has a green (lower impact) to red (higher impact) colour scale.

Impact categories		SFH_warm	SFH_moderate	SFH_cold	MFH_warm	MFH_moderate	MFH_cold	Average SFH	Average MFH	EU housing average
Climate change	kg CO2 eq	5.20E+03	6.90E+03	8.08E+03	3.51E+03	5.54E+03	4.73E+03	6.68E+03	4.79E+03	5.73E+03
Ozone depletion	kg CFC-11 eq	5.85E-04	8.49E-04	1.76E-03	3.96E-04	6.84E-04	9.89E-04	8.44E-04	6.00E-04	7.22E-04
Human toxicity, non-cancer effects	CTUh	5.60E-04	6.64E-04	1.27E-03	4.42E-04	5.21E-04	7.28E-04	6.73E-04	5.05E-04	5.88E-04
Human toxicity, cancer effects	CTUh	7.47E-05	9.06E-05	1.53E-04	5.98E-05	7.29E-05	1.01E-04	9.06E-05	6.99E-05	8.02E-05
Particulate matter	kg PM2.5 eq	5.57E+00	7.03E+00	1.37E+01	4.35E+00	5.38E+00	7.47E+00	7.07E+00	5.14E+00	6.10E+00
Ionizing radiation HH	kBq U235 eq	4.98E+02	5.14E+02	1.06E+03	3.17E+02	4.32E+02	6.16E+02	5.34E+02	4.02E+02	4.68E+02
Photochemical ozone formation	kg NMVOC eq	1.18E+01	1.59E+01	2.56E+01	8.04E+00	1.27E+01	1.47E+01	1.57E+01	1.12E+01	1.34E+01
Acidification	molc H+ eq	2.52E+01	3.53E+01	5.63E+01	1.67E+01	2.89E+01	3.23E+01	3.46E+01	2.48E+01	2.97E+01
Terrestrial eutrophication	molc N eq	3.91E+01	4.74E+01	8.77E+01	2.64E+01	3.74E+01	5.01E+01	4.78E+01	3.43E+01	4.10E+01
Freshwater eutrophication	kg P eq	3.58E-01	3.74E-01	7.65E-01	2.31E-01	3.19E-01	4.48E-01	3.88E-01	2.95E-01	3.41E-01
Marine eutrophication	kg N eq	3.55E+00	4.31E+00	8.05E+00	2.40E+00	3.41E+00	4.60E+00	4.35E+00	3.12E+00	3.73E+00
Freshwater ecotoxicity	CTUe	2.27E+03	2.97E+03	4.73E+03	1.72E+03	2.33E+03	2.88E+03	2.94E+03	2.15E+03	2.54E+03
Land use	kg C deficit	9.17E+03	1.21E+04	2.35E+04	6.67E+03	9.36E+03	1.21E+04	1.21E+04	8.57E+03	1.03E+04
Water resource depletion	m3 water eq	3.81E+02	3.86E+02	7.25E+02	2.34E+02	3.24E+02	4.57E+02	3.99E+02	3.00E+02	3.49E+02
Mineral, fossil & ren resource depletion	kg Sb eq	2.74E-01	2.92E-01	4.74E-01	3.29E-01	2.26E-01	3.26E-01	2.97E-01	2.67E-01	2.82E-01

Contribution by life cycle stages

Table 38 shows the contribution of different life cycle stages to the impact categories (based on the characterised inventory results before normalisation and weighting). The life cycle stages in orange are the ones identified as "most relevant" for the impact category, as they are contributing to more than 80%. Results show that there is a huge difference between the impacts of the use phase (from 53% to 96%). Figure 19 and Table 39 summarise the contribution of the various life cycle phases to the overall impact per impact category. Compared to the baseline scenario a slight decrease (few percentages) in importance of the use phase is noticed and a slight increase in importance of the other life cycle stages.

Table 38. Contribution by life cycle stages of the BoP housing for the scenario of night attenuation (SC1) compared to baseline (BL)

Climate change			**Human toxicity, cancer**			**Particulate matter**		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC1	*BL*		*SC1*	*BL*		*SC1*	*BL*
PRODUCTION	9	8	PRODUCTION	42	13	PRODUCTION	9	7
CONSTRUCTION	0.9	0.8	CONSTRUCTION	2.0	1.3	CONSTRUCTION	0.8	0.7
USE	90	91	USE	53	84	USE	85	87
MAINTENANCE	1.4	1.2	MAINTENANCE	3.0	2.7	MAINTENANCE	4.9	4.2
END OF LIFE	-1.4	-1.3	END OF LIFE	-0.1	-0.4	END OF LIFE	0.6	0.5

Ozone depletion			**Human toxicity, non-cancer**			**Ionizing radiation HH**		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC1	*BL*		*SC1*	*BL*		*SC1*	*BL*
PRODUCTION	4	4	PRODUCTION	14	40	PRODUCTION	4	4
CONSTRUCTION	0.91	0.81	CONSTRUCTION	1.5	1.9	CONSTRUCTION	0.8	0.7
USE	92	93	USE	82	56	USE	94	94
MAINTENANCE	1.5	1.3	MAINTENANCE	3.4	2.8	MAINTENANCE	1.1	1.0
END OF LIFE	0.84	0.76	END OF LIFE	-0.6	-0.1	END OF LIFE	0.6	0.6

Photochemical ozone formation			**Acidification**			**Terrestrial eutrophication**		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC1	*BL*		*SC1*	*BL*		*SC1*	*BL*
PRODUCTION	11	10	PRODUCTION	7	6	PRODUCTION	11	11
CONSTRUCTION	1.9	1.7	CONSTRUCTION	1.0	1.0	CONSTRUCTION	2.2	2.0
USE	84	86	USE	87	88	USE	81	83
MAINTENANCE	2.7	2.4	MAINTENANCE	4.3	3.9	MAINTENANCE	2.7	2.5
END OF LIFE	0.1	0.1	END OF LIFE	0.3	0.3	END OF LIFE	2.2	2.1

Freshwater eutrophication			**Marine eutrophication**			**Freshwater ecotoxicity**		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC1	*BL*		*SC1*	*BL*		*SC1*	*BL*
PRODUCTION	9	8	PRODUCTION	11	10	PRODUCTION	20	19
CONSTRUCTION	0.8	0.7	CONSTRUCTION	2.2	2.0	CONSTRUCTION	4.2	3.9
USE	91	92	USE	82	83	USE	69	72
MAINTENANCE	1.3	1.0	MAINTENANCE	2.6	2.3	MAINTENANCE	3.6	3.2
END OF LIFE	-1.9	-1.9	END OF LIFE	2.3	2.1	END OF LIFE	2.9	2.7

Land use			**Water resource depletion**			**Resource depletion**		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC1	*BL*		*SC1*	*BL*		*SC1*	*BL*
PRODUCTION	9	8	PRODUCTION	3	3	PRODUCTION	19	18
CONSTRUCTION	1.3	1.1	CONSTRUCTION	0.5	0.5	CONSTRUCTION	1.5	1.5
USE	86	88	USE	96	97	USE	56	59
MAINTENANCE	3.8	3.3	MAINTENANCE	0.4	0.3	MAINTENANCE	21.9	17.9
END OF LIFE	-0.9	-0.8	END OF LIFE	-0.5	-0.5	END OF LIFE	1.5	4.0

Figure 19. Contribution of life cycle phases of the BoP housing for the scenario night attenuation

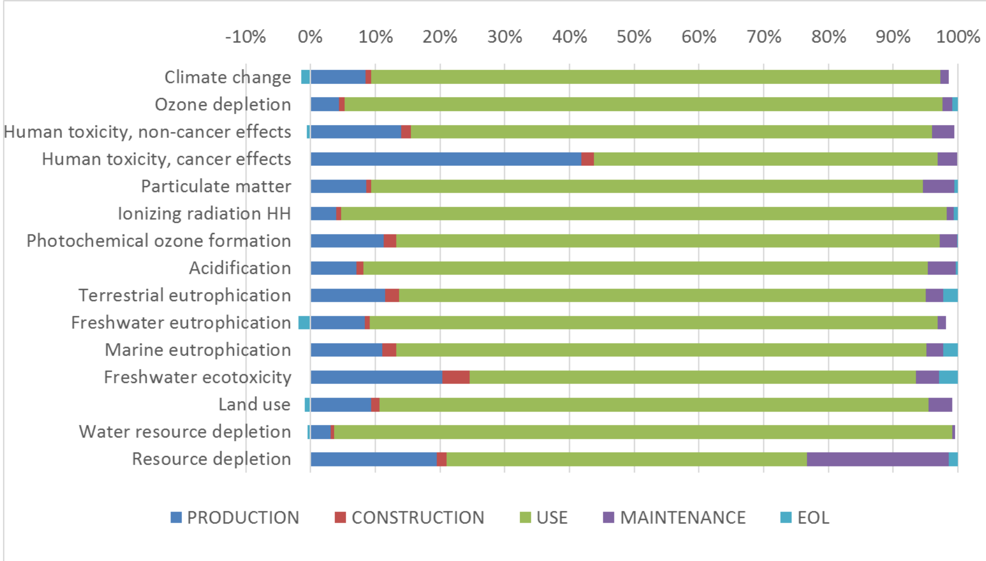


Table 39. Environmental impacts related to housing per person per year in EU-27 (total and per life cycle stages) for the scenario night attenuation. A colour scale is applied to the results in each column, from green (lowest contribution), to red (highest contribution).

Impact category	Unit	PRODUCTION	%	CONSTRUCTION	%	USE	%	Maintenance	%	EOL	%	TOTAL	%
Climate change	**kg CO2 eq**	2.07E+02	8.8	2.15E+01	0.91	2.14E+03	90	3.30E+01	1.4	-3.42E+01	-1.4	**2.36E+03**	**100**
Ozone depletion	**kg CFC-11 eq**	1.30E-05	4.4	2.70E-06	0.91	2.75E-04	92	4.49E-06	1.5	2.51E-06	0.8	**2.98E-04**	**100**
Human toxicity, non-cancer effects	**CTUh**	3.45E-05	14.2	3.58E-06	1.47	1.98E-04	82	8.27E-06	3.4	-1.46E-06	-0.6	**2.43E-04**	**100**
Human toxicity, cancer effects	**CTUh**	1.39E-05	41.9	6.69E-07	2.02	1.76E-05	53	9.88E-07	3.0	-4.68E-08	-0.1	**3.31E-05**	**100**
Particulate matter	**kg PM2.5 eq**	2.15E-01	8.6	1.91E-02	0.76	2.15E+00	85	1.22E-01	4.9	1.43E-02	0.6	**2.52E+00**	**100**
Ionizing radiation HH	**kBq U235 eq**	7.57E+00	3.9	1.52E+00	0.79	1.81E+02	94	2.09E+00	1.1	1.22E+00	0.6	**1.93E+02**	**100**
Photochemical ozone formation	**kg NMVOC eq**	6.23E-01	11.3	1.07E-01	1.93	4.65E+00	84	1.47E-01	2.7	6.98E-03	0.1	**5.53E+00**	**100**
Acidification	**molc H+ eq**	8.71E-01	7.1	1.28E-01	1.05	1.07E+01	87	5.27E-01	4.3	4.00E-02	0.3	**1.23E+01**	**100**
Terrestrial eutrophication	**molc N eq**	1.94E+00	11.5	3.75E-01	2.22	1.38E+01	81	4.60E-01	2.7	3.78E-01	2.2	**1.69E+01**	**100**
Freshwater eutrophication	**kg P eq**	1.23E-02	8.8	1.06E-03	0.75	1.28E-01	91	1.84E-03	1.3	-2.73E-03	-1.9	**1.41E-01**	**100**
Marine eutrophication	**kg N eq**	1.71E-01	11.1	3.40E-02	2.21	1.26E+00	82	3.99E-02	2.6	3.57E-02	2.3	**1.54E+00**	**100**
Freshwater ecotoxicity	**CTUe**	2.13E+02	20.3	4.41E+01	4.20	7.24E+02	69	3.76E+01	3.6	3.02E+01	2.9	**1.05E+03**	**100**
Land use	**kg C deficit**	4.06E+02	9.5	5.55E+01	1.30	3.69E+03	86	1.61E+02	3.8	-3.81E+01	-0.9	**4.27E+03**	**100**
Water resource depletion	**m3 water eq**	4.52E+00	3.1	7.30E-01	0.51	1.39E+02	96	5.24E-01	0.4	-6.91E-01	-0.5	**1.44E+02**	**100**
Mineral, fossil & ren resource depletion	**kg Sb eq**	2.27E-02	19.5	1.78E-03	1.53	6.48E-02	56	2.55E-02	21.9	1.70E-03	1.5	**1.16E-01**	**100**

8.3 Scenario 2 – External wall insulation – increased insulation thickness

Description and aim:

The aim of this scenario is to assess the potential environmental benefits arising from the renovation of the facades of housing across the whole life cycle of EU buildings.

Area of intervention:

- Hotspot addressed: the energy consumption during the use phase for space heating
- Whole basket - renovation
- Life cycle stage: production phase and use phase (energy consumption for space heating)

Policy relevance: Energy and resource efficiency in the building sector

Rationale for building the scenario:

Thanks to the Energy Performance Directive (2006/32/EC) and its amendments (2009/125/EC, 2010/30/EU, 2012/27/EU) new buildings (from 2006 onwards) have a good energy performance. Compared to these new buildings, buildings built before 2006 have in general a very low energy performance. This is mainly due to a lower insulation level of the building skin. The majority of the building stock moreover consists of buildings built before 2006 with a low yearly replacement rate. Increasing the insulation level of the existing building stock hence has a high potential in reducing the overall environmental impact of the housing stock in the EU.

The insulation level of older buildings is a lot lower (if insulated at all) compared to current common practice of new buildings. Improving the insulation level is seen, hence, as a major opportunity in the overall aim to reduce energy consumption (heating) in the EU. The roof, windows and facades are the most important parts of the buildings envelope, which can be improved. As improving the windows has already been assessed in Sala et al. 2016, the roof and facades are identified as the parts of the building to be further assessed. Based on the dynamic energy simulations done by Baldinelli (2016), the facades seem to have the highest improvement potential. This can be mainly explained by the fact that the amount of façade area per dwelling is higher than the amount of roof area, and hence improving the insulation level of the walls has a higher energy saving potential. Moreover, the single family houses have a pitched roof (except for the most recent house in the warm climatic zone) with an unheated (unused) attic below which functions as air insulation layer. For the multi-family houses additional insulation of the roof only has an important benefit for the apartments on the top floor, explaining the relatively low benefit for the apartments in the other floors of the apartment block.

Parameters modified in the model:

The following parameters are modified to model this scenario:

- Production phase: façade insulation (stone wool) is added to the inventory
- Construction phase: 4% loss of the additional insulation is added to the inventory (including production, transport and EoL of the 4% additional material)
- Use phase: calculated reduction in heating demand (from dynamic energy simulation from Baldinelli 2016) is deducted from the baseline heating demand. The calculation of the energy demand takes into account the climatic zone, building type (SFH and MFH) and construction period.
- EoL phase: additional façade insulation is added to the inventory

The study of Baldinelli (2016) identified the potential reduction in heating demand of a reference single-family and multi-family house when increasing the insulation level of the facades compared to a baseline case (in line with the basic scenario within the BoP). Table

40 and Table 41 summarise the assumptions and findings related to the scenario of increasing façade insulation.

Table 40. Summary of assumptions in Baldinelli (2016) regarding the thermal transmittance of the facade in the base case configuration

U-VALUE OF WALLS (W/m^2K)						
Typology	Single-family house			Multi-family house		
Years of construction	<1970	1970-1989	1990-2010	<1970	1970-1989	1990-2010
Warm zone	1.65	1.40	0.85	1.63	1.36	0.83
Moderate zone	1.63	0.82	0.45	1.58	0.95	0.58
Cold zone	0.50	0.33	0.29	0.60	0.40	0.47

For the analysis of the scenario on increased insulation level in the facades, Baldinelli assumed the addition of an auxiliary layer that halves the thermal transmittance of the walls. This insulation level is by no means meant as reflective the optimal insulation level in renovation cases, as higher insulation levels should be strived for in order to avoid lock-in effects. The scenario of reducing the thermal transmittance to half of its value is rather a pragmatic choice (as it overcomes the problem linked to the absence of common levels of insulation requirements throughout the EU Member States) and should be seen as representing the potential benefit of increasing the façade insulation. Higher benefits are for sure possible by applying higher insulation levels.

Table 41. Summary of results in Baldinelli (2016) regarding the reduction in heating demand due to the increased insulation level of the facades (single-family and multi-family houses).

		Single-family house Warm zone			Single-family house Moderate zone			Single-family house Cold zone		
City		**Athens**			**Strasbourg**			**Helsinki**		
Years of construction		< 1970	1970-1989	1990-2010	< 1970	1970-1989	1990-2010	<1970	1970-1989	1990-2010
Size (m^2)		100	100	130	90	100	100	100	120	120
Base case	**Heating energy consumption (kWh/year)**	9.350	5.380	5.869	15.913	14.500	8.184	19.606	14.586	13.219
Vertical walls insulation	**Heating energy consumption (kWh/year)**	7.431	3.917	4.605	11.800	11.848	6.948	17.539	12.505	11.597
	Heating savings	-21%	-27%	-22%	-26%	-18%	-15%	-11%	-14%	-12%

		Multi-family house Warm zone			Multi-family house Moderate zone			Multi-family house Cold zone		
City		**Athens**			**Strasbourg**			**Helsinki**		
Years of construction		< 1970	1970-1989	1990-2010	< 1970	1970-1989	1990-2010	<1970	1970-1989	1990-2010
Size (m^2)		90	90	90	60	60	60	60	60	60
Base case	**Heating energy consumption (kWh/year)**	4.515	2.961	1.953	9.898	6.596	3.627	9.236	6.705	6.598
Vertical walls insulation	**Heating energy consumption (kWh/year)**	3.258	1.939	1.313	7.283	5.073	2.729	7.686	5.646	5.407
	Heating savings	-28%	-35%	-33%	-26%	-23%	-25%	-17%	-16%	-18%

Results

Table 42 and Table 43 summarise respectively the characterised and normalised results for the second scenario for the whole BoP housing stock, expressed as impact per EU citizen. In the last column of the tables, the results are also shown for the baseline scenario in order to get a first idea on the effect of this intervention analysed.

Table 42. Characterised results, BoP housing scenario increased wall insulation (yearly impact EU citizen)

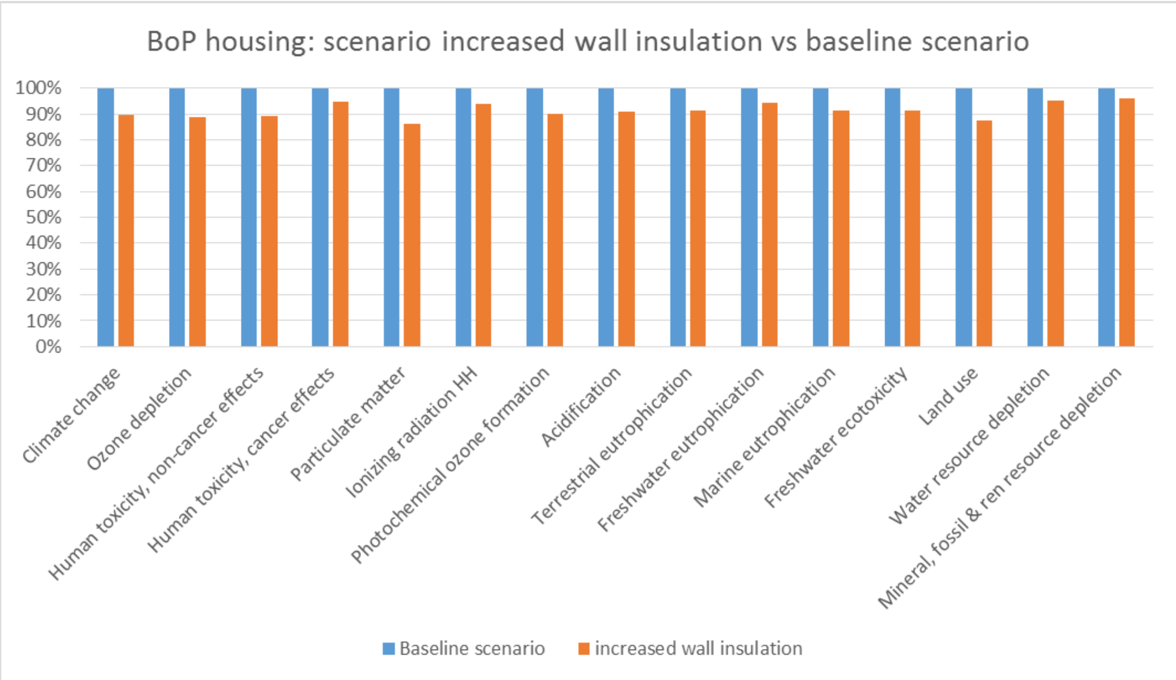
Impact category	Unit	Scenario increased wall insulation	Baseline scenario
Climate change	kg CO_2 eq	2.34E+03	2.62E+03
Ozone depletion	kg CFC-11 eq	2.95E-04	3.33E-04
Human toxicity, non-cancer effects	CTUh	2.40E-04	2.70E-04
Human toxicity, cancer effects	CTUh	3.29E-05	3.48E-05
Particulate matter	kg $PM_{2.5}$ eq	2.50E+00	2.90E+00
Ionizing radiation HH	kBq U^{235} eq	1.92E+02	2.05E+02
Photochemical ozone formation	kg NMVOC eq	5.49E+00	6.11E+00
Acidification	molc H^+ eq	1.22E+01	1.34E+01
Terrestrial eutrophication	molc N eq	1.68E+01	1.84E+01
Freshwater eutrophication	kg P eq	1.40E-01	1.48E-01
Marine eutrophication	kg N eq	1.53E+00	1.68E+00
Freshwater ecotoxicity	CTUe	1.04E+03	1.14E+03
Land use	kg C deficit	4.23E+03	4.84E+03
Water resource depletion	m^3 water eq	1.44E+02	1.51E+02
Resource depletion	kg Sb eq	1.13E-01	1.18E-01

Table 43. Normalised results, BoP housing scenario increased wall insulation

Impact category	Scenario increased wall insulation	Baseline scenario
Climate change	2.58E-01	2.89E-01
Ozone depletion	1.37E-02	1.54E-02
Human toxicity. non-cancer effects	4.51E-01	5.06E-01
Human toxicity. cancer effects	8.93E-01	9.42E-01
Particulate matter	6.57E-01	7.62E-01
Ionizing radiation HH	1.70E-01	1.81E-01
Photochemical ozone formation	1.73E-01	1.93E-01
Acidification	2.56E-01	2.83E-01
Terrestrial eutrophication	9.56E-02	1.05E-01
Freshwater eutrophication	9.44E-02	1.00E-01
Marine eutrophication	9.06E-02	9.94E-02
Freshwater ecotoxicity	1.19E-01	1.30E-01
Land use	5.67E-02	6.49E-02
Water resource depletion	1.77E+00	1.85E+00
Resource depletion	1.12E+00	1.17E+00

The comparison with the baseline scenario is also graphically presented in Figure 20 for the characterised results. The environmental impact of the BoP housing has reduced for all impact categories by 4% -14% dependent on the impact category.

Figure 20. Characterised results. BoP housing scenario increased wall insulation compared to baseline scenario (yearly impact EU citizen)



As already mentioned for the scenario on night attenuation, it is worth noting that also the two scenarios on external walls insulation (scenario 2 and scenario 3) act on space heating, which was a hotspot for the use phase of the baseline. The highest contribution of space heating was on particulate matter formation (70% of the total impact of PM in the use phase). The use phase contributed for 87% of the overall impact of the BoP housing on PM. Therefore, the contribution of space heating was 60% of the overall impact of the BoP on PM. The reduction obtained through the implementation of this scenario is proportional to this contribution.

Table 44 shows the results per person, whereas Table 45 reports the environmental impact associated to a single dwelling in each climatic zone taking into account the number of dwellings for each different age of construction and their impact (weighted average).

Compared to the baseline scenario, the environmental impact is reduced for each dwelling type in each climatic zone and for each impact category. The impact of the average EU housing has reduced for all impact categories with the highest reduction for particulate matter (14%). followed by land use (12%) and climate change. ozone depletion and human toxicity – cancer effects (all 11% reduction) and with the lowest reduction for resource depletion (4%).

Table 44. Annual environmental per person. Each line has a green (lower impact) to red (higher impact) colour scale.

Impact categories		SFH_warm	SFH_moderate	SFH_cold	MFH_warm	MFH_moderate	MFH_cold	Average SFH	Average MFH	EU housing average
Climate change	kg CO2 eq	1.60E+03	2.54E+03	2.89E+03	1.70E+03	2.73E+03	2.81E+03	2.38E+03	2.37E+03	2.37E+03
Ozone depletion	kg CFC-11 eq	1.80E-04	3.12E-04	6.34E-04	1.92E-04	3.38E-04	5.85E-04	3.00E-04	2.98E-04	2.99E-04
Human toxicity, non-cancer effects	CTUh	1.77E-04	2.43E-04	4.56E-04	2.12E-04	2.54E-04	4.29E-04	2.39E-04	2.48E-04	2.43E-04
Human toxicity, cancer effects	CTUh	2.22E-05	3.33E-05	5.48E-05	2.93E-05	3.59E-05	6.00E-05	3.21E-05	3.47E-05	3.32E-05
Particulate matter	kg PM2.5 eq	1.82E+00	2.59E+00	4.93E+00	2.08E+00	2.62E+00	4.41E+00	2.54E+00	2.51E+00	2.53E+00
Ionizing radiation HH	kBq U235 eq	1.49E+02	1.89E+02	3.81E+02	1.55E+02	2.17E+02	3.66E+02	1.89E+02	2.02E+02	1.95E+02
Photochemical ozone formation	kg NMVOC eq	3.65E+00	5.86E+00	9.22E+00	3.90E+00	6.23E+00	8.69E+00	5.58E+00	5.53E+00	5.56E+00
Acidification	molc H+ eq	7.70E+00	1.30E+01	2.02E+01	8.12E+00	1.43E+01	1.92E+01	1.23E+01	1.23E+01	1.23E+01
Terrestrial eutrophication	molc N eq	1.20E+01	1.75E+01	3.15E+01	1.29E+01	1.85E+01	2.97E+01	1.70E+01	1.70E+01	1.70E+01
Freshwater eutrophication	kg P eq	1.07E-01	1.37E-01	2.73E-01	1.12E-01	1.59E-01	2.65E-01	1.37E-01	1.47E-01	1.41E-01
Marine eutrophication	kg N eq	1.09E+00	1.59E+00	2.89E+00	1.16E+00	1.69E+00	2.73E+00	1.55E+00	1.55E+00	1.55E+00
Freshwater ecotoxicity	CTUe	6.93E+02	1.09E+03	1.70E+03	8.37E+02	1.15E+03	1.71E+03	1.04E+03	1.06E+03	1.05E+03
Land use	kg C deficit	2.94E+03	4.47E+03	8.44E+03	3.20E+03	4.59E+03	7.16E+03	4.34E+03	4.22E+03	4.29E+03
Water resource depletion	m3 water eq	1.12E+02	1.42E+02	2.58E+02	1.15E+02	1.62E+02	2.72E+02	1.41E+02	1.51E+02	1.45E+02
Mineral, fossil & ren resource depletion	kg Sb eq	7.87E-02	1.05E-01	1.67E-01	1.59E-01	1.09E-01	1.90E-01	1.03E-01	1.30E-01	1.14E-01

Table 45. Annual environmental impact for a dwelling in EU-27. Results per dwelling: each line has a green (lower impact) to red (higher impact) color scale.

Impact categories		SFH_warm	SFH_moderate	SFH_cold	MFH_warm	MFH_moderate	MFH_cold	Average SFH	Average MFH	EU housing average
Climate change	kg CO2 eq	5.50E+03	6.89E+03	8.18E+03	3.45E+03	5.33E+03	4.71E+03	6.72E+03	4.64E+03	5.68E+03
Ozone depletion	kg CFC-11 eq	6.19E-04	8.47E-04	1.79E-03	3.89E-04	6.56E-04	9.80E-04	8.49E-04	5.81E-04	7.14E-04
Human toxicity, non-cancer effects	CTUh	6.06E-04	6.60E-04	1.29E-03	4.31E-04	5.00E-04	7.19E-04	6.77E-04	4.88E-04	5.82E-04
Human toxicity, cancer effects	CTUh	7.60E-05	9.04E-05	1.55E-04	5.94E-05	7.15E-05	1.01E-04	9.08E-05	6.89E-05	7.98E-05
Particulate matter	kg PM2.5 eq	6.26E+00	7.01E+00	1.40E+01	4.22E+00	5.13E+00	7.39E+00	7.18E+00	4.94E+00	6.05E+00
Ionizing radiation HH	kBq U235 eq	5.12E+02	5.13E+02	1.08E+03	3.15E+02	4.23E+02	6.13E+02	5.36E+02	3.96E+02	4.65E+02
Photochemical ozone formation	kg NMVOC eq	1.25E+01	1.59E+01	2.61E+01	7.92E+00	1.22E+01	1.46E+01	1.58E+01	1.08E+01	1.33E+01
Acidification	molc H+ eq	2.64E+01	3.53E+01	5.71E+01	1.65E+01	2.79E+01	3.21E+01	3.48E+01	2.42E+01	2.94E+01
Terrestrial eutrophication	molc N eq	4.11E+01	4.75E+01	8.92E+01	2.61E+01	3.63E+01	4.97E+01	4.82E+01	3.35E+01	4.08E+01
Freshwater eutrophication	kg P eq	3.65E-01	3.72E-01	7.73E-01	2.28E-01	3.11E-01	4.45E-01	3.88E-01	2.89E-01	3.38E-01
Marine eutrophication	kg N eq	3.72E+00	4.31E+00	8.18E+00	2.36E+00	3.31E+00	4.57E+00	4.38E+00	3.05E+00	3.71E+00
Freshwater ecotoxicity	CTUe	2.38E+03	2.97E+03	4.81E+03	1.70E+03	2.26E+03	2.86E+03	2.95E+03	2.10E+03	2.52E+03
Land use	kg C deficit	1.01E+04	1.21E+04	2.39E+04	6.50E+03	8.96E+03	1.20E+04	1.23E+04	8.27E+03	1.03E+04
Water resource depletion	m3 water eq	3.86E+02	3.86E+02	7.31E+02	2.33E+02	3.19E+02	4.55E+02	4.00E+02	2.97E+02	3.48E+02
Mineral, fossil & ren resource depletion	kg Sb eq	2.70E-01	2.85E-01	4.73E-01	3.22E-01	2.16E-01	3.18E-01	2.90E-01	2.59E-01	2.74E-01

Contribution by life cycle stages

Table 46 shows the contribution of different life cycle stages to the impact categories (based on the characterised inventory results before normalisation and weighting). The life cycle stages in orange are the ones identified as "most relevant" for the impact category. as they are contributing to more than 80% showing that there is a huge gap between the impact of the use phase (from 53% to 96%) Figure 21 and Table 47 summarise the contribution of the various life cycle phases to the overall impact per impact category. Compared to the baseline scenario a slight decrease (few percentages) in importance of the use phase is noticed and a slight increase in importance of the other life cycle stages.

Table 46. Contribution by life cycle stages of the BoP housing for the scenario of increased wall insulation (SC2) compared to baseline (BL)

Climate change			**Human toxicity, cancer**			**Particulate matter**		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC2	*BL*		*SC2*	*BL*		*SC2*	*BL*
PRODUCTION	9	8	PRODUCTION	42	13	PRODUCTION	9	7
CONSTRUCTION	0.9	0.8	CONSTRUCTION	2.0	1.3	CONSTRUCTION	0.8	0.7
USE	90	91	USE	53	84	USE	85	87
MAINTENANCE	1.5	1.2	MAINTENANCE	3.0	2.7	MAINTENANCE	5.0	4.2
END OF LIFE	-1.5	-1.3	END OF LIFE	-0.1	-0.4	END OF LIFE	0.6	0.5
Ozone depletion			**Human toxicity, non-cancer**			**Ionizing radiation HH**		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC2	*BL*		*SC2*	*BL*		*SC2*	*BL*
PRODUCTION	4	4	PRODUCTION	14	40	PRODUCTION	4	4
CONSTRUCTION	0.92	0.81	CONSTRUCTION	1.5	1.9	CONSTRUCTION	0.8	0.7
USE	92	93	USE	82	56	USE	93	94
MAINTENANCE	1.6	1.3	MAINTENANCE	3.1	2.8	MAINTENANCE	1.1	1.0
END OF LIFE	0.86	0.76	END OF LIFE	-0.5	-0.1	END OF LIFE	0.6	0.6
Photochemical ozone formation			**Acidification**			**Terrestrial eutrophication**		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC2	*BL*		*SC2*	*BL*		*SC2*	*BL*
PRODUCTION	11	10	PRODUCTION	7	6	PRODUCTION	12	11
CONSTRUCTION	2.0	1.7	CONSTRUCTION	1.1	1.0	CONSTRUCTION	2.2	2.0
USE	84	86	USE	87	88	USE	81	83
MAINTENANCE	2.8	2.4	MAINTENANCE	4.4	3.9	MAINTENANCE	2.9	2.5
END OF LIFE	0.1	0.1	END OF LIFE	0.3	0.3	END OF LIFE	2.3	2.1
Freshwater eutrophication			**Marine eutrophication**			**Freshwater ecotoxicity**		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC2	*BL*		*SC2*	*BL*		*SC2*	*BL*
PRODUCTION	9	8	PRODUCTION	11	10	PRODUCTION	21	19
CONSTRUCTION	0.8	0.7	CONSTRUCTION	2.2	2.0	CONSTRUCTION	4.3	3.9
USE	91	92	USE	82	83	USE	69	72
MAINTENANCE	1.2	1.0	MAINTENANCE	2.7	2.3	MAINTENANCE	3.6	3.2
END OF LIFE	-2.0	-1.9	END OF LIFE	2.4	2.1	END OF LIFE	2.9	2.7
Land use			**Water resource depletion**			**Resource depletion**		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC2	*BL*		*SC2*	*BL*		*SC2*	*BL*
PRODUCTION	10	8	PRODUCTION	3	3	PRODUCTION	19	18
CONSTRUCTION	1.3	1.1	CONSTRUCTION	0.5	0.5	CONSTRUCTION	1.5	1.5
USE	86	88	USE	96	97	USE	57	59
MAINTENANCE	3.9	3.3	MAINTENANCE	0.4	0.3	MAINTENANCE	18.7	17.9
END OF LIFE	-0.9	-0.8	END OF LIFE	-0.5	-0.5	END OF LIFE	4.2	4.0

Figure 21. Contribution of life cycle phases of the BoP housing for the scenario increased wall insulation

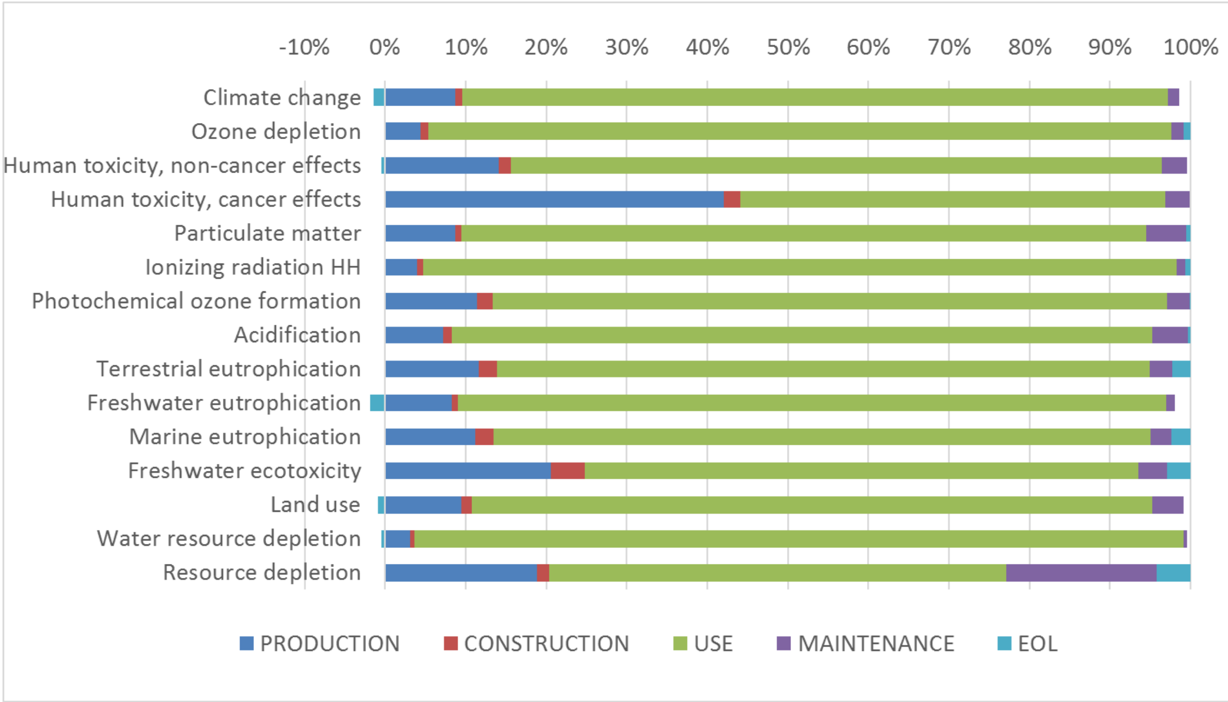


Table 47. Environmental impacts related to housing per person per year in EU-27 (total and per life cycle stages) for the scenario increased wall insulation. A colour scale is applied to the results in each column from green (lowest contribution) to red (highest contribution).

Impact category	Unit	PRODUCTION	%	CONSTRUCTION	%	USE	%	Maintenance	%	EOL	%	TOTAL	%
Climate change	**kg CO2 eq**	2.08E+02	8.9	2.15E+01	0.92	2.10E+03	90	3.43E+01	1.5	-3.42E+01	-1.5	**2.33E+03**	**100**
Ozone depletion	**kg CFC-11 eq**	1.30E-05	4.4	2.71E-06	0.92	2.70E-04	92	4.55E-06	1.6	2.52E-06	0.9	**2.93E-04**	**100**
Human toxicity, non-cancer effects	**CTUh**	3.40E-05	14.2	3.56E-06	1.49	1.95E-04	82	7.45E-06	3.1	-1.10E-06	-0.5	**2.39E-04**	**100**
Human toxicity, cancer effects	**CTUh**	1.39E-05	42.2	6.68E-07	2.03	1.74E-05	53	9.76E-07	3.0	-4.62E-08	-0.1	**3.29E-05**	**100**
Particulate matter	**kg PM2.5 eq**	2.16E-01	8.7	1.91E-02	0.77	2.11E+00	85	1.24E-01	5.0	1.44E-02	0.6	**2.48E+00**	**100**
Ionizing radiation HH	**kBq U235 eq**	7.60E+00	4.0	1.53E+00	0.80	1.79E+02	93	2.18E+00	1.1	1.22E+00	0.6	**1.92E+02**	**100**
Photochemical ozone formation	**kg NMVOC eq**	6.25E-01	11.4	1.07E-01	1.95	4.57E+00	84	1.52E-01	2.8	7.42E-03	0.1	**5.46E+00**	**100**
Acidification	**molc H+ eq**	8.73E-01	7.2	1.28E-01	1.06	1.05E+01	87	5.37E-01	4.4	4.08E-02	0.3	**1.21E+01**	**100**
Terrestrial eutrophication	**molc N eq**	1.95E+00	11.6	3.76E-01	2.24	1.36E+01	81	4.80E-01	2.9	3.80E-01	2.3	**1.68E+01**	**100**
Freshwater eutrophication	**kg P eq**	1.21E-02	8.7	1.05E-03	0.75	1.27E-01	91	1.62E-03	1.2	-2.76E-03	-2.0	**1.39E-01**	**100**
Marine eutrophication	**kg N eq**	1.71E-01	11.2	3.40E-02	2.23	1.24E+00	82	4.08E-02	2.7	3.59E-02	2.4	**1.52E+00**	**100**
Freshwater ecotoxicity	**CTUe**	2.13E+02	20.5	4.41E+01	4.25	7.12E+02	69	3.69E+01	3.6	3.05E+01	2.9	**1.04E+03**	**100**
Land use	**kg C deficit**	4.06E+02	9.7	5.56E+01	1.32	3.62E+03	86	1.64E+02	3.9	-3.79E+01	-0.9	**4.21E+03**	**100**
Water resource depletion	**m3 water eq**	4.52E+00	3.2	7.31E-01	0.51	1.38E+02	96	5.40E-01	0.4	-6.89E-01	-0.5	**1.43E+02**	**100**
Mineral, fossil & ren resource depletion	**kg Sb eq**	2.13E-02	18.9	1.73E-03	1.53	6.41E-02	57	2.11E-02	18.7	4.72E-03	4.2	**1.13E-01**	**100**

8.4 Scenario 3 – External wall insulation – recycled or bio-based insulation materials

Description and aim:

The aim of this scenario is to assess the potential environmental benefits arising from using recycled or bio-based insulation materials.

Area of intervention:

- Hotspot addressed: the resource consumption and overall environmental impact during production phase arising from the increased use of insulation materials needed to improve the energy performance of buildings
- Whole basket - renovation
- Life cycle stage: production phase and use phase (energy consumption for space heating)

Policy relevance: Resource efficient material flows and urban pressures on land and habitats

Rationale for building the scenario:

The potential for an increase in wood-based construction is a relevant policy topic. The importance of ensuring that the wood and wood-based materials used in the construction and renovation of buildings are sourced from legal and sustainable sources is a policy objective at EU level. Wood construction materials are renewable raw materials. As such their continued availability is dependent on the management of forests as biological systems and habitats. This factor is also the subject of ongoing debate in the LCA community and efforts are done to properly account for the potential environmental effects of forestry.

As the majority of the buildings in the EU need an energetic retrofit, this scenario analyses the potential benefits of using bio-based or recycled insulation materials for increasing the external wall insulation, instead of conventional ones (as it was the case in scenario 2). More specifically cellulose (blowing-in) will be used for improving the insulation level of the houses in the cold climate (timber frame) and wood fibre board will be used for improving the insulation level of the houses in the moderate and warm climate (brick walls).

Parameters modified in the model:

The following parameters are modified to model this scenario:

- Production phase: façade insulation is added to the inventory using cellulose for the cold climate (timber frame) and wood fiber board for the warm and moderate climate (brick walls).
- Construction phase: no changes
- Use phase: calculated reduction in heating demand (from dynamic energy simulation from Baldinelli 2016) is deducted from the baseline heating demand. The calculation of the energy demand takes into account the climatic zone, building type (SFH and MFH) and construction period.
- EoL phase: additional façade insulation is added to the inventory

For this scenario, identical thermal transmittance levels are assumed as for scenario 2, but these are achieved by using other insulation materials, more specifically cellulose in the cold climate and wood fiber board in the moderate and warm climate.

For cellulose the following lambda value is assumed: 0.038 W/mK. For wood fiber board the following lambda value is assumed: 0.038 W/mK. This leads to the insulation thicknesses as summarized in Table 48 and Table 49.

Table 48. Single-family houses: summary of the assumptions for the base case configuration (Lavagna 2014) and scenario 3

Dwelling type		Single Family House											
		SFH_warm_<1945	SFH_warm_1945-69	SFH_warm_1970-89	SFH_warm_1990-2010	SFH_mod_<1945	SFH_mod_1945-69	SFH_mod_1970-89	SFH_mod_1990-2010	SFH_cold_<1945	SFH_cold_1945-69	SFH_cold_1970-89	SFH_cold_1990-2010
Basis Scenario	Uvalue_walls (W/m²K)	1.71	1.71	1.47	0.82	1.54	1.54	0.98	0.50	0.64	0.64	0.52	0.39
	Insulation thickness_walls (m)	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.05	0.04	0.04	0.05	0.06
	Heating energy consumption (kWh/m².yr)	108	102	76	62	220	184	151	100	190	175	150	115
Scenario 3	Uvalue_walls (W/m²K)	0.86	0.86	0.74	0.41	0.77	0.77	0.49	0.25	0.32	0.32	0.26	0.195
	Insulation thickness_walls (m)	0.03	0.03	0.04	0.09	0.04	0.04	0.06	0.16	0.13	0.13	0.16	0.20
	Heating energy consumption (kWh/m².yr)	86	81	55	49	163	136	123	85	170	157	129	101

Table 49. Multi-family houses: summary of the assumptions for the base case configuration (Lavagna 2014) and scenario 3

Dwelling type		Multi Family House											
		MFH_warm_<1945	MFH_warm_1945-69	MFH_warm_1970-89	MFH_warm_1990-2010	MFH_mod_<1945	MFH_mod_1945-69	MFH_mod_1970-89	MFH_mod_1990-2010	MFH_cold_<1945	MFH_cold_1945-69	MFH_cold_1970-89	MFH_cold_1990-2010
Basis Scenario	Uvalue_walls (W/m²K)	1.76	1.76	1.47	0.81	1.55	1.55	0.98	0.54	0.71	0.71	0.54	0.58
	Insulation thickness_walls (m)	0.00	0.00	0.00	0.02	0.00	0.00	0.02	0.04	0.03	0.03	0.03	0.03
	Heating energy consumption (kWh/m².yr)	101	98	63	52	182	182	133	98	168	168	148	129
Scenario 3	Uvalue_walls (W/m²K)	0.88	0.88	0.74	0.41	0.775	0.775	0.49	0.27	0.355	0.355	0.27	0.29
	Insulation thickness_walls (m)	0.02	0.02	0.03	0.07	0.02	0.02	0.06	0.11	0.11	0.11	0.13	0.13
	Heating energy consumption (kWh/m².yr)	73	71	41	35	134	134	102	74	140	140	125	106

Results

Table 50 and Table 51 summarise respectively the characterised and normalised results for the third scenario for the whole BoP housing stock, expressed as impact per EU citizen. In the last column of the tables, the results are also shown for the baseline scenario in order to get a first idea on the effect of this first intervention analysed.

Table 50. Characterised results. BoP housing scenario biobased/recycled wall insulation compared to baseline scenario (yearly impact EU citizen)

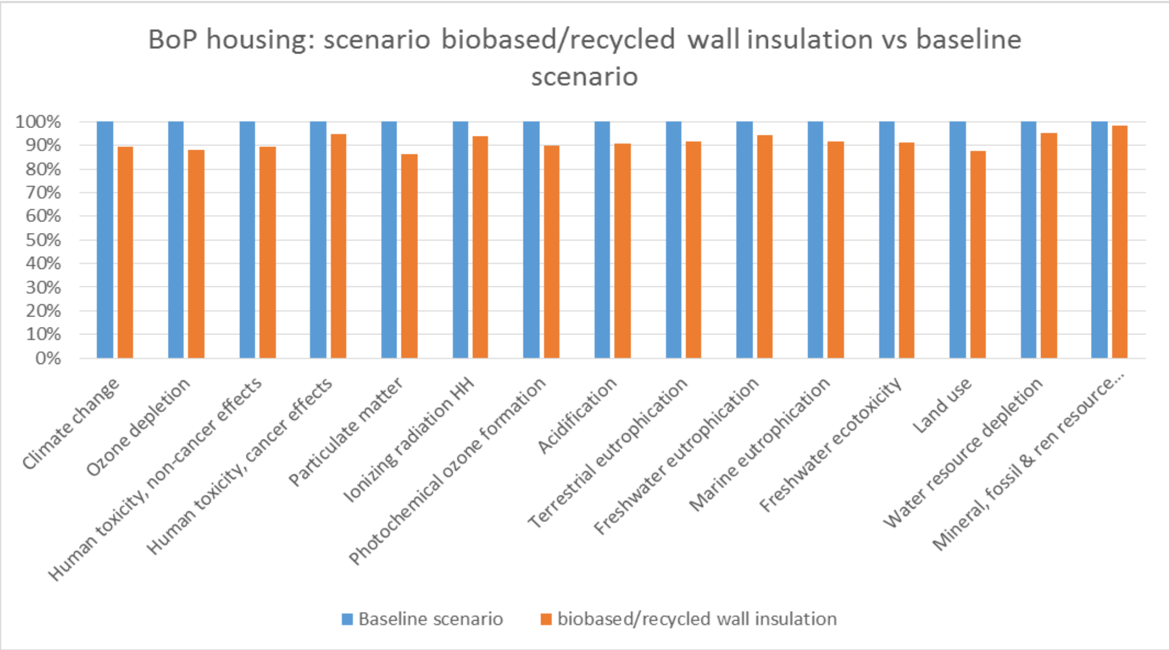
Impact category	Unit	Scenario biobased/recycled wall insulation	Baseline scenario
Climate change	kg CO_2 eq	2.34E+03	2.62E+03
Ozone depletion	kg CFC-11 eq	2.93E-04	3.33E-04
Human toxicity. non-cancer effects	CTUh	2.42E-04	2.70E-04
Human toxicity. cancer effects	CTUh	3.29E-05	3.48E-05
Particulate matter	kg $PM_{2.5}$ eq	2.50E+00	2.90E+00
Ionizing radiation HH	kBq U^{235} eq	1.92E+02	2.05E+02
Photochemical ozone formation	kg NMVOC eq	5.50E+00	6.11E+00
Acidification	molc H^+ eq	1.22E+01	1.34E+01
Terrestrial eutrophication	molc N eq	1.69E+01	1.84E+01
Freshwater eutrophication	kg P eq	1.40E-01	1.48E-01
Marine eutrophication	kg N eq	1.54E+00	1.68E+00
Freshwater ecotoxicity	CTUe	1.04E+03	1.14E+03
Land use	kg C deficit	4.24E+03	4.84E+03
Water depletion	m^3 water eq	1.43E+02	1.51E+02
Resource depletion	kg Sb eq	1.16E-01	1.18E-01

Table 51. Normalised results. BoP housing scenario biobased/recycled wall insulation compared to baseline scenario (yearly impact EU citizen)

Impact category	Scenario biobased/ recycled wall insulation	Baseline scenario
Climate change	2.57E-01	2.89E-01
Ozone depletion	1.36E-02	1.54E-02
Human toxicity. non-cancer effects	4.54E-01	5.06E-01
Human toxicity. cancer effects	8.92E-01	9.42E-01
Particulate matter	6.58E-01	7.62E-01
Ionizing radiation HH	1.70E-01	1.81E-01
Photochemical ozone formation	1.73E-01	1.93E-01
Acidification	2.57E-01	2.83E-01
Terrestrial eutrophication	9.60E-02	1.05E-01
Freshwater eutrophication	9.44E-02	1.00E-01
Marine eutrophication	9.10E-02	9.94E-02
Freshwater ecotoxicity	1.19E-01	1.30E-01
Land use	5.68E-02	6.49E-02
Water resource depletion	1.76E+00	1.85E+00
Resource depletion	1.15E+00	1.17E+00

The comparison with the baseline scenario is also graphically presented in Figure 22 for the characterised results. The environmental impact of the BoP housing has reduced for all impact categories by 1.5% -14% dependent on the impact category.

Figure 22. Characterised results. BoP housing scenario biobased/recycled wall insulation compared to baseline scenario (yearly impact EU citizen)



As the previous ones, also this scenario acts on space heating, which contributed to 60% of the overall impact of the BoP on PM. The reduction obtained through the implementation of this scenario should be interpreted as proportional to this contribution.

Table 52 and Table 53 show the results of the environmental impact associated to a single dwelling in each climatic zone taking into account the number of dwellings for each different age of construction and their impact (weighted average).

Compared to the baseline scenario, the environmental impact is reduced for each dwelling type in each climatic zone for the majority of the impact categories. The impact of the average EU housing has reduced for all impact categories with the highest reduction for particulate matter (13%), followed by land use (12%) and ozone depletion (11%) and climate change, human toxicity-cancer effects and photochemical ozone formation (all 10% reduction) and with the lowest reduction for resource depletion (2%).

Table 52. Annual environmental impact per person. Each line has a green (lower impact) to red (higher impact) colour scale.

Impact categories		SFH_warm	SFH_moderate	SFH_cold	MFH_warm	MFH_moderate	MFH_cold	Average SFH	Average MFH	EU housing average
Climate change	kg CO2 eq	1.69E+03	2.53E+03	2.90E+03	1.71E+03	2.74E+03	2.81E+03	2.38E+03	2.38E+03	2.38E+03
Ozone depletion	kg CFC-11 eq	1.88E-04	3.08E-04	6.34E-04	1.92E-04	3.38E-04	5.86E-04	2.99E-04	2.98E-04	2.98E-04
Human toxicity, non-cancer effects	CTUh	1.90E-04	2.44E-04	4.67E-04	2.13E-04	2.56E-04	4.35E-04	2.43E-04	2.49E-04	2.46E-04
Human toxicity, cancer effects	CTUh	2.46E-05	3.32E-05	5.50E-05	2.93E-05	3.59E-05	6.02E-05	3.25E-05	3.47E-05	3.34E-05
Particulate matter	kg PM2.5 eq	1.93E+00	2.58E+00	4.94E+00	2.09E+00	2.63E+00	4.41E+00	2.55E+00	2.52E+00	2.54E+00
Ionizing radiation HH	kBq U235 eq	1.52E+02	1.88E+02	4.06E+02	1.55E+02	2.17E+02	3.79E+02	1.90E+02	2.02E+02	1.95E+02
Photochemical ozone formation	kg NMVOC eq	3.93E+00	5.86E+00	9.23E+00	3.92E+00	6.25E+00	8.70E+00	5.63E+00	5.55E+00	5.59E+00
Acidification	molc H+ eq	8.07E+00	1.30E+01	2.02E+01	8.15E+00	1.43E+01	1.92E+01	1.24E+01	1.24E+01	1.24E+01
Terrestrial eutrophication	molc N eq	1.28E+01	1.75E+01	3.16E+01	1.29E+01	1.86E+01	2.97E+01	1.72E+01	1.71E+01	1.72E+01
Freshwater eutrophication	kg P eq	1.10E-01	1.37E-01	2.75E-01	1.13E-01	1.59E-01	2.67E-01	1.37E-01	1.48E-01	1.42E-01
Marine eutrophication	kg N eq	1.17E+00	1.59E+00	2.90E+00	1.17E+00	1.69E+00	2.73E+00	1.57E+00	1.56E+00	1.56E+00
Freshwater ecotoxicity	CTUe	7.53E+02	1.09E+03	1.72E+03	8.39E+02	1.15E+03	1.72E+03	1.05E+03	1.06E+03	1.06E+03
Land use	kg C deficit	3.15E+03	4.45E+03	8.48E+03	3.21E+03	4.60E+03	7.18E+03	4.37E+03	4.23E+03	4.31E+03
Water resource depletion	m3 water eq	1.14E+02	1.42E+02	2.60E+02	1.15E+02	1.62E+02	2.72E+02	1.41E+02	1.51E+02	1.45E+02
Mineral, fossil & ren resource depletion	kg Sb eq	7.72E-02	1.04E-01	2.64E-01	1.59E-01	1.09E-01	2.40E-01	1.06E-01	1.32E-01	1.17E-01

Table 53. Annual environmental impact for a dwelling in EU-27. Results per dwelling: each line has a green (lower impact) to red (higher impact) colour scale.

Impact categories		SFH_warm	SFH_moderate	SFH_cold	MFH_warm	MFH_moderate	MFH_cold	Average SFH	Average MFH	EU housing average
Climate change	kg CO2 eq	5.53E+03	6.85E+03	8.20E+03	3.46E+03	5.34E+03	4.71E+03	6.70E+03	4.65E+03	5.67E+03
Ozone depletion	kg CFC-11 eq	6.19E-04	8.37E-04	1.79E-03	3.89E-04	6.56E-04	9.81E-04	8.41E-04	5.81E-04	7.10E-04
Human toxicity, non-cancer effects	CTUh	6.14E-04	6.63E-04	1.32E-03	4.33E-04	5.02E-04	7.28E-04	6.82E-04	4.90E-04	5.86E-04
Human toxicity, cancer effects	CTUh	7.62E-05	9.01E-05	1.56E-04	5.95E-05	7.16E-05	1.01E-04	9.06E-05	6.90E-05	7.97E-05
Particulate matter	kg PM2.5 eq	6.33E+00	7.00E+00	1.40E+01	4.24E+00	5.15E+00	7.39E+00	7.18E+00	4.96E+00	6.06E+00
Ionizing radiation HH	kBq U235 eq	5.11E+02	5.09E+02	1.15E+03	3.14E+02	4.23E+02	6.35E+02	5.35E+02	3.97E+02	4.66E+02
Photochemical ozone formation	kg NMVOC eq	1.27E+01	1.59E+01	2.61E+01	7.95E+00	1.22E+01	1.46E+01	1.58E+01	1.09E+01	1.33E+01
Acidification	molc H+ eq	2.67E+01	3.53E+01	5.72E+01	1.65E+01	2.80E+01	3.21E+01	3.48E+01	2.42E+01	2.95E+01
Terrestrial eutrophication	molc N eq	4.15E+01	4.76E+01	8.93E+01	2.62E+01	3.64E+01	4.98E+01	4.83E+01	3.36E+01	4.09E+01
Freshwater eutrophication	kg P eq	3.67E-01	3.72E-01	7.78E-01	2.29E-01	3.11E-01	4.46E-01	3.88E-01	2.90E-01	3.38E-01
Marine eutrophication	kg N eq	3.77E+00	4.32E+00	8.21E+00	2.37E+00	3.32E+00	4.58E+00	4.40E+00	3.06E+00	3.72E+00
Freshwater ecotoxicity	CTUe	2.39E+03	2.95E+03	4.85E+03	1.70E+03	2.26E+03	2.87E+03	2.94E+03	2.10E+03	2.52E+03
Land use	kg C deficit	1.02E+04	1.21E+04	2.40E+04	6.52E+03	8.98E+03	1.20E+04	1.23E+04	8.29E+03	1.03E+04
Water resource depletion	m3 water eq	3.86E+02	3.84E+02	7.35E+02	2.33E+02	3.19E+02	4.56E+02	3.99E+02	2.97E+02	3.48E+02
Mineral, fossil & ren resource depletion	kg Sb eq	2.70E-01	2.83E-01	7.48E-01	3.22E-01	2.16E-01	4.02E-01	3.00E-01	2.63E-01	2.82E-01

Contribution by life cycle stages

Table 54 shows the contribution of different life cycle stages to the impact categories (based on the characterised inventory results before normalisation and weighting). The life cycle stages in orange are the ones identified as "most relevant" for the impact category, as they are contributing to more than 80% showing that there is a huge gap between the impact of the use phase (from 53% to 96%). Figure 23 and Table 55 summarise the contribution of the various life cycle phases to the overall impact per impact category. Compared to the baseline scenario a slight decrease (few percentages) in importance of the use phase is noticed and a slight increase in importance of the other life cycle stages.

Table 54. Contribution by life cycle stages of the BoP housing for the scenario of biobased/recycled wall insulation (SC3) compared to baseline (BL)

Climate change			Human toxicity, cancer			Particulate matter		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC3	*BL*		*SC3*	*BL*		*SC3*	*BL*
PRODUCTION	9	8	PRODUCTION	42	13	PRODUCTION	9	7
CONSTRUCTION	0.9	0.8	CONSTRUCTION	2.0	1.3	CONSTRUCTION	0.8	0.7
USE	90	91	USE	53	84	USE	85	87
MAINTENANCE	1.5	1.2	MAINTENANCE	3.0	2.7	MAINTENANCE	5.0	4.2
END OF LIFE	-1.5	-1.3	END OF LIFE	-0.1	-0.4	END OF LIFE	0.6	0.5
Ozone depletion			**Human toxicity, non-cancer**			**Ionizing radiation HH**		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC3	*BL*		*SC3*	*BL*		*SC3*	*BL*
PRODUCTION	4	4	PRODUCTION	14	40	PRODUCTION	4	4
CONSTRUCTION	0.92	0.81	CONSTRUCTION	1.5	1.9	CONSTRUCTION	0.8	0.7
USE	92	93	USE	82	56	USE	93	94
MAINTENANCE	1.6	1.3	MAINTENANCE	3.1	2.8	MAINTENANCE	1.1	1.0
END OF LIFE	0.86	0.76	END OF LIFE	-0.5	-0.1	END OF LIFE	0.6	0.6
Photochemical ozone formation			**Acidification**			**Terrestrial eutrophication**		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC3	*BL*		*SC3*	*BL*		*SC3*	*BL*
PRODUCTION	11	10	PRODUCTION	7	6	PRODUCTION	12	11
CONSTRUCTION	2.0	1.7	CONSTRUCTION	1.1	1.0	CONSTRUCTION	2.2	2.0
USE	84	86	USE	87	88	USE	81	83
MAINTENANCE	2.8	2.4	MAINTENANCE	4.4	3.9	MAINTENANCE	2.9	2.5
END OF LIFE	0.1	0.1	END OF LIFE	0.3	0.3	END OF LIFE	2.3	2.1
Freshwater eutrophication			**Marine eutrophication**			**Freshwater ecotoxicity**		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC3	*BL*		*SC3*	*BL*		*SC3*	*BL*
PRODUCTION	9	8	PRODUCTION	11	10	PRODUCTION	21	19
CONSTRUCTION	0.8	0.7	CONSTRUCTION	2.2	2.0	CONSTRUCTION	4.3	3.9
USE	91	92	USE	82	83	USE	69	72
MAINTENANCE	1.2	1.0	MAINTENANCE	2.7	2.3	MAINTENANCE	3.6	3.2
END OF LIFE	-2.0	-1.9	END OF LIFE	2.4	2.1	END OF LIFE	2.9	2.7
Land use			**Water resource depletion**			**Resource depletion**		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC3	*BL*		*SC3*	*BL*		*SC3*	*BL*
PRODUCTION	10	8	PRODUCTION	3	3	PRODUCTION	19	18
CONSTRUCTION	1.3	1.1	CONSTRUCTION	0.5	0.5	CONSTRUCTION	1.5	1.5
USE	86	88	USE	96	97	USE	57	59
MAINTENANCE	3.9	3.3	MAINTENANCE	0.4	0.3	MAINTENANCE	18.7	17.9
END OF LIFE	-0.9	-0.8	END OF LIFE	-0.5	-0.5	END OF LIFE	4.2	4.0

Figure 23. Contribution of life cycle phases of the BoP housing for the scenario biobased/recycled wall insulation

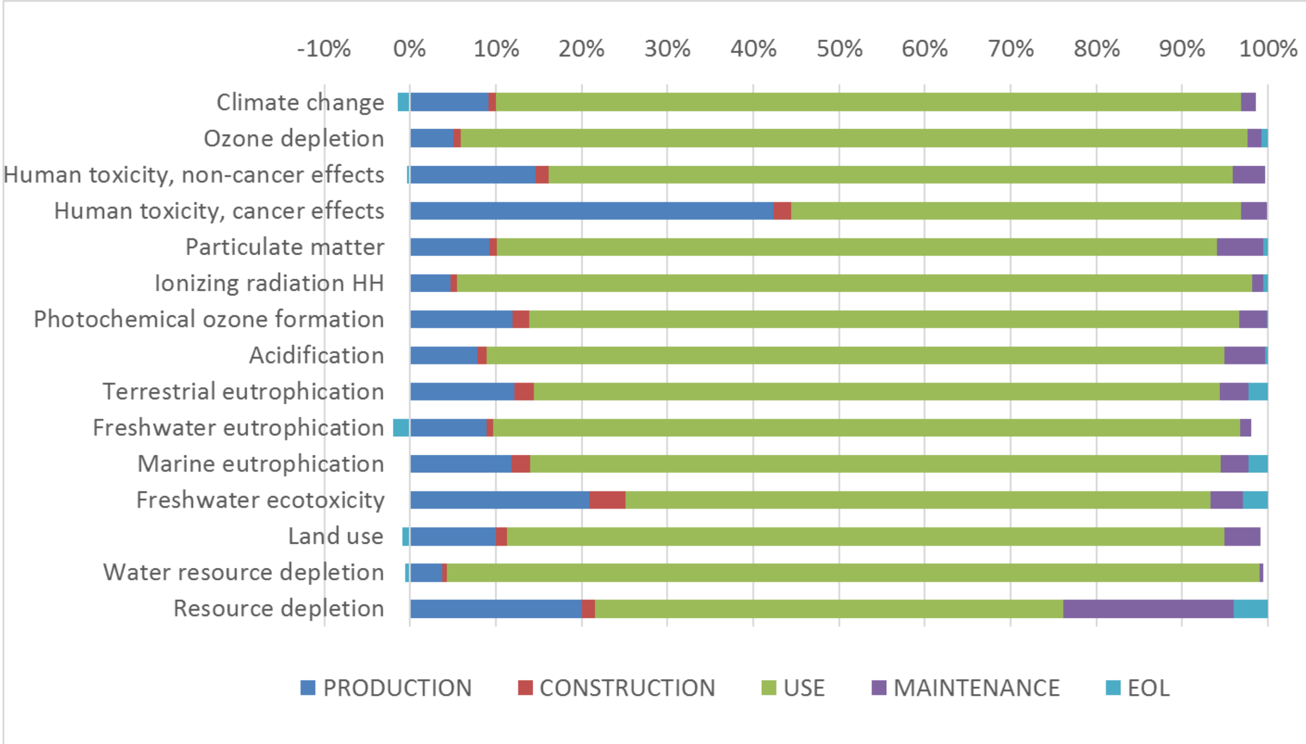


Table 55. Environmental impacts related to housing per person per year in EU-27 (total and per life cycle stages) for the scenario biobased/recycled wall insulation. A colour scale is applied to the results in each column from green (lowest contribution) to red (highest contribution).

Impact category	Unit	PRODUCTION	%	CONSTRUCTION	%	USE	%	Maintenance	%	EOL	%	TOTAL	%
Climate change	**kg CO2 eq**	2.20E+02	9.4	2.16E+01	0.92	2.10E+03	89	4.09E+01	1.7	-3.51E+01	-1.5	**2.35E+03**	**100**
Ozone depletion	**kg CFC-11 eq**	1.47E-05	5.0	2.71E-06	0.92	2.70E-04	92	4.58E-06	1.6	2.41E-06	0.8	**2.95E-04**	**100**
Human toxicity, non-cancer effects	**CTUh**	3.59E-05	14.8	3.60E-06	1.48	1.95E-04	80	9.23E-06	3.8	-8.61E-07	-0.4	**2.43E-04**	**100**
Human toxicity, cancer effects	**CTUh**	1.41E-05	42.5	6.69E-07	2.02	1.74E-05	53	1.01E-06	3.1	-4.61E-08	-0.1	**3.31E-05**	**100**
Particulate matter	**kg PM2.5 eq**	2.34E-01	9.3	1.94E-02	0.77	2.11E+00	84	1.36E-01	5.4	1.43E-02	0.6	**2.51E+00**	**100**
Ionizing radiation HH	**kBq U235 eq**	9.06E+00	4.7	1.53E+00	0.79	1.79E+02	93	2.55E+00	1.3	1.06E+00	0.5	**1.93E+02**	**100**
Photochemical ozone formation	**kg NMVOC eq**	6.62E-01	12.0	1.07E-01	1.94	4.57E+00	83	1.78E-01	3.2	7.58E-03	0.1	**5.53E+00**	**100**
Acidification	**molc H+ eq**	9.58E-01	7.8	1.29E-01	1.06	1.05E+01	86	5.89E-01	4.8	3.71E-02	0.3	**1.22E+01**	**100**
Terrestrial eutrophication	**molc N eq**	2.07E+00	12.2	3.78E-01	2.23	1.36E+01	80	5.65E-01	3.3	3.81E-01	2.2	**1.70E+01**	**100**
Freshwater eutrophication	**kg P eq**	1.31E-02	9.3	1.05E-03	0.75	1.27E-01	91	1.93E-03	1.4	-2.83E-03	-2.0	**1.40E-01**	**100**
Marine eutrophication	**kg N eq**	1.83E-01	11.8	3.42E-02	2.21	1.24E+00	80	4.92E-02	3.2	3.61E-02	2.3	**1.54E+00**	**100**
Freshwater ecotoxicity	**CTUe**	2.19E+02	20.9	4.41E+01	4.22	7.12E+02	68	3.95E+01	3.8	3.07E+01	2.9	**1.04E+03**	**100**
Land use	**kg C deficit**	4.35E+02	10.2	5.59E+01	1.31	3.62E+03	85	1.81E+02	4.3	-3.86E+01	-0.9	**4.25E+03**	**100**
Water resource depletion	**m3 water eq**	5.48E+00	3.8	7.33E-01	0.51	1.38E+02	96	6.73E-01	0.5	-8.16E-01	-0.6	**1.44E+02**	**100**
Mineral, fossil & ren resource depletion	**kg Sb eq**	2.35E-02	20.0	1.77E-03	1.51	6.41E-02	55	2.33E-02	19.8	4.69E-03	4.0	**1.17E-01**	**100**

8.5 Scenario 4 – Solar collector for domestic hot water

Description and aim:

The aim of this scenario is to assess the potential environmental benefits arising from producing hot water with renewable energy, i.e. solar energy.

Area of intervention:

- Hotspot addressed: the energy consumption during the use phase for domestic hot water.
- Whole basket – renovation and new buildings
- Life cycle stage: production + EoL phase (solar boiler) and use phase (energy consumption for the production of hot water)

Policy relevance: Energy and resource efficiency in the building sector

Rationale for building the scenario:

Renewable energy is seen as an important strategy within the EU to reduce the carbon emissions and increase resource efficiency in the building sector. A simple technology with relatively high benefits which can be applied at the level of the dwelling is a thermal solar boiler for the production of domestic hot water. For this reason, the installation of a solar boiler is selected as the third scenario.

Parameters modified in the model:

The following parameters are modified to model this scenario:

- Production phase: solar boiler (i.e. collectors. pump. control system and storage tank) is added to the inventory
- Construction phase: no changes
- Use phase: calculated production of hot water with solar boiler to be deducted from the baseline hot water production. The calculation of the production of hot water takes into account the climatic zone and the number of people in the dwelling.
- EoL phase: solar boiler EoL treatment

Assumptions for the calculation of the production of hot water with solar boiler are the following. A collector surface of 1.2 m²/person is assumed for both the single family and multifamily houses.

Based on expert judgement, for the single-family houses a storage tank of 250 litres is assumed in the warm climate, and 200 litres in the moderate and cold climate. For the multi-family houses, it is assumed that one large storage tank (2500 litres in the warm climate, 1400 litres in the moderate and 1000 litres in the cold climate) is installed for the whole building. These assumptions lead to the following modelling parameters:

Table 56. Size of solar collector (m²) / dwelling

	solar collector (m²)/dwelling							
	SFH				MFH			
	<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
zone 1	4.12	4.12	4.12	4.12	2.44	2.44	2.44	2.44
zone 2	3.25	3.25	3.25	3.25	2.46	2.46	2.46	2.46
zone 3	3.39	3.39	3.39	3.39	2.01	2.01	2.01	2.01

Table 57. Size of water storage tank (litres) / dwelling

	water storage tank (litres)/dwelling							
	SFH				MFH			
	<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
zone 1	250				=2500/16			
zone 2	200				=1400/16			
zone 3	200				=1000/16			

It is furthermore assumed that the inhabitants consume 60 litres of hot water per day, per person with the following characteristics:

- T_{in} (warm climate) = 15°C
- T_{in} (moderate climate) = 10°C
- T_{in} (clod climate) = 5°C
- T_{out} = 45°C

The solar boiler system contributes to the production of domestic hot water, resulting in a reduced need of additional water heating. The production by the solar boiler system has been calculated with dynamic energy simulations (Baldinelli, 2016) and have led to the results presented in Table 58. Table 59 summarizes the remaining annual energy demand for domestic hot water by the conventional system (i.e. not covered by the solar collector), expressed in kWh/dwelling*year. Both the amount of energy produced by the solar system as the remaining amount to be covered by the conventional systems (in line with the assumptions of the BoP baseline scenario) are summarised in the tables.

Table 58. Results dynamic energy simulations: annual energy production by solar collector system (kWh/dwelling*year)

	annual energy production solar collector (kWh)/dwelling							
	SFH				MFH			
	<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
zone 1	1,554	1,554	1,554	1,554	860	860	860	860
zone 2	439	439	439	439	397	397	397	397
zone 3	453	453	453	453	314	314	314	314

Table 59. Remaining annual energy demand for domestic hot water to be covered by the conventional system (kWh/dwelling*year)

	annual remaining energy demand to be covered by the conventional system (kWh)/dwelling							
	SFH				MFH			
	<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
zone 1	516	516	516	516	365	365	365	365
zone 2	2,403	2,403	2,403	2,403	1,747	1,747	1,747	1,747
zone 3	2,850	2,850	2,850	2,850	1,642	1,642	1,642	1,642

Results:

Table 60 and Table 61 summarise respectively the characterised and normalised results for the fourth scenario for the whole BoP housing stock, expressed as impact per EU citizen. In the last column of the tables, the results are also shown for the baseline scenario in order to get a first idea on the effect of this first intervention analysed.

Table 60. Characterised results. BoP housing scenario solar collector for DHW compared to baseline scenario (yearly impact EU citizen)

Impact category	Unit	Scenario solar collector for DHW	Baseline scenario
Climate change	kg CO_2 eq	2.56E+03	2.62E+03
Ozone depletion	kg CFC-11 eq	3.24E-04	3.33E-04
Human toxicity. non-cancer effects	CTUh	2.68E-04	2.70E-04
Human toxicity. cancer effects	CTUh	3.51E-05	3.48E-05
Particulate matter	kg $PM_{2.5}$ eq	2.85E+00	2.90E+00
Ionizing radiation HH	kBq U^{235} eq	2.01E+02	2.05E+02
Photochemical ozone formation	kg NMVOC eq	6.00E+00	6.11E+00
Acidification	molc H^+ eq	1.32E+01	1.34E+01
Terrestrial eutrophication	molc N eq	1.81E+01	1.84E+01
Freshwater eutrophication	kg P eq	1.48E-01	1.48E-01
Marine eutrophication	kg N eq	1.65E+00	1.68E+00
Freshwater ecotoxicity	CTUe	1.13E+03	1.14E+03
Land use	kg C deficit	4.74E+03	4.84E+03
Water resource depletion	m^3 water eq	1.47E+02	1.51E+02
Resource depletion	kg Sb eq	1.18E-01	1.18E-01

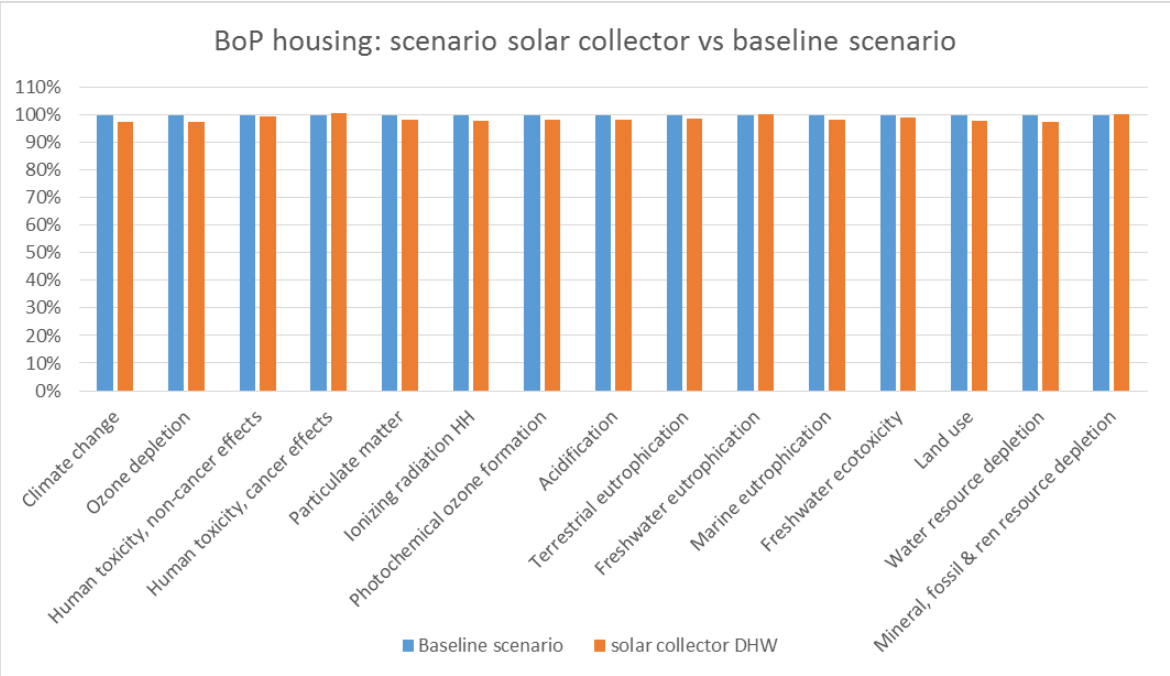
Table 61. Normalised results. BoP housing scenario solar collector for DHW compared to baseline scenario (yearly impact EU citizen)

Impact category	Scenario solar collector for DHW	Baseline scenario
Climate change	2.81E-01	2.89E-01
Ozone depletion	1.50E-02	1.54E-02
Human toxicity. non-cancer effects	5.03E-01	5.06E-01
Human toxicity. cancer effects	9.51E-01	9.42E-01
Particulate matter	7.48E-01	7.62E-01
Ionizing radiation HH	1.78E-01	1.81E-01
Photochemical ozone formation	1.89E-01	1.93E-01
Acidification	2.78E-01	2.83E-01
Terrestrial eutrophication	1.03E-01	1.05E-01
Freshwater eutrophication	1.00E-01	1.00E-01
Marine eutrophication	9.77E-02	9.94E-02
Freshwater ecotoxicity	1.29E-01	1.30E-01
Land use	6.35E-02	6.49E-02
Water resource depletion	1.81E+00	1.85E+00
Resource depletion	1.17E+00	1.17E+00

The comparison with the baseline scenario is also graphically presented in Figure 24 for the characterised results. The environmental impact of the BoP housing has reduced for the majority of the impact categories by 0.6% - 2.6% dependent on the impact category. Two impact categories have slightly increased in impact: human toxicity – cancer effects (0.9% increase) and resource depletion (0.2% increase).

The impact to human toxicity is mainly coming from the flat plate collector. Looking at the flat plate collector, the highest contribution comes from the aluminium and chromium steel and to a lesser extent from the copper. The slightly increased impact on resource depletion is coming from the additional materials used for the production of the solar collector itself.

Figure 24. Characterised results. BoP housing scenario solar collector for DHW compared to baseline scenario (yearly impact EU citizen)



When interpreting the results, it is worth noting that the heating of domestic hot water had the highest contribution in the use phase of the baseline (around 10%-15% in almost all the impact categories). The use phase contributed for 87% of the overall impact of the BoP housing on PM. Therefore, the contribution of domestic water heating was around 13% of the overall impact of the BoP on most of the impact categories. The reduction obtained through the implementation of this scenario is proportional to this contribution.

Table 62 shows the results per person. Table 63 reports the environmental impact associated to a single dwelling in each climatic zone taking into account the number of dwellings for each different age of construction and their impact (weighted average).

Compared to the baseline scenario, the environmental impact is reduced for each dwelling type in each climatic zone for the majority of the impact categories. The impact of the average EU housing has reduced for all impact categories with the highest reduction for ozone depletion (2.5%), climate change (2.4%), water resource depletion (2.3%) and ionizing radiation (2.1%). An increase in impact is identified for the impact categories human toxicity – cancer effects (0.9%) and for resource depletion (0.2%).

Table 62. Annual environmental impact per person. Each line has a green (lower impact) to red (higher impact) colour scale.

Impact categories		SFH_warm	SFH_moderate	SFH_cold	MFH_warm	MFH_moderate	MFH_cold	Average SFH	Average MFH	EU housing average
Climate change	kg CO2 eq	1.59E+03	2.83E+03	3.01E+03	1.80E+03	3.00E+03	2.95E+03	2.60E+03	2.58E+03	2.59E+03
Ozone depletion	kg CFC-11 eq	1.80E-04	3.51E-04	6.70E-04	2.04E-04	3.72E-04	6.26E-04	3.31E-04	3.25E-04	3.29E-04
Human toxicity, non-cancer effects	CTUh	1.95E-04	2.73E-04	4.90E-04	2.47E-04	2.80E-04	4.67E-04	2.67E-04	2.77E-04	2.71E-04
Human toxicity, cancer effects	CTUh	2.31E-05	3.61E-05	5.81E-05	3.04E-05	3.80E-05	6.33E-05	3.45E-05	3.65E-05	3.53E-05
Particulate matter	kg PM2.5 eq	2.07E+00	2.93E+00	5.35E+00	2.56E+00	2.92E+00	4.88E+00	2.86E+00	2.89E+00	2.87E+00
Ionizing radiation HH	kBq U235 eq	1.46E+02	2.01E+02	3.95E+02	1.57E+02	2.27E+02	3.83E+02	1.98E+02	2.10E+02	2.03E+02
Photochemical ozone formation	kg NMVOC eq	3.74E+00	6.50E+00	9.70E+00	4.24E+00	6.81E+00	9.24E+00	6.11E+00	6.02E+00	6.07E+00
Acidification	molc H+ eq	7.68E+00	1.44E+01	2.11E+01	8.54E+00	1.55E+01	2.02E+01	1.34E+01	1.33E+01	1.33E+01
Terrestrial eutrophication	molc N eq	1.22E+01	1.91E+01	3.31E+01	1.38E+01	1.99E+01	3.16E+01	1.83E+01	1.83E+01	1.83E+01
Freshwater eutrophication	kg P eq	1.08E-01	1.48E-01	2.86E-01	1.17E-01	1.68E-01	2.80E-01	1.46E-01	1.56E-01	1.50E-01
Marine eutrophication	kg N eq	1.11E+00	1.73E+00	3.04E+00	1.25E+00	1.82E+00	2.90E+00	1.67E+00	1.67E+00	1.67E+00
Freshwater ecotoxicity	CTUe	7.17E+02	1.21E+03	1.80E+03	8.98E+02	1.24E+03	1.82E+03	1.14E+03	1.15E+03	1.14E+03
Land use	kg C deficit	3.14E+03	5.02E+03	8.96E+03	3.73E+03	5.09E+03	7.76E+03	4.83E+03	4.73E+03	4.79E+03
Water resource depletion	m3 water eq	1.09E+02	1.48E+02	2.66E+02	1.13E+02	1.68E+02	2.70E+02	1.46E+02	1.53E+02	1.49E+02
Mineral, fossil & ren resource depletion	kg Sb eq	7.94E-02	1.12E-01	1.76E-01	1.61E-01	1.15E-01	1.99E-01	1.08E-01	1.35E-01	1.19E-01

Table 63. Annual environmental impact for a dwelling in EU-27. Results per dwelling: each line has a green (lower impact) to red (higher impact) color scale.

Impact categories		SFH_warm	SFH_moderate	SFH_cold	MFH_warm	MFH_moderate	MFH_cold	Average SFH	Average MFH	EU housing average
Climate change	kg CO2 eq	5.46E+03	7.68E+03	8.51E+03	3.66E+03	5.87E+03	4.94E+03	7.36E+03	5.05E+03	6.20E+03
Ozone depletion	kg CFC-11 eq	6.18E-04	9.52E-04	1.89E-03	4.14E-04	7.27E-04	1.05E-03	9.38E-04	6.36E-04	7.86E-04
Human toxicity, non-cancer effects	CTUh	6.68E-04	7.39E-04	1.39E-03	5.01E-04	5.52E-04	7.83E-04	7.54E-04	5.47E-04	6.50E-04
Human toxicity, cancer effects	CTUh	7.91E-05	9.78E-05	1.64E-04	6.16E-05	7.58E-05	1.06E-04	9.76E-05	7.25E-05	8.50E-05
Particulate matter	kg PM2.5 eq	7.10E+00	7.94E+00	1.51E+01	5.20E+00	5.76E+00	8.18E+00	8.10E+00	5.70E+00	6.89E+00
Ionizing radiation HH	kBq U235 eq	5.02E+02	5.45E+02	1.12E+03	3.19E+02	4.44E+02	6.41E+02	5.61E+02	4.11E+02	4.86E+02
Photochemical ozone formation	kg NMVOC eq	1.28E+01	1.76E+01	2.74E+01	8.61E+00	1.34E+01	1.55E+01	1.73E+01	1.18E+01	1.45E+01
Acidification	molc H+ eq	2.63E+01	3.89E+01	5.96E+01	1.73E+01	3.04E+01	3.38E+01	3.78E+01	2.60E+01	3.19E+01
Terrestrial eutrophication	molc N eq	4.20E+01	5.17E+01	9.37E+01	2.81E+01	3.92E+01	5.29E+01	5.19E+01	3.61E+01	4.39E+01
Freshwater eutrophication	kg P eq	3.69E-01	4.02E-01	8.10E-01	2.38E-01	3.30E-01	4.70E-01	4.13E-01	3.06E-01	3.59E-01
Marine eutrophication	kg N eq	3.81E+00	4.70E+00	8.60E+00	2.54E+00	3.57E+00	4.85E+00	4.72E+00	3.28E+00	4.00E+00
Freshwater ecotoxicity	CTUe	2.46E+03	3.27E+03	5.09E+03	1.82E+03	2.46E+03	3.04E+03	3.22E+03	2.27E+03	2.74E+03
Land use	kg C deficit	1.08E+04	1.36E+04	2.54E+04	7.56E+03	9.99E+03	1.30E+04	1.37E+04	9.31E+03	1.15E+04
Water resource depletion	m3 water eq	3.73E+02	4.03E+02	7.51E+02	2.30E+02	3.30E+02	4.53E+02	4.12E+02	3.02E+02	3.57E+02
Mineral, fossil & ren resource depletion	kg Sb eq	2.72E-01	3.02E-01	4.98E-01	3.26E-01	2.27E-01	3.34E-01	3.06E-01	2.68E-01	2.87E-01

Contribution by life cycle stages

Table 64 shows the contribution of different life cycle stages to the impact categories (based on the characterised inventory results before normalisation and weighting). The life cycle stages in orange are the ones identified as "most relevant" for the impact category, as they are contributing to more than 80% showing that there is a huge gap between the impact of the use phase (from 54% to 97%). Figure 25 and Table 65 summarise the contribution of the various life cycle phases to the overall impact per impact category. Compared to the baseline scenario a slight decrease (few percentages) in importance of the use phase is noticed and a slight increase in importance of the other life cycle stages.

Table 64. Contribution by life cycle stages of the BoP housing for the scenario solar collector for DHW (SC4) compared to baseline (BL)

Climate change			Human toxicity, cancer			Particulate matter		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC4	*BL*		*SC4*	*BL*		*SC4*	*BL*
PRODUCTION	8	8	PRODUCTION	41	13	PRODUCTION	9	7
CONSTRUCTION	0.9	0.8	CONSTRUCTION	2.0	1.3	CONSTRUCTION	0.7	0.7
USE	91	91	USE	54	84	USE	87	87
MAINTENANCE	1.5	1.2	MAINTENANCE	3.9	2.7	MAINTENANCE	4.4	4.2
END OF LIFE	-1.3	-1.3	END OF LIFE	-0.1	-0.4	END OF LIFE	0.5	0.5
Ozone depletion			**Human toxicity, non-cancer**			**Ionizing radiation HH**		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC4	*BL*		*SC4*	*BL*		*SC4*	*BL*
PRODUCTION	4	4	PRODUCTION	13	40	PRODUCTION	4	4
CONSTRUCTION	0.86	0.81	CONSTRUCTION	1.4	1.9	CONSTRUCTION	0.8	0.7
USE	93	93	USE	82	56	USE	94	94
MAINTENANCE	1.3	1.3	MAINTENANCE	3.5	2.8	MAINTENANCE	1.2	1.0
END OF LIFE	0.95	0.76	END OF LIFE	-0.5	-0.1	END OF LIFE	0.7	0.6
Photochemical ozone formation			**Acidification**			**Terrestrial eutrophication**		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC4	*BL*		*SC4*	*BL*		*SC4*	*BL*
PRODUCTION	11	10	PRODUCTION	7	6	PRODUCTION	11	11
CONSTRUCTION	1.8	1.7	CONSTRUCTION	1.0	1.0	CONSTRUCTION	2.1	2.0
USE	85	86	USE	88	88	USE	82	83
MAINTENANCE	2.7	2.4	MAINTENANCE	4.2	3.9	MAINTENANCE	2.8	2.5
END OF LIFE	0.1	0.1	END OF LIFE	0.3	0.3	END OF LIFE	2.0	2.1
Freshwater eutrophication			**Marine eutrophication**			**Freshwater ecotoxicity**		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC4	*BL*		*SC4*	*BL*		*SC4*	*BL*
PRODUCTION	9	8	PRODUCTION	10	10	PRODUCTION	19	19
CONSTRUCTION	0.8	0.7	CONSTRUCTION	2.1	2.0	CONSTRUCTION	3.9	3.9
USE	90	92	USE	83	83	USE	70	72
MAINTENANCE	2.3	1.0	MAINTENANCE	2.7	2.3	MAINTENANCE	3.8	3.2
END OF LIFE	-2.0	-1.9	END OF LIFE	2.1	2.1	END OF LIFE	2.7	2.7
Land use			**Water resource depletion**			**Resource depletion**		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC4	*BL*		*SC4*	*BL*		*SC4*	*BL*
PRODUCTION	9	8	PRODUCTION	3	3	PRODUCTION	19	18
CONSTRUCTION	1.2	1.1	CONSTRUCTION	0.5	0.5	CONSTRUCTION	1.5	1.5
USE	88	88	USE	97	97	USE	57	59
MAINTENANCE	3.4	3.3	MAINTENANCE	0.4	0.3	MAINTENANCE	18.2	17.9
END OF LIFE	-0.8	-0.8	END OF LIFE	-0.5	-0.5	END OF LIFE	4.7	4.0

Figure 25. Contribution of life cycle phases of the BoP housing for the scenario solar collector for DHW

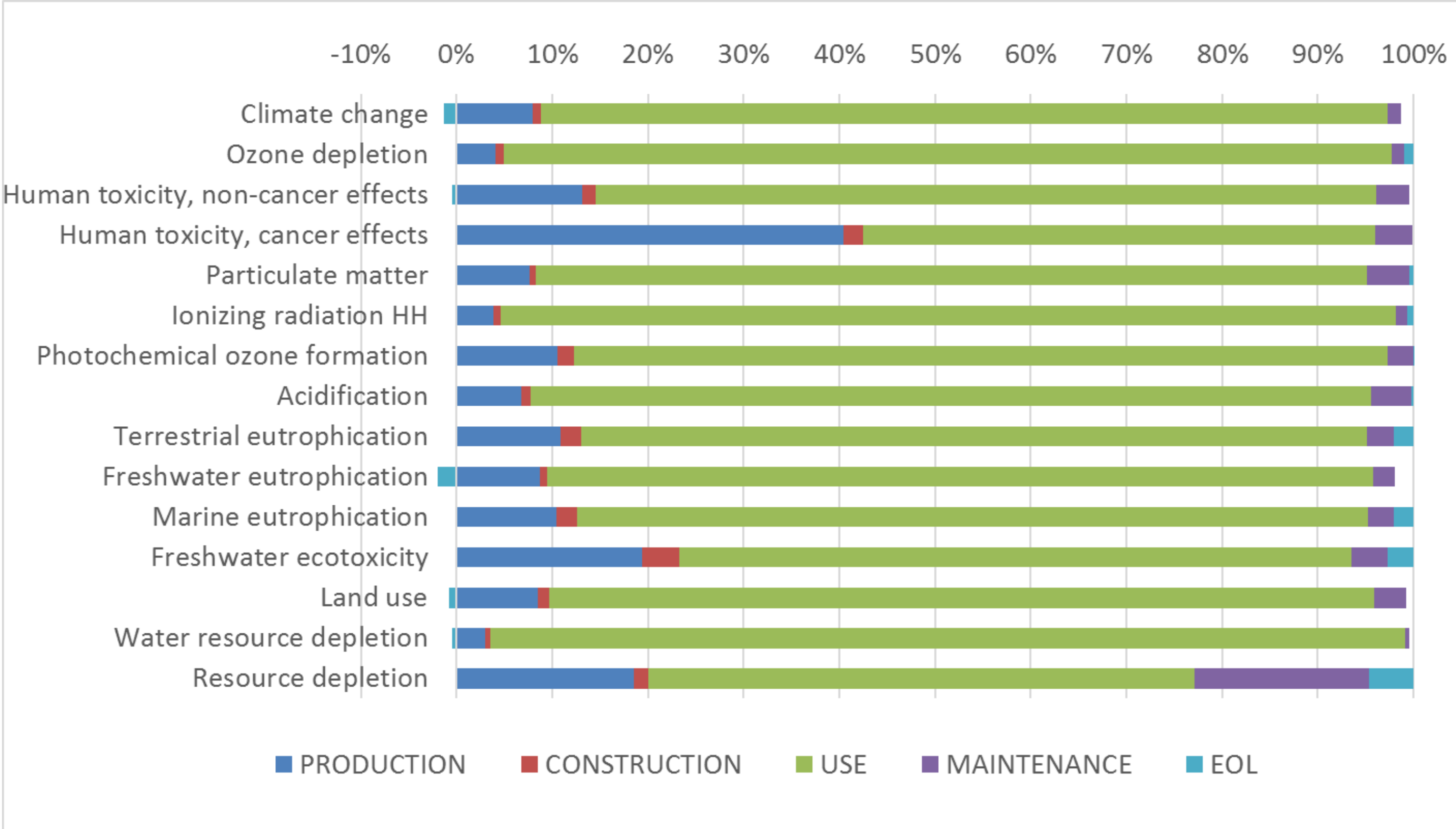


Table 65. Environmental impacts related to housing per person per year in EU-27 (total and per life cycle stages) for the scenario solar collector. A colour scale is applied to the results in each column from green (lowest contribution) to red (highest contribution).

Impact category	Unit	PRODUCTION	%	CONSTRUCTION	%	USE	%	Maintenance	%	EOL	%	TOTAL	%
Climate change	**kg CO2 eq**	2.09E+02	8.2	2.21E+01	0.86	2.32E+03	91	3.75E+01	1.5	-3.44E+01	-1.3	**2.56E+03**	**100**
Ozone depletion	**kg CFC-11 eq**	1.32E-05	4.1	2.78E-06	0.86	3.01E-04	93	4.21E-06	1.3	3.07E-06	0.9	**3.24E-04**	**100**
Human toxicity, non-cancer effects	**CTUh**	3.57E-05	13.3	3.67E-06	1.37	2.21E-04	82	9.43E-06	3.5	-1.21E-06	-0.5	**2.68E-04**	**100**
Human toxicity, cancer effects	**CTUh**	1.42E-05	40.6	6.91E-07	1.97	1.88E-05	54	1.36E-06	3.9	-4.18E-08	-0.1	**3.51E-05**	**100**
Particulate matter	**kg PM2.5 eq**	2.17E-01	7.6	1.95E-02	0.68	2.47E+00	87	1.26E-01	4.4	1.29E-02	0.5	**2.85E+00**	**100**
Ionizing radiation HH	**kBq U235 eq**	7.76E+00	3.9	1.57E+00	0.78	1.88E+02	94	2.32E+00	1.2	1.33E+00	0.7	**2.01E+02**	**100**
Photochemical ozone formation	**kg NMVOC eq**	6.31E-01	10.5	1.10E-01	1.83	5.10E+00	85	1.61E-01	2.7	4.05E-03	0.1	**6.00E+00**	**100**
Acidification	**molc H+ eq**	8.89E-01	6.7	1.31E-01	1.00	1.16E+01	88	5.55E-01	4.2	3.45E-02	0.3	**1.32E+01**	**100**
Terrestrial eutrophication	**molc N eq**	1.97E+00	10.9	3.86E-01	2.13	1.49E+01	82	5.07E-01	2.8	3.70E-01	2.0	**1.81E+01**	**100**
Freshwater eutrophication	**kg P eq**	1.35E-02	9.1	1.12E-03	0.76	1.33E-01	90	3.42E-03	2.3	-3.04E-03	-2.0	**1.48E-01**	**100**
Marine eutrophication	**kg N eq**	1.73E-01	10.5	3.49E-02	2.11	1.36E+00	83	4.49E-02	2.7	3.40E-02	2.1	**1.65E+00**	**100**
Freshwater ecotoxicity	**CTUe**	2.19E+02	19.4	4.45E+01	3.93	7.94E+02	70	4.31E+01	3.8	3.08E+01	2.7	**1.13E+03**	**100**
Land use	**kg C deficit**	4.08E+02	8.6	5.67E+01	1.20	4.14E+03	88	1.63E+02	3.4	-3.55E+01	-0.8	**4.74E+03**	**100**
Water resource depletion	**m3 water eq**	4.51E+00	3.1	7.31E-01	0.50	1.42E+02	97	5.52E-01	0.4	-7.18E-01	-0.5	**1.47E+02**	**100**
Mineral, fossil & ren resource depletion	**kg Sb eq**	2.19E-02	18.5	1.77E-03	1.50	6.75E-02	57	2.16E-02	18.2	5.53E-03	4.7	**1.18E-01**	**100**

8.6 Scenario 5 – Floor finishing with bio-based materials

Description and aim:

The aim of this scenario is to assess the potential environmental benefits arising from using bio-based floor finishes (i.e. hardwood parquet).

Area of intervention:

- Hotspot addressed: ceramic tiles (and finishing materials in general) were identified as one of the hotspots in the production phase (i.e. for freshwater ecotoxicity & resource depletion) and the maintenance/replacement phase (i.e. for particulate matter).
- Whole basket
- Life cycle stage: production phase and maintenance/replacement phase

Policy relevance: Resource efficiency in the building sector

Rationale for building the scenario:

The importance of ensuring that the wood and wood-based materials used in the construction and renovation of buildings are sourced from legal and sustainable sources is a policy objective at EU level. Wood construction materials are renewable raw materials. As such their continued availability is dependent on the management of forests as biological systems and habitats. This factor is also the subject of ongoing debate in the LCA community and efforts are done to properly account for the potential environmental effects of forestry.

Parameters modified in the model:

The following parameters are modified to model this scenario:

- Production: replace ceramic tiles by hardwood parquet for the floors
- Construction phase: no changes
- Use phase (maintenance): replacements of floor changes from ceramic tiles to hardwood parquet for the floors
- EoL phase: change from ceramic tiles to hardwood parquet for the floors

Results:

Table 66 and Table 67 summarise respectively the characterised and normalised results for the fifth scenario for the whole BoP housing stock, expressed as impact per EU citizen. In the last column of the tables, the results are also shown for the baseline scenario in order to get a first idea on the effect of this first intervention analysed.

Table 66. Characterised results. BoP housing scenario biobased floor finishing compared to baseline scenario (yearly impact EU citizen)

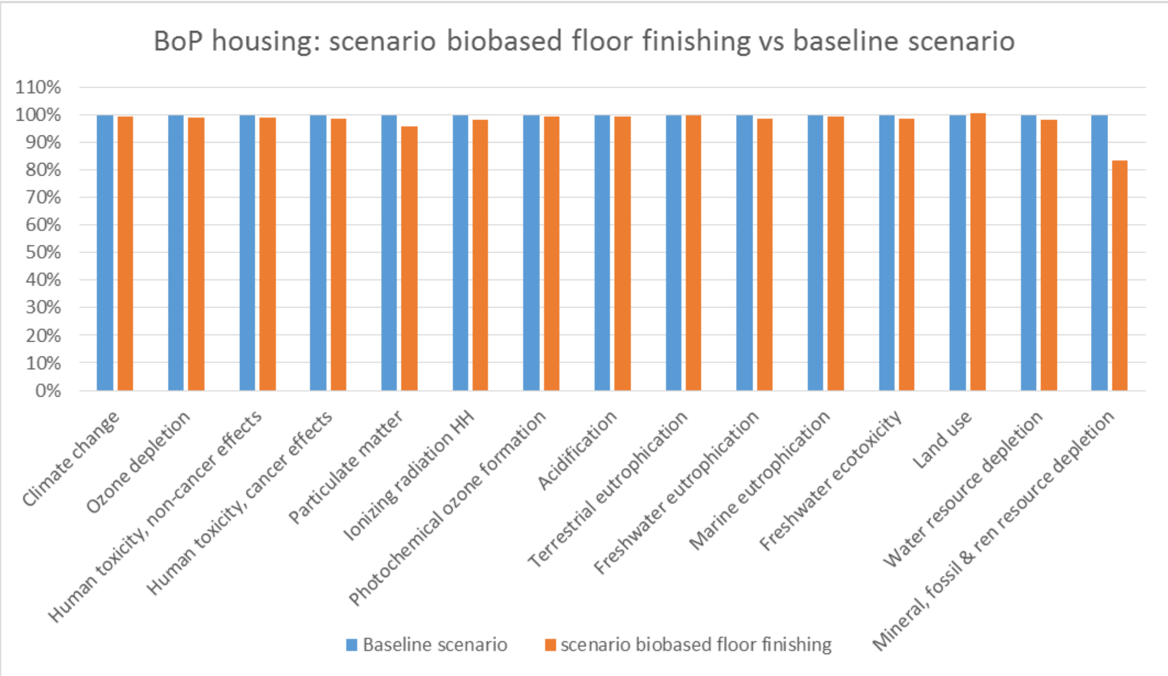
Impact category	Unit	Scenario biobased floor finish	Baseline scenario
Climate change	kg CO_2 eq	2.60E+03	2.62E+03
Ozone depletion	kg CFC-11 eq	3.30E-04	3.33E-04
Human toxicity. non-cancer effects	CTUh	2.68E-04	2.70E-04
Human toxicity. cancer effects	CTUh	3.43E-05	3.48E-05
Particulate matter	kg $PM_{2.5}$ eq	2.78E+00	2.90E+00
Ionizing radiation HH	kBq U^{235} eq	2.02E+02	2.05E+02
Photochemical ozone formation	kg NMVOC eq	6.09E+00	6.11E+00
Acidification	molc H^+ eq	1.33E+01	1.34E+01
Terrestrial eutrophication	molc N eq	1.84E+01	1.84E+01
Freshwater eutrophication	kg P eq	1.46E-01	1.48E-01
Marine eutrophication	kg N eq	1.67E+00	1.68E+00
Freshwater ecotoxicity	CTUe	1.12E+03	1.14E+03
Land use	kg C deficit	4.87E+03	4.84E+03
Water resource depletion	m^3 water eq	1.48E+02	1.51E+02
Resource depletion	kg Sb eq	9.86E-02	1.18E-01

Table 67. Normalised results. BoP housing scenario biobased floor finishing compared to baseline scenario (yearly impact EU citizen)

Impact category	Scenario biobased floor finish	Baseline scenario
Climate change	2.86E-01	2.89E-01
Ozone depletion	1.53E-02	1.54E-02
Human toxicity. non-cancer effects	5.02E-01	5.06E-01
Human toxicity. cancer effects	9.30E-01	9.42E-01
Particulate matter	7.32E-01	7.62E-01
Ionizing radiation HH	1.78E-01	1.81E-01
Photochemical ozone formation	1.92E-01	1.93E-01
Acidification	2.81E-01	2.83E-01
Terrestrial eutrophication	1.04E-01	1.05E-01
Freshwater eutrophication	9.89E-02	1.00E-01
Marine eutrophication	9.89E-02	9.94E-02
Freshwater ecotoxicity	1.28E-01	1.30E-01
Land use	6.53E-02	6.49E-02
Water resource depletion	1.82E+00	1.85E+00
Resource depletion	9.76E-01	1.17E+00

The comparison with the baseline scenario is also graphically presented in Figure 26 for the characterised results. The environmental impact of the BoP housing has reduced for all impact categories by 0.3% -16.4%, except for land use (increase of 0.7%).

Figure 26. Characterised results. BoP housing scenario biobased floor finishing compared to baseline scenario (yearly impact EU citizen)



When interpreting the results, it is worth noting that this scenario acts on the materials used for flooring (ceramic tiles in the baseline), which was a hotspot for the production phase of the baseline. The highest contribution of production phase was on abiotic resource depletion (ADP) (60% of the total impact of ADP in the production phase). The production phase contributed for 18% of the overall impact of the BoP housing on ADP. Therefore, the contribution of the ceramic tiles was 10% of the overall impact of the BoP on ADP. The reduction obtained through the implementation of this scenario is proportional to this contribution.

Table 68 and Table 69 show the results of the environmental impact associated to a single dwelling in each climatic zone taking into account the number of dwellings for each different age of construction and their impact (weighted average).

Compared to the baseline scenario, the environmental impact is reduced for each dwelling type in both the warm and moderate climatic zone for all impact categories except for land use. For the latter a slight increase is identified. The impact of the average EU housing has reduced for all impact categories except for land use, with the highest reduction for resource depletion (16.4%), followed by particulate matter (3.9%).

Table 68. Annual environmental impact per person. Each line has a green (lower impact) to red (higher impact) colour scale.

Impact categories		SFH_warm	SFH_moderate	SFH_cold	MFH_warm	MFH_moderate	MFH_cold	Average SFH	Average MFH	EU housing average
Climate change	kg CO2 eq	1.71E+03	2.85E+03	3.04E+03	1.90E+03	3.02E+03	2.97E+03	2.64E+03	2.62E+03	2.63E+03
Ozone depletion	kg CFC-11 eq	1.94E-04	3.54E-04	6.83E-04	2.15E-04	3.76E-04	6.35E-04	3.37E-04	3.32E-04	3.35E-04
Human toxicity, non-cancer effects	CTUh	1.96E-04	2.71E-04	4.92E-04	2.47E-04	2.80E-04	4.66E-04	2.66E-04	2.77E-04	2.70E-04
Human toxicity, cancer effects	CTUh	2.24E-05	3.50E-05	5.81E-05	2.98E-05	3.75E-05	6.34E-05	3.36E-05	3.60E-05	3.46E-05
Particulate matter	kg PM2.5 eq	2.03E+00	2.86E+00	5.41E+00	2.46E+00	2.87E+00	4.89E+00	2.80E+00	2.82E+00	2.81E+00
Ionizing radiation HH	kBq U235 eq	1.52E+02	2.01E+02	4.00E+02	1.61E+02	2.27E+02	3.86E+02	1.99E+02	2.11E+02	2.04E+02
Photochemical ozone formation	kg NMVOC eq	3.93E+00	6.55E+00	9.81E+00	4.40E+00	6.87E+00	9.30E+00	6.18E+00	6.12E+00	6.16E+00
Acidification	molc H+ eq	8.10E+00	1.44E+01	2.13E+01	8.87E+00	1.56E+01	2.03E+01	1.35E+01	1.34E+01	1.35E+01
Terrestrial eutrophication	molc N eq	1.27E+01	1.92E+01	3.35E+01	1.42E+01	2.01E+01	3.18E+01	1.85E+01	1.86E+01	1.85E+01
Freshwater eutrophication	kg P eq	1.09E-01	1.45E-01	2.86E-01	1.16E-01	1.66E-01	2.79E-01	1.44E-01	1.54E-01	1.48E-01
Marine eutrophication	kg N eq	1.16E+00	1.75E+00	3.08E+00	1.29E+00	1.83E+00	2.92E+00	1.69E+00	1.69E+00	1.69E+00
Freshwater ecotoxicity	CTUe	7.27E+02	1.19E+03	1.81E+03	9.01E+02	1.24E+03	1.83E+03	1.13E+03	1.15E+03	1.13E+03
Land use	kg C deficit	3.36E+03	5.13E+03	9.08E+03	3.95E+03	5.21E+03	7.81E+03	4.95E+03	4.89E+03	4.92E+03
Water resource depletion	m3 water eq	1.12E+02	1.49E+02	2.68E+02	1.15E+02	1.68E+02	2.83E+02	1.47E+02	1.55E+02	1.50E+02
Mineral, fossil & ren resource depletion	kg Sb eq	6.26E-02	9.10E-02	1.77E-01	1.34E-01	9.57E-02	1.99E-01	8.91E-02	1.14E-01	9.95E-02

Table 69. Annual environmental impact for a dwelling in EU-27. Results per dwelling: each line has a green (lower impact) to red (higher impact) color scale.

Impact categories		SFH_warm	SFH_moderate	SFH_cold	MFH_warm	MFH_moderate	MFH_cold	Average SFH	Average MFH	EU housing average
Climate change	kg CO2 eq	5.87E+03	7.73E+03	8.61E+03	3.85E+03	4.42E+03	4.97E+03	7.48E+03	4.25E+03	5.86E+03
Ozone depletion	kg CFC-11 eq	6.64E-04	9.59E-04	1.93E-03	4.37E-04	5.51E-04	1.06E-03	9.53E-04	5.40E-04	7.45E-04
Human toxicity, non-cancer effects	CTUh	6.73E-04	7.34E-04	1.39E-03	5.02E-04	4.09E-04	7.80E-04	7.51E-04	4.62E-04	6.06E-04
Human toxicity, cancer effects	CTUh	7.69E-05	9.50E-05	1.64E-04	6.05E-05	5.37E-05	1.06E-04	9.50E-05	5.90E-05	7.69E-05
Particulate matter	kg PM2.5 eq	6.97E+00	7.75E+00	1.53E+01	5.00E+00	4.25E+00	8.20E+00	7.94E+00	4.73E+00	6.32E+00
Ionizing radiation HH	kBq U235 eq	5.22E+02	5.44E+02	1.13E+03	3.26E+02	3.27E+02	6.46E+02	5.64E+02	3.44E+02	4.54E+02
Photochemical ozone formation	kg NMVOC eq	1.35E+01	1.78E+01	2.77E+01	8.93E+00	1.01E+01	1.56E+01	1.75E+01	1.00E+01	1.37E+01
Acidification	molc H+ eq	2.78E+01	3.91E+01	6.02E+01	1.80E+01	2.31E+01	3.40E+01	3.82E+01	2.19E+01	3.00E+01
Terrestrial eutrophication	molc N eq	4.37E+01	5.20E+01	9.47E+01	2.89E+01	2.94E+01	5.32E+01	5.24E+01	3.05E+01	4.14E+01
Freshwater eutrophication	kg P eq	3.73E-01	3.94E-01	8.10E-01	2.36E-01	2.39E-01	4.67E-01	4.08E-01	2.51E-01	3.29E-01
Marine eutrophication	kg N eq	3.96E+00	4.73E+00	8.70E+00	2.62E+00	2.68E+00	4.88E+00	4.77E+00	2.78E+00	3.77E+00
Freshwater ecotoxicity	CTUe	2.49E+03	3.23E+03	5.13E+03	1.83E+03	1.80E+03	3.06E+03	3.19E+03	1.88E+03	2.53E+03
Land use	kg C deficit	1.15E+04	1.39E+04	2.57E+04	8.02E+03	7.73E+03	1.31E+04	1.40E+04	8.12E+03	1.11E+04
Water resource depletion	m3 water eq	3.86E+02	4.03E+02	7.58E+02	2.34E+02	2.40E+02	4.75E+02	4.15E+02	2.51E+02	3.32E+02
Mineral, fossil & ren resource depletion	kg Sb eq	2.15E-01	2.47E-01	5.00E-01	2.72E-01	1.40E-01	3.34E-01	2.52E-01	1.97E-01	2.24E-01

Contribution by life cycle stages

Table 70 shows the contribution of different life cycle stages to the impact categories (based on the characterised inventory results before normalisation and weighting). The life cycle stages in orange are the ones identified as "most relevant" for the impact category, as they are contributing to more than 80% showing that there is a huge gap between the impact of the use phase (from 56% to 98%). Figure 27 and Table 71 summarise the contribution of the various life cycle phases to the overall impact per impact category.

Table 70. Contribution by life cycle stages of the BoP housing for the scenario biobased floor finishing (SC5) compared to baseline (BL)

Climate change			Human toxicity, cancer			Particulate matter		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC5	*BL*		*SC5*	*BL*		*SC5*	*BL*
PRODUCTION	8	8	PRODUCTION	40	13	PRODUCTION	6	7
CONSTRUCTION	0.8	0.8	CONSTRUCTION	1.9	1.3	CONSTRUCTION	0.6	0.7
USE	92	91	USE	56	84	USE	91	87
MAINTENANCE	0.8	1.2	MAINTENANCE	2.2	2.7	MAINTENANCE	2.3	4.2
END OF LIFE	-1.6	-1.3	END OF LIFE	-0.2	-0.4	END OF LIFE	0.4	0.5
Ozone depletion			**Human toxicity, non-cancer**			**Ionizing radiation HH**		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC5	*BL*		*SC5*	*BL*		*SC5*	*BL*
PRODUCTION	4	4	PRODUCTION	12	40	PRODUCTION	4	4
CONSTRUCTION	0.82	0.81	CONSTRUCTION	1.3	1.9	CONSTRUCTION	0.8	0.7
USE	94	93	USE	84	56	USE	96	94
MAINTENANCE	0.9	1.3	MAINTENANCE	2.3	2.8	MAINTENANCE	0.2	1.0
END OF LIFE	0.52	0.76	END OF LIFE	-0.4	-0.1	END OF LIFE	0.0	0.6
Photochemical ozone formation			**Acidification**			**Terrestrial eutrophication**		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC5	*BL*		*SC5*	*BL*		*SC5*	*BL*
PRODUCTION	10	10	PRODUCTION	6	6	PRODUCTION	10	11
CONSTRUCTION	1.8	1.7	CONSTRUCTION	1.0	1.0	CONSTRUCTION	2.1	2.0
USE	86	86	USE	89	88	USE	83	83
MAINTENANCE	2.2	2.4	MAINTENANCE	3.4	3.9	MAINTENANCE	2.2	2.5
END OF LIFE	0.0	0.1	END OF LIFE	0.0	0.3	END OF LIFE	1.9	2.1
Freshwater eutrophication			**Marine eutrophication**			**Freshwater ecotoxicity**		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC5	*BL*		*SC5*	*BL*		*SC5*	*BL*
PRODUCTION	8	8	PRODUCTION	10	10	PRODUCTION	18	19
CONSTRUCTION	0.7	0.7	CONSTRUCTION	2.0	2.0	CONSTRUCTION	3.9	3.9
USE	93	92	USE	84	83	USE	73	72
MAINTENANCE	0.3	1.0	MAINTENANCE	2.1	2.3	MAINTENANCE	2.5	3.2
END OF LIFE	-2.4	-1.9	END OF LIFE	2.0	2.1	END OF LIFE	2.6	2.7
Land use			**Water resource depletion**			**Resource depletion**		
Life cycle stage	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*		*Life cycle stage*	*Contrib. (%)*	
	SC5	*BL*		*SC5*	*BL*		*SC5*	*BL*
PRODUCTION	9	8	PRODUCTION	3	3	PRODUCTION	12.3	18
CONSTRUCTION	1.2	1.1	CONSTRUCTION	0.5	0.5	CONSTRUCTION	1.4	1.5
USE	87	88	USE	98	97	USE	70	59
MAINTENANCE	3.6	3.3	MAINTENANCE	-0.5	0.3	MAINTENANCE	11.7	17.9
END OF LIFE	-0.9	-0.8	END OF LIFE	-1.2	-0.5	END OF LIFE	4.5	4.0

Figure 27. Contribution of life cycle phases of the BoP housing for the scenario bio-based floor finishing

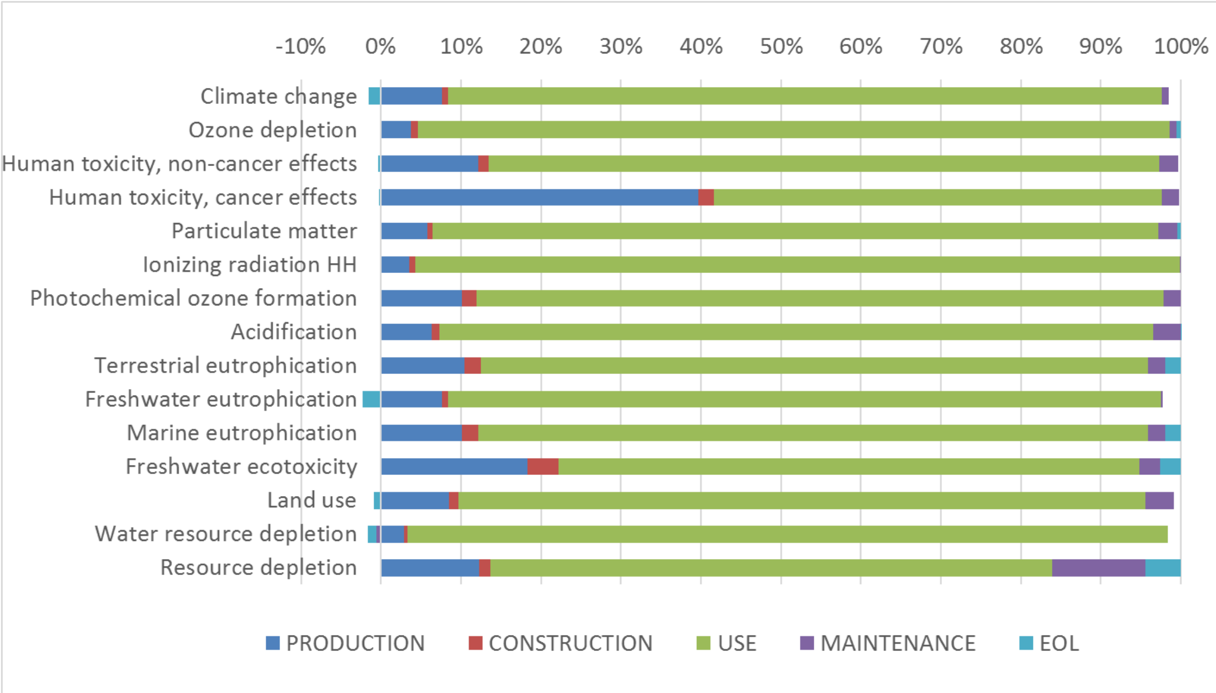


Table 71. Environmental impacts related to housing per person per year in EU-27 (total and per life cycle stages) for the scenario biobased floor finishing. A colour scale is applied to the results in each column from green (lowest contribution) to red (highest contribution).

Impact category	Unit	PRODUCTION	%	CONSTRUCTION	%	USE	%	Maintenance	%	EOL	%	TOTAL	%
Climate change	**kg CO2 eq**	2.05E+02	7.9	2.15E+01	0.83	2.40E+03	92	2.11E+01	0.8	-4.19E+01	-1.6	**2.60E+03**	**100**
Ozone depletion	**kg CFC-11 eq**	1.25E-05	3.8	2.70E-06	0.82	3.10E-04	94	3.09E-06	0.9	1.70E-06	0.5	**3.30E-04**	**100**
Human toxicity, non-cancer effects	**CTUh**	3.29E-05	12.3	3.52E-06	1.31	2.26E-04	84	6.25E-06	2.3	-1.06E-06	-0.4	**2.68E-04**	**100**
Human toxicity, cancer effects	**CTUh**	1.37E-05	39.8	6.62E-07	1.93	1.93E-05	56	7.57E-07	2.2	-6.37E-08	-0.2	**3.43E-05**	**100**
Particulate matter	**kg PM2.5 eq**	1.61E-01	5.8	1.71E-02	0.61	2.53E+00	91	6.54E-02	2.3	1.19E-02	0.4	**2.79E+00**	**100**
Ionizing radiation HH	**kBq U235 eq**	7.25E+00	3.6	1.52E+00	0.75	1.93E+02	96	3.20E-01	0.2	-2.10E-02	0.0	**2.02E+02**	**100**
Photochemical ozone formation	**kg NMVOC eq**	6.18E-01	10.2	1.07E-01	1.76	5.23E+00	86	1.31E-01	2.2	-7.93E-04	0.0	**6.09E+00**	**100**
Acidification	**molc H+ eq**	8.47E-01	6.4	1.28E-01	0.96	1.19E+01	89	4.57E-01	3.4	1.95E-03	0.0	**1.33E+01**	**100**
Terrestrial eutrophication	**molc N eq**	1.92E+00	10.5	3.77E-01	2.05	1.53E+01	83	4.02E-01	2.2	3.54E-01	1.9	**1.84E+01**	**100**
Freshwater eutrophication	**kg P eq**	1.18E-02	8.0	1.04E-03	0.71	1.37E-01	93	4.03E-04	0.3	-3.50E-03	-2.4	**1.46E-01**	**100**
Marine eutrophication	**kg N eq**	1.69E-01	10.1	3.41E-02	2.04	1.40E+00	84	3.49E-02	2.1	3.35E-02	2.0	**1.67E+00**	**100**
Freshwater ecotoxicity	**CTUe**	2.06E+02	18.3	4.38E+01	3.89	8.17E+02	73	2.84E+01	2.5	2.96E+01	2.6	**1.12E+03**	**100**
Land use	**kg C deficit**	4.24E+02	8.7	5.64E+01	1.16	4.26E+03	87	1.74E+02	3.6	-4.39E+01	-0.9	**4.87E+03**	**100**
Water resource depletion	**m3 water eq**	4.40E+00	3.0	7.31E-01	0.49	1.46E+02	98	-7.81E-01	-0.5	-1.71E+00	-1.2	**1.48E+02**	**100**
Mineral, fossil & ren resource depletion	**kg Sb eq**	1.21E-02	12.3	1.37E-03	1.39	6.93E-02	70	1.15E-02	11.7	4.40E-03	4.5	**9.87E-02**	**100**

8.7 Scenario 6 – Timber frame

Description and aim:

This scenario aims to assess the potential benefits arising from using bio-based materials in the building structure. The results are referred to one single dwelling and represents an example of the potential benefits achievable by using bio-based materials for new buildings in moderate climate, as a case-study.

Area of intervention:

- Hotspot: Human toxicity cancer effect is one of the three most relevant impact categories of the BoP housing and the 42% is due to the reinforcing steel used by the reinforced concrete massive components. Bio-based materials in structural and non-structural components have the potential of at least partially replace reinforcing steel and more in general massive systems and therefore to reduce the environmental impact across the whole life cycle of EU buildings.
- "Representative product" within the basket (newly built single family house in moderate climate)
- Life cycle stage: production phase

Policy relevance: Resource efficient material flows and urban pressures on land and habitats

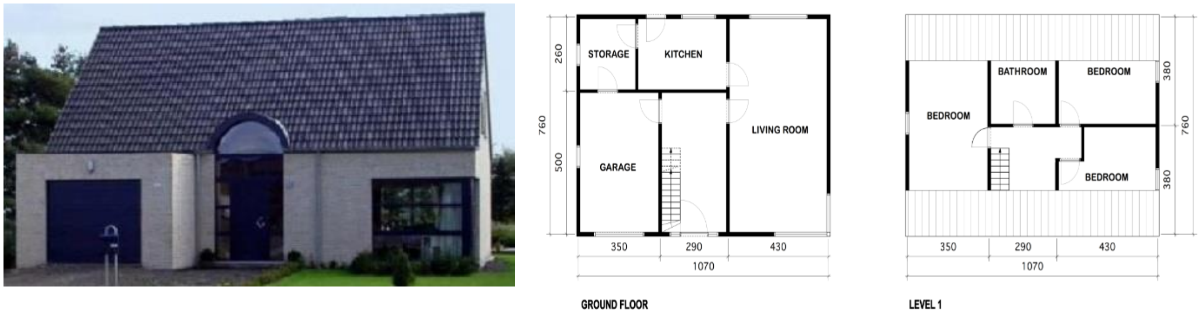
Rationale for building the scenario:

The potential for an increase in wood-based construction is a relevant policy topic. The importance of ensuring that the wood and wood-based materials used in the construction and renovation of buildings are sourced from legal and sustainable sources is a policy objective at EU level. Wood construction materials are renewable raw materials. As such their continued availability is dependent on the management of forests as biological systems and habitats. This factor is also the subject of ongoing debate in the LCA community and efforts are done to properly account for the potential environmental effects of forestry.

This scenario is not suitable for being built by varying a parameter in the baseline, because it implies a completely different construction approach. Therefore, to better account for potential effects of the scenario in terms of variation of environmental impacts, a detailed case study is used to compare the standard frame and the timber one.

As case-study it has been chosen a detached house with two floors (ground floor and 1 upper floor under the pitched roof), located in Belgium (Figure 28). Since the house is a relatively new construction located in a moderate climatic zone, the "product" SFH_Moderate_1990-2010 from the BoP housing has been selected as benchmark scenario. The dwelling has a total floor area of 159 m² and ground floor area of 81 m². As the dwelling area is larger than the 100 m² which was identified as the most representative size in the BoP for this "product category", the building is resized to 100 m² for the calculation of the bill of materials.

Figure 28. Picture and floor plan of the representative detached single-family house.



Two variants of the detached dwelling have been analysed. They correspond to two technological scenarios: the current common practice (solid structure) and the bio-based material scenario. The technical solutions for each building element according to the two scenarios are summarised in Table 72.

Table 72. Detached house: Technical solutions for the two scenarios: traditional (solid) and bio-based. Comparison with the reference building from the BoP Housing.

Building element	**Reference from BoP:**	**Common practice in the case study used for the scenario**	**Bio-based scenario (applied to the case study)**
Foundation	reinforced concrete curb	reinforced concrete beam	sand-lime bricks
Floor on grade	ceramic tiles on reinforced concrete	ceramic tiles on in situ reinforced concrete slab	linoleum on thermofloor
Outer wall	insulated brick cavity wall	insulated brick cavity wall	insulated timber frame with wood claddings
Inner wall	rockwool insulated timber frame	brick	timber frame
Intermediate floor	ceramic tiles on light concrete screed	ceramic tiles on reinforced concrete floor	hardwood parquet on wooden joists and beams
Pitched roof	ceramic roof tiles on wooden roof batens and board	ceramic roof tiles on wooden perlings and arrises	wood shingles on wooden perlings and arrises
Windows	PVC frame, double glazing	PVC frame with double glazing	wood frame with double glazing
Inner doors	not included in the model	MDF	MDF
Outer door	not included in the model	PVC frame, double glazing	wood frame, double glazing
Garage door	not included in the model	aluminium	aluminium

The energy performance has been defined through two steps. In a first step, the energy performance requirements for residential buildings in Belgium to date have been defined (Table 73). In a second step, these requirements have been translated into building solutions for the two different technical solutions of the detached house.

According to the energy performance requirements for residential buildings to date (2015) for Belgium A.A. (2007), the maximum value for the net energy demand is equal to 70 kWh/m^2 year, this value has been set in the to two technological scenarios as cautionary assumption.

Table 73. Energy Performance requirements in Belgium for residential buildings in 2015.

Requirements	**2015**
Umax-values building skin	Umax (W/m^2K)
windows	1.8
glazing	1.1
roof	0.24
wall	0.24
floor	0.3
doors and garage doors	2
max net energy demand	70 kWh/m^2

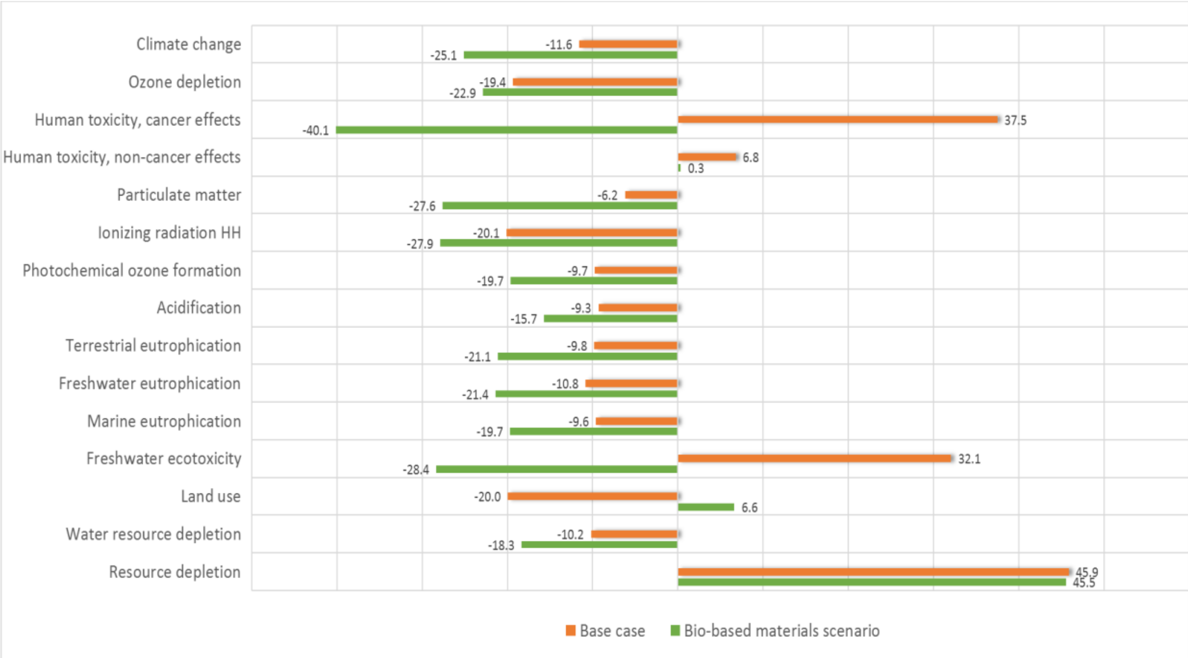
The environmental impact was evaluated using ILCD v. 1.08 (EC-JRC, 2011). Long-term emissions were excluded. In Table 74 a summary of the characterized results per dwelling for the reference BoP scenario and the two technological scenarios are summarized.

Figure 29 shows for each impact category the attended benefits and burdens deriving from the substitution of common materials (orange bar) with bio-based materials (green bar) in the specific case study. It also shows the deviation of the two scenarios from the average impact of the correspondent dwelling modelled in the BoP which impact values are scaled to be on the vertical axis in the histogram graph.

Table 74. Characterized results – comparison of the annual environmental impact per dwelling according to the common practice and bio-based scenarios.

Impact category	**Unit**	**BoP reference scenario: SFH_moderate_1990-2010**	**Common practice scenario**	**Bio-based scenario**
Climate change	kg CO_2 eq	5.25E+03	4.64E+03	3.93E+03
Ozone depletion	kg CFC-11 eq	6.69E-04	5.39E-04	5.16E-04
Human toxicity, non-cancer effects	CTUh	7.97E-05	1.10E-04	4.77E-05
Human toxicity, cancer effects	CTUh	4.97E-04	5.30E-04	4.98E-04
Particulate matter	kg $PM_{2.5}$ eq	5.02E+00	4.71E+00	3.64E+00
Ionizing radiation HH	kBq U^{235} eq	3.95E+02	3.15E+02	2.85E+02
Photochemical ozone formation	kg NMVOC eq	1.23E+01	1.11E+01	9.89E+00
Acidification	molc H^+ eq	2.75E+01	2.49E+01	2.32E+01
Terrestrial eutrophication	molc N eq	3.77E+01	3.40E+01	2.97E+01
Freshwater eutrophication	kg P eq	2.82E-01	2.52E-01	2.22E-01
Marine eutrophication	kg N eq	3.39E+00	3.06E+00	2.72E+00
Freshwater ecotoxicity	CTUe	2.47E+03	3.26E+03	1.77E+03
Land use	kg C deficit	9.23E+03	7.39E+03	9.84E+03
Water resource depletion	m^3 water eq	5.06E+02	2.56E+02	2.30E+02
Resource depletion	kg Sb eq	3.10E-01	4.53E-01	4.51E-01

Figure 29. Comparison between the common practice and the bio-based scenarios, the reference value is represented by the BoP reference building results (i.e. results for the baseline scenario of the BoP housing are put as 0).



From the comparison of the two scenarios it comes out that benefits in the environmental impact are expected for all the impact categories with the exception of *land use* where the use of biomass has a relevant role. The largest reduction is on human toxicity and ecotoxicity impact categories. This can be due to the substitution of reinforced steel, which was a hotspot for those impacts in the baseline model. The difference between the common practice scenario ("base case" in Figure 29) and the bio-based scenario can be extrapolated to the whole BoP housing. In the interpretation of results, it should be considered that those results are referred to a specific case study, referring to a building that is similar to one of the representative buildings of the BoP (namely the SFH in moderate climate, built between 1990 and 2010). As shown in Figure 29, in most of the impact categories, the results of the case study (common practice scenario) are lower than those for the representative product in the BoP. The only exception is the impact category *resource depletion,* for which the difference with the BoP housing reference scenario is quite important (45%). This happens because the common practice scenario is more detailed than the baseline model of the BoP, i.e. it includes more construction materials. This is an example on how results of this micro-scale analysis are important for the BoP refinement. The inventory of each component of the specific case study includes more details than the correspondent one into the BoP model, which had to be simplified to cope with macro-scale objectives. Therefore, the comparative results gave some information for BoP models validation and suggestions for the system boundary extension.

8.8 Scenario 7 – Smart windows

Description and aim:

This scenario aims to assess the potential benefits arising from renovation of windows across the whole life cycle of EU buildings. The analysis is referred both to one single dwelling and to the population of the EU-27, and represents an example of the potential benefits achievable by using smart-windows for renovation of old buildings and by installing them in new buildings.

Area of intervention:

- Hotspot: the energy consumption during the use phase is responsible for the 80% of impacts in 11 impact categories out 15. It is well known from literature that the impact of the envelope, and of the windows in particular, is one of the main hot spot across the majority of the impact categories.
- Whole basket
- Life cycle stage: production phase and use phase (energy consumption)

Policy relevance: Energy and resource efficiency in the building sector

Rationale for building the scenario:

Windows directly affect the energy consumption and the environmental impacts as they are typically responsible for a large fraction of the heat losses in buildings (Appelfeld et al., 2010), up to 60% according to Gustavsen et al. 2007, and as the energy consumption related to these losses (in the EU-27) amounts to 600-700 TWh in 2012 (http://www.ecodesign-windows.eu/documents.htm).

Recently, windows have been also of high interest within the European policy activity. The product group "Windows" has been regulated by the Construction Products Regulation (Regulation (EU) N. 305/2011) and indirectly by the Energy Performance of Buildings Directive (Directive 2002/91/EC). The Working Plan for energy-related products (2012-2014) in the context of the Ecodesign Directive (Directive 2009/125/EC), adopted by the Commission (SWD (2012) 434 final), includes windows among the priority product groups for an energy labelling scheme. The Working Plan estimates the energy savings potential to be reached through Ecodesign requirements in 785 PJ/year as of 2030 (SWD(2012)434). In this context, the "Preparatory study on the Ecodesign of Window Products" (http://www.ecodesign-windows.eu/documents.htm.) is on-going and it has the goal of evaluating potential measures on Ecodesign and Energy Labelling of windows.

Currently there are many fenestration systems that proved to have a large potential for improving window performance, such as: multilayer glazing, new spacer solutions, vacuum glazing, low emissivity (low-e) coating, solar cell glazing, aerogels, glazing cavity gas fills, frame with composite materials, highly insulated windows frames (Gustavsen et al., 2007), phase change material window products, and smart windows. In particular, smart windows can change their properties to adjust to outside and indoor conditions (Jelle et al., 2012) e.g. transparent conductors and electrochromic windows, based on different metal oxides as well as polymers, gasochromic devices, liquid crystal devices, and electrophoretic or suspended-particle devices. The goal of this specific eco-innovative scenario is to make a macro-scale analysis of the potential of "smart windows" in building renovation.

To this purpose, a life cycle based model of a "smart window" has been substituted into each BoP housing "product" inventory in the *maintenance phase*. Since the life span of the BoP "products" has been assumed equal to 100 years and the window life span equal to 33 years, into the building's inventory two windows replacement have been included. In case of the old buildings (<1990) it was assumed that the "smart window" replaces the previous window only for the second replacement time whereas in case of the more recent built dwellings both the window's substitutions were done with "smart windows" (Table 75).

Table 75. Plan for window substitution during the buildings life

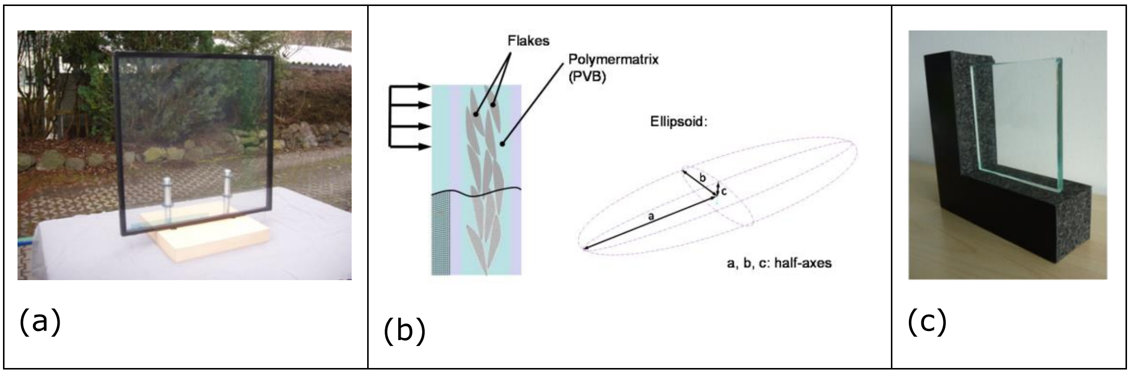
	years									
SFH and MFH life	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
warm_1945-69	SG			DG			SW			
warm_1970-89	DG			DG			SW			
warm_1990-2010	DG			SW			SW			
moderate_1945-69	SG			DG			SW			
moderate_1970-89	DG			DG			SW			
moderate_1990-2010	DG			SW			SW			
cold_1945-69	SG			DG			SW			
cold_1970-89	DG			DG			SW			
cold_1990-2010	TG			SW			SW			

SG: single-glass
DG: double-glass
TG: tripled-glass
SW: smart window

The "smart window" model have been developed during the EU FP7 HarWin Project (Harvesting solar energy with multifunctional glass-polymer windows) The HarWin project started in 1st September 2012 and finished at the end of August 2015. The duration was 36 months. During that period EC-JRC-H.08 was in charge of assessing the environmental impacts of new multi-purpose windows along its life cycle (Baldassarri et al., 2016).

The "smart window" have been designed with a laminated glass containing glass-polymer composite interlayers, that are mechanically reinforced materials, which enable weight reduction, high visible light transmission, thermal, and sound barrier enhanced properties. The project objectives included the use of latent heat storing elements such as phase changing materials (PCM) integrated for additional energy efficiency and polymer foam-glassfibre-reinforced framing (GFRP) for weight reduction (Figure 30).

Figure 30. HarWin window main components - 1a) First demonstrator, 1b) Design concept for the glazing system, 1c) Light weight frame (Baldassarri et al., 2016)



The potential energy benefits from the use of the innovative window have been estimated from dynamic simulations on two case studies (detached house and multi-family house) for different climatic zones and two different building ages. Table 76 shows the results of the energy savings evaluated for heating during the winter. These percentages were then used to accordingly modify the inventory of the use phase (and in particular energy consumption for heating) of each "product" of the BoP housing. In that way we followed a different approach in the evaluation of eco-innovative scenarios i.e. through changing the parameters in the available LCA model for the housing.

Table 76. Energy savings evaluated from dynamic simulations on the two case studies showed in the same figure

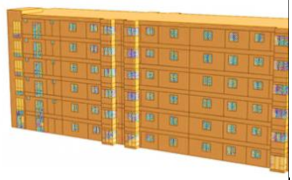
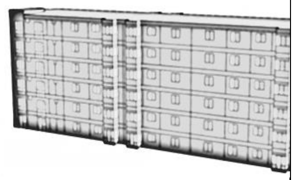
Energy savings	SHF		MFH	
	New	Old	New	Old
				
Cold	9.6%	11.6%	9.3%	14.7%
Moderate	7.0%	10.7%	9.2%	14.4%
Warm	8.6%	9.2%	9.1%	15.5%

Table 77 shows the different refurbishment rates that were applied to the different product groups within the basket.

Table 77. Windows refurbishment plan of the BoP housing

Refurbishment rate Scenario1	Old building	New building	Refurbishment rate Scenario 2	Old building	New building
Cold	20%	50%	Cold	30%	40%
Moderate	15%	40%	Moderate	10%	15%
Warm	10%	20%	Warm	5%	10%

The environmental impact was evaluated using ILCD v. 1.08 (EC-JRC, 2011). Long-term emissions were excluded. Figure 31 shows that benefits up to 20% are expected with smart windows are installed on one dwelling.

Figure 31. Results of the implementation of Smart windows scenario for one dwelling. Results are expressed as % variation compared to the baseline (set as 0).

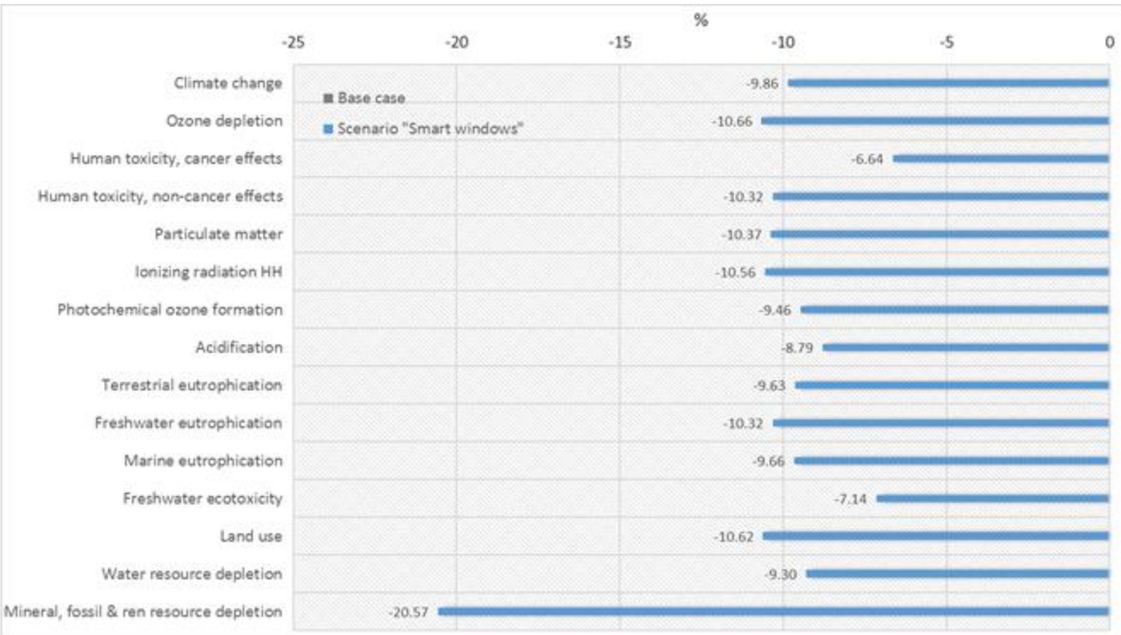
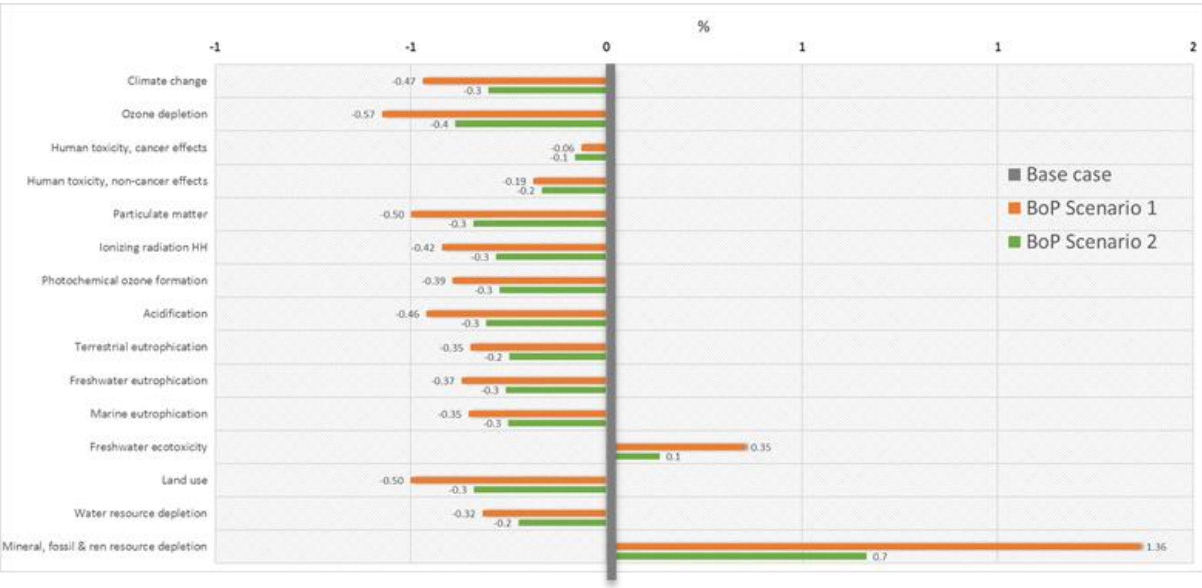


Table 78 shows a summary of the characterized results per average EU citizen for the reference BoP scenario and the two scenarios of refurbishment. Figure 32 shows for each impact category the attended benefits and burdens deriving from the substitution of windows according with the two refurbishment rate plans (orange and green bars) within the whole BoP housing. It also shows the deviation of the two scenarios from the impact of the base case BoP housing which impact values are scaled to be on the vertical axis in the histogram graph.

Table 78. Characterized results – comparison of the annual environmental impact per average EU-27 citizen according to base case and to scenarios of window refurbishment

Impact category	**Unit**	**BoP Base case**	**BoP Scenario 1**	**BoP Scenario 2**
Climate change	kg CO_2 eq	2.20E+03	2.19E+03	2.20E+03
Ozone depletion	kg CFC-11 eq	2.89E-04	2.87E-04	2.87E-04
Human toxicity, cancer effects	CTUh	3.19E-05	3.18E-05	3.18E-05
Human toxicity, non-cancer effects	CTUh	2.10E-04	2.09E-04	2.09E-04
Particulate matter	kg $PM_{2.5}$ eq	2.11E+00	2.09E+00	2.10E+00
Ionizing radiation HH	kBq U^{235} eq	1.78E+02	1.78E+02	1.78E+02
Photochemical ozone formation	kg NMVOC eq	5.05E+00	5.03E+00	5.04E+00
Acidification	molc H^+ eq	1.13E+01	1.12E+01	1.13E+01
Terrestrial eutrophication	molc N eq	1.55E+01	1.55E+01	1.55E+01
Freshwater eutrophication	kg P eq	1.26E-01	1.25E-01	1.25E-01
Marine eutrophication	kg N eq	1.41E+00	1.41E+00	1.41E+00
Freshwater ecotoxicity	CTUe	9.84E+02	9.87E+02	9.85E+02
Land use	kg C deficit	3.91E+03	3.89E+03	3.90E+03
Water resource depletion	m^3 water eq	2.11E+02	2.10E+02	2.11E+02
Resource depletion	kg Sb eq	1.08E-01	1.10E-01	1.09E-01

Figure 32. Comparison between the two scenarios of window refurbishment (as % variation compared to theb baseline). The reference value is represented by the BoP base case scenario results (i.e. results for the baseline scenario of the BoP housing are put as 0).



From the analysis of the results of both the scenarios it comes out that benefits in the environmental impact are expected for all the impact categories with the exception of *freshwater ecotoxicity* and *resource depletion*. The increase of the impact in the resource depletion is partly related to the higher impact of the materials used for the "smart windows" and partly due to the more accurate model used for smart window than the one used for windows within the BoP baseline. Further improvement in the reliability of the results could be obtained through the refinement of the BoP housing baseline model to include more details on windows (gaskets, metal structure). However, benefits at the EU-28 level depend strongly on the assumption of uptake of refurbishment rates.

8.9 Scenario 8 – Combination of energy-related scenarios

Description and aim:

This scenario aims at assessing the potential effect of the combination of some of the measures tested in the previous scenarios. More in detail, it assumes the combined implementation of three scenarios, namely night attenutation of temperature set (scenario 1), external wall insulation (scenario 2) and installation of a solar collector (scenario 4) on the European building stock.

Rationale for building the scenario:

The three measures chosen for the combined scenario were selected because they can be jointly implemented on the same building (SFH or MFH) without interfering with each other and their effect is expected to increase if they are implemented jointly.

The modelling of the combined scenario is based on the same assumptions used for the modelling of the three separate scenarios. Therefore, the LCI of the combined scenario is simply the combination of the LCIs of the three scenarios already modelled individually.

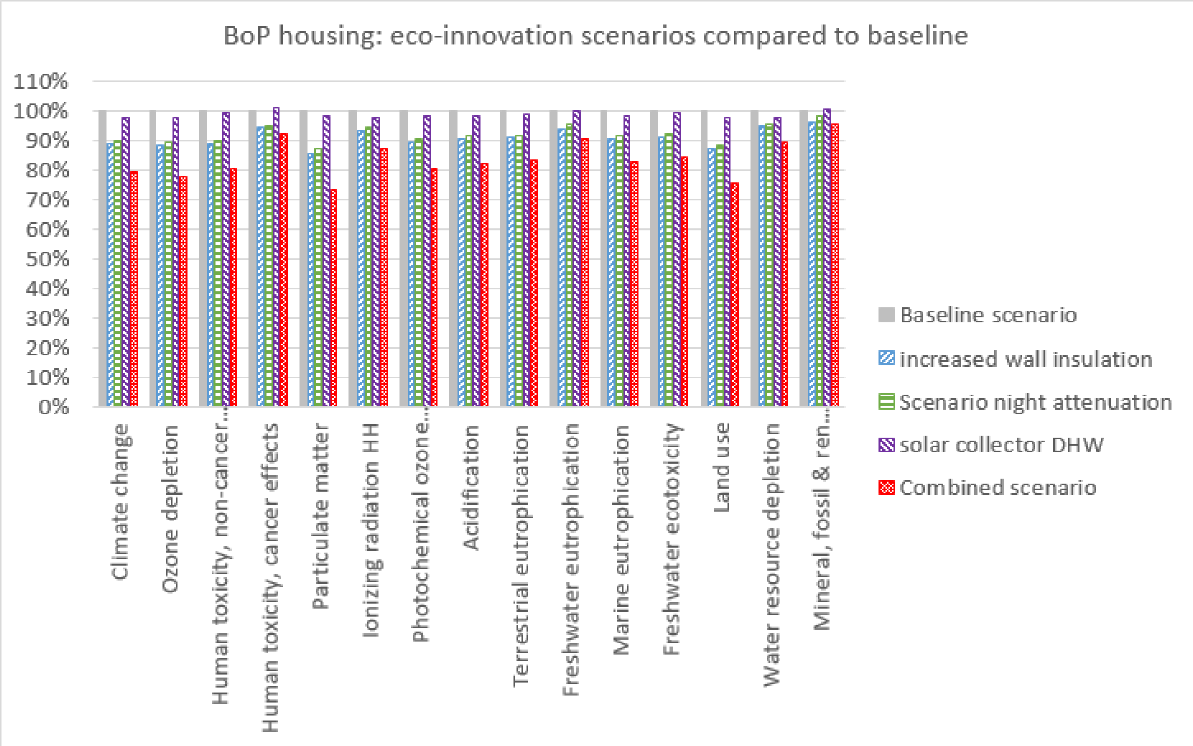
The only parameter that is specific for the combined scenario is the expected reduction in energy use, and the change in the ratio of energy sources (in the case of DHW, due to the contribution of the solar collector, as it is in scenario 4). To calculate the expected energy reduction, a new dynamic energy simulation has been run, similarly to the ones already developed for the individual scenarios.

In Table 79 the characterised results for the baseline and the combined scenario for the whole BoP housing stock, expressed as impact per EU citizen are presented. Figure 33 compares the impact of the three scenarios and the combined one with the baseline scenario, for each of the impact categories.

Table 79. Characterised results, BoP housing energy-related scenarios (yearly impact per average EU citizen)

Impact category	Unit	Baseline scenario	Combined scenario
Climate change	kg CO_2 eq	2.62E+03	2.08E+03
Ozone depletion	kg CFC-11 eq	3.33E-04	2.60E-04
Human toxicity, non-cancer effects	CTUh	2.70E-04	2.17E-04
Human toxicity, cancer effects	CTUh	3.48E-05	3.20E-05
Particulate matter	kg $PM_{2.5}$ eq	2.90E+00	2.13E+00
Ionizing radiation HH	kBq U^{235} eq	2.05E+02	1.78E+02
Photochemical ozone formation	kg NMVOC eq	6.11E+00	4.93E+00
Acidification	molc H^+ eq	1.34E+01	1.10E+01
Terrestrial eutrophication	molc N eq	1.84E+01	1.53E+01
Freshwater eutrophication	kg P eq	1.48E-01	1,34E-01
Marine eutrophication	kg N eq	1.68E+00	1.39E+00
Freshwater ecotoxicity	CTUe	1.14E+03	9.61E+02
Land use	kg C deficit	4.84E+03	3.66E+03
Water resource depletion	m^3 water eq	1.51E+02	1.35E+02
Resource depletion	kg Sb eq	1.18E-01	1.13E-01

Figure 33. Characterised results, BoP housing energy-related scenarios compared to the baseline scenario (yearly impact EU citizen)



As expected, the combination of several energy-related measures is a good way to ensure a larger reduction of impacts compared to the implementation of the single measures. The combine scenario leads to a reduction of 15-20% for the majority of the impact categories, and of less than 10% for only two impact categories (human toxicity, cancer effects and abiotic resource depletion). Of course, the same approach can be adopted for different kinds of improvements, combining also energy-related and non-energy-related measures.

8.10 Scenario 9 – Installation of PV systems for electricity production

Description and aim: This scenario analyses the effect of an increase in installation of PV systems on the roof of private houses, as a contribution to the supply of electricity. The scenario makes use of the model of the PV system developed in the BoP appliances (Reale et al., 2017), implemented on the housing stock modelled in the BoP on Housing, i.e. on Single-family Houses (SFH) and Multi-family Houses (MFH) in three climatic zones of Europe (warm, moderate and cold).

Area of intervention:

- Hotspot: impacts from electricity consumption during the use phase of dwellings
- Acts on the entire building stock
- Life cycle stage: use stage

Policy relevance: Energy efficiency directive (EC, 2012) and resource efficiency directive (EC 2011).

Rationale for building the scenario: around 20% of the installed PV capacity in Europe is in the residential sector. Almost all of this capacity consists of PV systems installed on the roof of private houses, for self-consumption by households (EPIA, 2014). There is consensus on the large potential of PV systems as contributors to electricity generation by renewable sources in the future. However, only few studies quantify the potential for installation of PV system on the roofs of private houses in Europe.

The IEA photovoltaic power system programme (PVPS Task 7) developed a method to calculate the roof area per person that is available and suitable for PV installation in the European building stock (Nowak et al., 2002). The method derives some rules of thumbs to calculate the "solar architecturally suitable area" starting from the ground floor area of buildings. The method considers the architectural suitability, i.e. the portion of the roof that is actually available (e.g. excluding historical elements, technical systems, etc.) and the solar suitability, i.e. the area (out of the architectural suitability portion) that has minimum solar yield to allow for the installation of panels. The results of the study indicate that for each m^2 of roof in the building stock, $0.4m^2$ can be considered as suitable for the installation of PV panels. Starting from this result, and considering the building stock of Central Western Europe, the authors calculated that the area potentially available for the installation of PV systems on residential buildings is $9m^2$ per citizen.

When building the scenario, we considered that there is a portion of private building that has already been used for the installation of PV system, so the current available area should be less than $9m^2$ per citizen. Since there are no data on the roof area that is currently used in Europe for the installation of PV system, the scenario is built by making some assumptions on the share of area that it still available for future installations. Two options are tested: 20% of the total available area (i.e. 1.8 m^2 per person) and 60% of the total available area (i.e. 5.4 m^2 per person). The two options are chosen arbitrarily to represent the minimum and the maximum potential expansion of the roof area covered by PV systems in the European building stock as modelled in the BoP Housing.

Figure 34 summarizes all the assumptions and the steps followed to calculate the installed PV surface, the electricity produced by the PV system and the remaining electricity need of the dwelling, to be covered by the use of electricity from the grid. Details about the calculations are provided below.

Figure 34. Calculation flow and related assumptions used to model the PV scenario

a) Solar architecturally suitable roof area per person (average of EU conditions), calculated by Nowak at al (2002).	$9m^2/p$	
b) Reduced suitable roof area per person (20% of a) or 60% of a)), to take into account that some roofs may already have PV installed and that non all the potential may be used.	PV_MIN 1.8 m^2/p	PV_MAX 5.4 m^2/p
c) Available area per dwelling, calculated considering the number of persons in each dwelling type of the BoP Housing	PV_MIN 3.01-6.17 m^2	PV_MAX 9.04-18.52 m^2
d) Annual electricity production by PV system in each dwelling type (considering a different production in the three zones, depending on the climatic conditions)	PV_MIN 331-1131 kWh	PV_MAX 994-3392 kWh
e) Remaining annual electricity demand to be covered by the conventional system (electricity demand of the dwelling minus electricity produced by the PV system)	PV_MIN 2420-10938 kWh	PV_MAX 1082-9819 kWh

<u>Parameters modified in the model</u>:

The scenario has been modelled consistently with what was done for the scenario on the installation of solar collectors (Scenario 4), i.e. including the PV system LCI in the model of the representative dwellings that compose the building stock of the BoP housing and reducing the amount of electricity taken from the grid during the use phase of the building, proportionally to the expected electricity production from the PV system.

The following parameters are modified to model this scenario:

- Production phase: the PV system (production of raw materials, manufacture, and packaging) is added to the inventory (x m^2 per dwelling, proportionally to the number of people that are supposed to live there according to the BoP Housing baseline model)
- Construction phase: the transport of the PV to the construction site is added to this phase
- Use phase: the calculated production of electricity from the PV system is deducted from the baseline use of electricity from the grid.
- Maintenance: the maintenance of the PV is added to the inventory of the maintenance of the building
- EoL phase: the EoL of the PV system is added to the inventory of the EoL of the building.

As mentioned before, two options are tested regarding the surface of PV installed per person:

- option "PV_MIN": 1.8 m^2 per person
- option "PV_MAX": 5.4 m^2 per person

These assumptions lead to the modelling parameters reported in Table 80 and Table 81, based on the number of persons living in each type of dwelling.

Table 80. Size of PV system (m²/dwelling) – option "PV_MIN" (1.8 m²/person)*

		SFH				MFH			
		<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
zone 1	People/dwelling	3.43				2.03			
	PV surface (m^2)	6.17	6.17	6.17	6.17	3.65	3.65	3.65	3.65
zone 2	People/dwelling	2.71				2.05			
	PV surface (m^2)	4.88	4.88	4.88	4.88	3.68	3.68	3.68	3.68
zone 3	People/dwelling	2.83				1.67			
	PV surface (m^2)	5.09	5.09	5.09	5.09	3.01	3.01	3.01	3.01

* Zone 1: warm climate, zone 2: moderate climate; zone 3: cold climate.

Table 81. Size of PV system (m²/dwelling) – option "PV_MAX" (5.4 m²/person)

		SFH				MFH			
		<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
zone 1	People/dwelling	3.43				2.03			
	PV surface (m^2)	18.52	18.52	18.52	18.52	10.96	10.96	10.96	10.96
zone 2	People/dwelling	2.71				2.05			
	PV surface (m^2)	14.65	14.65	14.65	14.65	11.05	11.05	11.05	11.05
zone 3	People/dwelling	2.83				1.67			
	PV surface (m^2)	15.27	15.27	15.27	15.27	9.04	9.04	9.04	9.04

The PV system contributes to the production of electricity, resulting in a reduced need of electricity from the grid. The PV system produces 145 kWh/m² installed, if considering the average European conditions of solar irradiation. To better differentiate the electricity production potential in the three climatic zones considered, an average value for each of the three zones was applied in the model. The values derive from the PVGIS system (Šùri et al., 2007), which estimates the potential of solar electricity generation in Europe starting from spatialized solar radiation data. The values used for each zone are: 183 kWh/m² for the warm zone, 140 kWh/m² for the moderate zone and 110 kWh/m² for the cold zone. The electricity produced in one year by the surface of PV installed in each dwelling, calculated starting from these values, is reported in Table 82 for option PV_MIN and in Table 83 for option PV_MAX.

Table 82. Annual electricity production by PV system in each dwelling type, for the option "PV_MIN" (kWh/dwelling*year^{-1})

		SFH				MFH			
		<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
zone 1	kWh/dwelling*year^{-1}	1,131				669			
zone 2	kWh/dwelling*year^{-1}	683				515			
zone 3	kWh/dwelling*year^{-1}	559				331			

Table 83. Annual electricity production by PV system in each dwelling type, for the option "PV_MAX" (kWh/dwelling*year^{-1})

		SFH				MFH			
		<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
zone 1	kWh/dwelling*year^{-1}	3,392				2,007			
zone 2	kWh/dwelling*year^{-1}	2,048				1,545			
zone 3	kWh/dwelling*year^{-1}	1,678				994			

Table 84 and Table 85 summarize the remaining annual electricity demand by the conventional system (i.e. electricity form the grid), for the options "PV_MIN" and "PV_MAX" respectively.

Table 84. Remaining annual electricity demand to be covered by the conventional system, for the option "PV_MIN" (kWh/dwelling*year^{-1})

	SFH				MFH			
	<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
zone 1	4,192	4,172	4,081	4,094	2,576	2,567	2,456	2,420
zone 2	4,421	4,228	4,141	3,838	3,097	3,094	2,919	2,795
zone 3	10,938	10,663	10,752	9,970	6,148	6,255	6,034	5,818

Table 85. Remaining annual electricity demand to be covered by the conventional system, for the option "PV_MAX" (kWh/dwelling*year^{-1})

	SFH				MFH			
	<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
zone 1	1,931	1,911	1,820	1,833	1,238	1,229	1,118	1,082
zone 2	3,055	2,863	2,776	2,472	2,067	2,064	1,889	1,765
zone 3	9,819	9,544	9,633	8,851	5,486	5,593	5,371	5,156

When the option "PV_MIN" is applied, the amount of electricity taken from the grid is reduced by 20% in zone 1 (warm climate), by 15% in zone 2 (moderate climate) and by 5% in zone 3 (cold climate) (Table 86). When the option "PV_MAX" is applied, the reduction is around 62%-65% in warm climate, between 40% and 45% in moderate climate and around 15% in cold climate (Table 87). The lower reduction in cold climate is explained by the larger need of electricity per dwelling compared to the other climate zones, due to a larger use of electricity for space heating and to the lower amount of electricity that the PV system can produce in cold climate.

Table 86. Reduction (as %) of electricity taken from the grid, when the PV system is installed according to option "PV_MIN"

	SFH				MFH			
	<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
zone 1	-21%	-21%	-22%	-22%	-21%	-21%	-21%	-22%
zone 2	-13%	-14%	-14%	-15%	-14%	-14%	-15%	-16%
zone 3	-5%	-5%	-5%	-5%	-5%	-5%	-5%	-5%

Table 87. Reduction (as %) of electricity taken from the grid, when the PV system is installed according to option "PV_MAX"

	SFH				MFH			
	<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
zone 1	-64%	-64%	-65%	-65%	-62%	-62%	-64%	-65%
zone 2	-40%	-42%	-42%	-45%	-43%	-43%	-45%	-47%
zone 3	-15%	-15%	-15%	-16%	-15%	-15%	-16%	-16%

<u>Results:</u>

The two options tested allow for a reduction in all impact categories except freshwater ecotoxicity and resource depletion (Figure 35 and Table 88). The reduction in almost all of the impact categories considered is due to the reduced need of electricity from the grid, thanks to the electricity produced by the PV system. On the contrary, the increase in resource depletion impact is due to the materials, and especially metals, used to produce the PV panel and mounting structures. This impact is only partially compensated by the reduced impact from energy carriers, coming from the reduced use of electricity from the grid, and results in an additional 1.7% impact in the scenario PV_MIN and 5.2% in the scenario PV_MAX.

In order to better analyse the contribution of the two types of resources, the same inventory was characterized also using CML-IA method v. 4.8. This method applies the abiotic depletion (ADP) concept, similarly to the version recommended in the ILCD method, but considering the contribution of energy carriers and mineral and metal resources separately. In addition, it takes the crustal content as reference for the calculation of the ADP, instead of the reserve base, as it is in the version recommended in the ILCD method.

When the inventory is characterized with CML-IA 4.8 method, the effect of the installation of the PV system is a reduction in the impact category ADP – energy carriers (-5% for the scenario PV_MIN and -15% for the scenario PV_MAX) and an increase in the impact category ADP – minerals and metals (+9% for the scenario PV_MIN and +28% for the scenario PV_MAX).

Finally, the increase in freshwater ecotoxicity impact comes from the emissions generated during the transoceanic transport of the component of the PV system, which is a hotspot of the PV life cycle, as mentioned before.

Figure 35. Relative results of the scenarios PV_MIN and PV_MAX compared to the baseline, taken as 100%

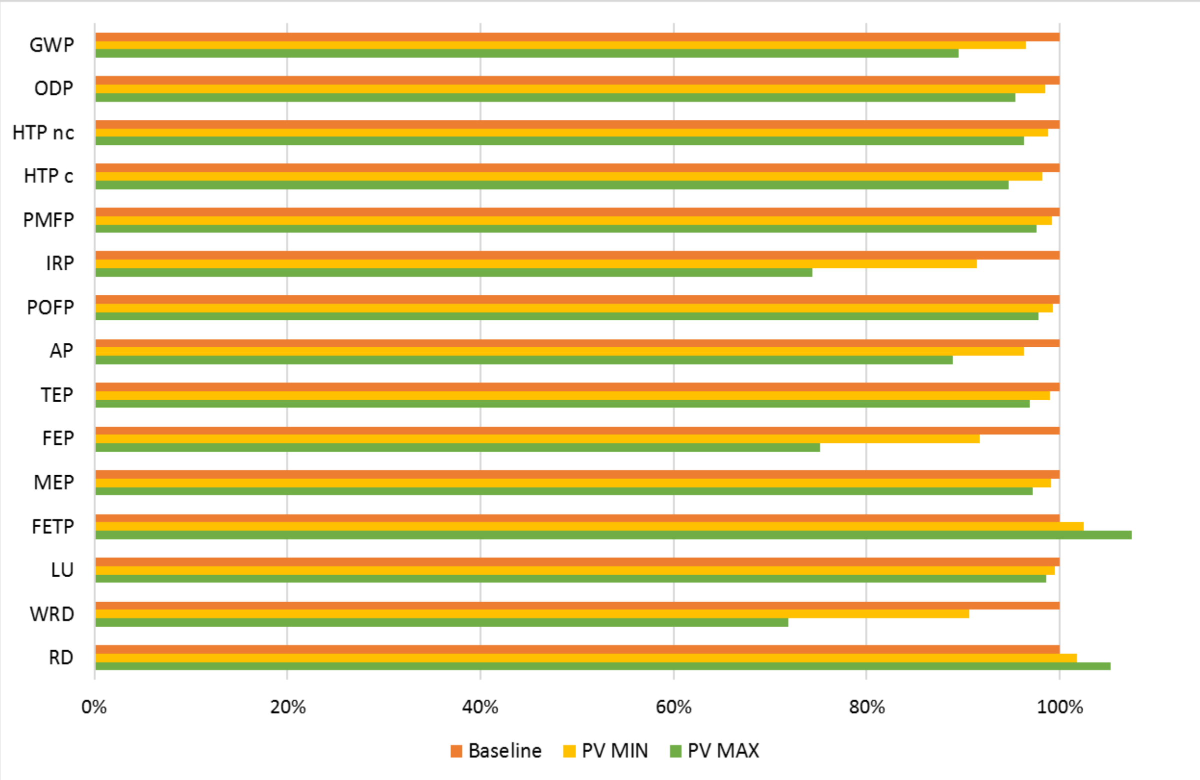


Table 88. Results of the scenarios PV_MIN and PV_MAX compared to the baseline

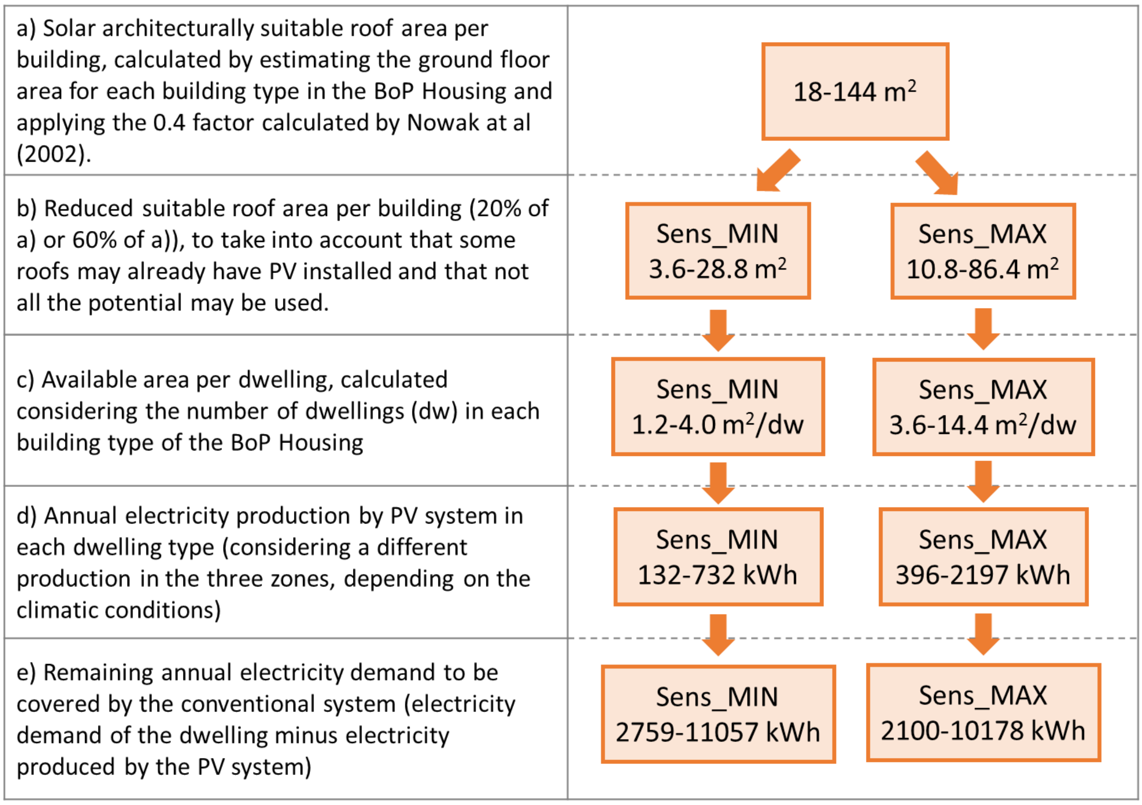
Impact category	Unit	Baseline	PV_MIN		PV_MAX	
Climate change	kg CO_2 eq	2.62E+03	2.53E+03	*-3.5%*	2.35E+03	*-10.5%*
Ozone depletion	kg CFC-11 eq	3.33E-04	3.28E-04	*-1.5%*	3.17E-04	*-4.6%*
Human toxicity, non-cancer effects	CTUh	2.70E-04	2.67E-04	*-1.2%*	2.60E-04	*-3.7%*
Human toxicity, cancer effects	CTUh	3.48E-05	3.41E-05	*-1.8%*	3.29E-05	*-5.3%*
Particulate matter	kg $PM_{2.5}$ eq	2.90E+00	2.88E+00	*-0.8%*	2.83E+00	*-2.4%*
Ionizing radiation, effects on human health	kBq U^{235} eq	2.05E+02	1.87E+02	*-8.5%*	1.52E+02	*-25.6%*
Photochemical ozone formation	kg NMVOC eq	6.11E+00	6.07E+00	*-0.7%*	5.98E+00	*-2.2%*
Acidification	molc H^+ eq	1.34E+01	1.29E+01	*-3.7%*	1.19E+01	*-11.1%*
Terrestrial eutrophication	molc N eq	1.84E+01	1.83E+01	*-1.0%*	1.79E+01	*-3.1%*
Freshwater eutrophication	kg P eq	1.48E-01	1.36E-01	*-8.3%*	1.12E-01	*-24.8%*
Marine eutrophication	kg N eq	1.68E+00	1.66E+00	*-0.9%*	1.63E+00	*-2.8%*
Freshwater ecotoxicity	CTUe	1.14E+03	1.17E+03	*2.5%*	1.22E+03	*7.4%*
Land use	kg C deficit	4.84E+03	4.82E+03	*-0.5%*	4.78E+03	*-1.4%*
Water resource depletion	m^3 water eq	1.51E+02	1.37E+02	*-9.4%*	1.08E+02	*-28.1%*
Resource depletion	kg Sb eq	1.18E-01	1.20E-01	*1.7%*	1.24E-01	*5.2%*
ADP – fossil resources	MJ	4.84E+04	4.61E+04	*-4.9%*	4.14E+04	*-14.6%*
ADP – minerals and metals	kg Sb eq	5.13E-03	5.61E-03	*9.4%*	6.57E-03	*28.2%*

8.10.1 Sensitivity analysis on the PV surface installed

A sensitivity analysis has been performed in order to test the assumption on the surface of PV installed. The result of the calculations made by Nowak at al. (2002) may not be fully consistent with the building stock and the representative dwellings selected for the baseline scenario of the BoP housing. Therefore, a slightly different approach is tested in this sensitivity analysis, starting from the features of the representative dwellings included in the BoP.

Figure 36 summarizes the assumptions and the steps followed to calculate the installed PV surface, the electricity produced by the PV system and the remaining electricity need of the dwelling for the sensitivity analysis.

Figure 36. Calculation flow and related assumptions used to model the PV sensitivity scenario



The ground floor area of the two types of buildings (i.e. SFH and MFH) is calculated as follows. The model of the SFH assumes a detached house with two floors. Therefore, the ground floor area is calculated as half of the total dwelling area (which varies from 90 m^2 to 130 m^2, depending on the climatic zone and the year of construction). The model of the MFH assumes a low-rise building with four floors and sixteen dwellings, four per each floor. Therefore, the ground floor area is calculated by multiplying the area of one dwelling (ranging from 60 m^2 to 90 m^2, depending on the climatic zone) by four. Then, the ground floor area is divided by sixteen, to calculate the ground floor area per dwelling.

The resulting numbers are used as a basis for calculating the solar architecturally suitable area on the roof, according to the model by Nowak at al. (2002). Then, two sub-scenarios are calculated, "Sensitivity_MIN" and "Sensitivity_MAX", following the same assumptions used before, i.e. 20% of the total available area and 60% of the total available area respectively. Data are presented in Table 89 and Table 90. Starting from the calculated surface of PV installed, the annual electricity production of the PV system on each dwelling, and the respective reduction of the need of electricity taken from the grid is calculated, following the same rationale explained before for the two options "PV_MIN" and "PV_MAX". Results are reported below (from Table 91 to Table 98).

Table 89. Summary of features of SFH in the BoP Housing and PV surface assumed in the options "Sensitivity_MIN" and "Sensitivity_MAX"

Dwelling type	Single Family House											
	SFH_warm_<1945	SFH_warm_1945-69	SFH_warm_1970-89	SFH_warm_1990-2010	SFH_moderate_<1945	SFH_moderate_1945-69	SFH_moderate_1970-89	SFH_moderate_1990-2010	SFH_cold_<1945	SFH_cold_1945-69	SFH_cold_1970-89	SFH_cold_1990-2010
Building typology	Detached House											
Number of dwelling	1											
Number of floors	2											
Lifetime of the building	100 years											
Climate	warm				moderate				cold			
Year of construction	<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
Model dwelling size (m^2)	100			130	90		100		100		120	
Ground floor area (m^2)	50	50	50	65	45	45	50	50	50	50	60	60
Solar architecturally suitable area (m^2)	20	20	20	26	18	18	20	20	20	20	24	24
PV surface installed in "Sensitivity_MIN"	4.0	4.0	4.0	5.2	3.6	3.6	4.0	4.0	4.0	4.0	4.8	4.8
PV surface installed in "Sensitivity_MAX"	12.0	12.0	12.0	15.6	10.8	10.8	12.0	12.0	12.0	12.0	14.4	14.4

Table 90. Summary of features of MFH in the BoP Housing and PV surface assumed in the options "Sensitivity_MIN" and "Sensitivity_MAX"

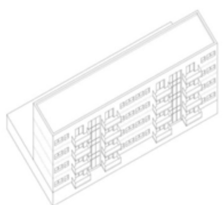
Dwelling type	Multi-Family House											
	MFH_warm_<1945	MFH_warm_1945-69	MFH_warm_1970-89	MFH_warm_1990-2010	MFH_moderate_<1945	MFH_moderate_1945-69	MFH_moderate_1970-89	MFH_moderate_1990-2010	MFH_cold_<1945	MFH_cold_1945-69	MFH_cold_1970-89	MFH_cold_1990-2010
Building typology	Low-rise > 10 apartment											
Number of dwelling	16											
Number of floors	4											
Lifetime of the building	100 years											
Climate	warm				moderate				cold			
Year of construction	<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
Model dwelling size (m^2)	90				60				60			
Ground floor area (m^2)	360	360	360	360	240	240	240	240	240	240	240	240
Solar architecturally suitable area (m^2)	9	9	9	9	6	6	6	6	6	6	6	6
PV surface installed in "Sensitivity_MIN"	1.8	1.8	1.8	1.8	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
PV surface installed in "Sensitivity_MAX"	5.4	5.4	5.4	5.4	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6

Table 91. Size of PV system (m²/dwelling) – option "Sensitivity_MIN"

		SFH				MFH			
		<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
zone 1	PV surface (m^2)	4.00	4.00	4.00	5.20	1.80	1.80	1.80	1.80
zone 2	PV surface (m^2)	3.60	3.60	4.00	4.00	1.20	1.20	1.20	1.20
zone 3	PV surface (m^2)	4.00	4.00	4.80	4.80	1.20	1.20	1.20	1.20

Table 92. Size of PV system (m²/dwelling) – option "Sensitivity_MAX"

		SFH				MFH			
		<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
zone 1	PV surface (m^2)	12.00	12.00	12.00	15.60	5.40	5.40	5.40	5.40
zone 2	PV surface (m^2)	10.80	10.80	12.00	12.00	3.60	3.60	3.60	3.60
zone 3	PV surface (m^2)	12.00	12.00	14.40	14.40	3.60	3.60	3.60	3.60

Table 93. Annual electricity production by PV system in each dwelling type, for the option "Sensitivity_MIN" (kWh/dwelling*year^{-1})

		SFH				MFH			
		<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
zone 1	kWh/dwelling*year^{-1}	732	732	732	952	330	330	330	330
zone 2	kWh/dwelling*year^{-1}	503	503	559	559	168	168	168	168
zone 3	kWh/dwelling*year^{-1}	439	439	527	527	132	132	132	132

Table 94. Annual electricity production by PV system in each dwelling type, for the option "Sensitivity_MAX" (kWh/dwelling*year^{-1})

		SFH				MFH			
		<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
zone 1	kWh/dwelling*year^{-1}	2,197	2,197	2,197	2,857	989	989	989	989
zone 2	kWh/dwelling*year^{-1}	1,510	1,510	1,678	1,678	503	503	503	503
zone 3	kWh/dwelling*year^{-1}	1,318	1,318	1,582	1,582	396	396	396	396

Table 95. Remaining annual electricity demand to be covered by the conventional system, for the option "Sensitivity_MIN" (kWh/dwelling*year^{-1})

	SFH				MFH			
	<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
zone 1	4,590	4,570	4,479	4,492	2,916	2,906	2,796	2,759
zone 2	4,600	4,408	4,320	4,017	3,444	3,441	3,266	3,142
zone 3	11,057	10,782	10,872	10,090	6,348	6,455	6,233	6,018

Table 96. Remaining annual electricity demand to be covered by the conventional system, for the option "Sensitivity_MAX" (kWh/dwelling*year^{-1})

	SFH				MFH			
	<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
zone 1	3,125	3,105	3,014	3,028	2,256	2,247	2,136	2,100
zone 2	3,593	3,401	3,313	3,010	3,108	3,105	2,930	2,806
zone 3	10,178	9,903	9,993	9,211	6,084	6,191	5,969	5,754

Table 97. Reduction (as %) for electricity taken from the grid, when the PV system is installed according to option "Sensitivity_MIN"

	SFH				MFH			
	<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
zone 1	-14%	-14%	-14%	-14%	-10%	-10%	-11%	-11%
zone 2	-10%	-10%	-10%	-11%	-5%	-5%	-5%	-5%
zone 3	-4%	-4%	-4%	-4%	-2%	-2%	-2%	-2%

Table 98. Reduction (as %) for electricity taken from the grid, when the PV system is installed according to option "Sensitivity_MAX"

	SFH				MFH			
	<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
zone 1	-41%	-41%	-42%	-42%	-30%	-31%	-32%	-32%
zone 2	-30%	-31%	-31%	-33%	-14%	-14%	-15%	-15%
zone 3	-11%	-12%	-12%	-13%	-6%	-6%	-6%	-6%

When the option "Sensitivity_MIN" is applied, the amount of electricity taken from the grid is reduced by 10%-14% in zone 1 (warm climate), by 5%-10% in zone 2 (moderate climate) and by 2%-4% in zone 3 (cold climate) (Table 97). When the option "Sensitivity_MAX" is applied, the reduction is around 30%-42% in warm climate, between 14% and 33% in moderate climate and between 6% and 13% in cold climate (Table 98).

In general, the estimation of the surface available per building leads to a lower surface availability (61% less) compared to the estimation per person done by the IEA (Nowak et al, 2002). This is reflected in a lower amount of electricity produced by the PV systems installed (-45% compared to the options calculated using data from IEA) (Table 99).

Table 99. Surface of PV systems installed and related electricity production in the four options tested

	PV_MIN	**PV_MAX**	**Sens_MIN**	**Sens_MAX**
Total PV surface (m^2)	8.91E+08	2.67E+09	3.49E+08	1.05E+09
Total electricity produced (kWh/y)	9.21E+10	2.76E+11	5.11E+10	1.53E+11

Results:

As expected, the two options tested in the sensitivity analysis lead to lower reduction of impact compared to the respective two options tested before (Figure 37 and Table 100). The reason is the lower surface availability (and related electricity production) compared to the estimation done by IEA and used in the two option PV_MIN and PV_MAX.

The reduction of impacts obtained in the two sensitivity scenarios ranges from -0.2% for land use to -5.4% for water depletion in the case of Sensitivity_MIN and from -0.6% for land use to -16.2% for water depletion in the case of Sensitivity_MAX. As before, there is an increase of impact for the impact categories freshwater ecotoxicity (+1.6% for Sensitivity_MIN and +4.8% for Sensitivity_MAX) and resource depletion (+1.2% for Sensitivity_MIN and +3.6% for Sensitivity_MAX).

It is difficult to evaluate which of the two options can be considered more close to reality, especially because there are only few studies conducted at the European scale to estimate the PV potential in terms of roof surface available and related electricity generation. A study by Izquierdo et al (2008) estimated an available roof surface of 14m^2/person, with a range of uncertainty of +/-4.5m^2/person. This number is slightly higher than the one calculated by Nowak et al. (2002) and used for the PV scenario. In fact, the number calculated by Nowak et al. (2002), i.e. 9 m^2, corresponds to the lower bound of the interval proposed by them. However, the difference could be also attributed to the variability of building features among European countries. Defaix et al. (2012) applied the same approach of Nowak and colleagues to calculate the available roof surface, but using a more detailed set of data about the building stock characteristics in each European country. According to their findings, Spain has a larger roof surface available, compared to other European countries.

The same study estimates the potential for electricity generation from building integrated PV systems. The estimated electricity production from PV systems installed on roofs and façades of residential buildings is 588 TWh per year. If we upscale the number obtained in the scenarios PV (MIN and MAX) and the related sensitivity (MIN and MAX) to 100% (i.e. removing the effect of the 20% and 60% reduction applied to take into consideration the ratio of PV already installed), we obtain a potential production of 461 TWh/y in the PV scenarios (area estimated per person) and 256 TWh/y in the sensitivity (area calculated per building). When comparing this study to the study by Defaix et al. it is worthy to consider that the number provided by Defaix et al. includes also the contribution of PV installed on façades (around 30-40% of the total).

The results obtained by applying the approach per person to the building stock of the BoP Housing are more in line with results of other studies conducted in Europe, both for what concerns the estimated available roof surface and the electricity generation potential.

On the contrary, it is worthy to underline that the approach per building can better simulate a real situation when the focus of the analysis is the single building and not the entire building stock, because it ensures that the estimated area of PV installed can really fit into the representative buildings, as they are modelled in the BoP.

Figure 37. Relative results of the scenarios Sensitivity_MIN, Sensitivity_MAX, PV_MIN and PV_MAX compared to the baseline, taken as 100%

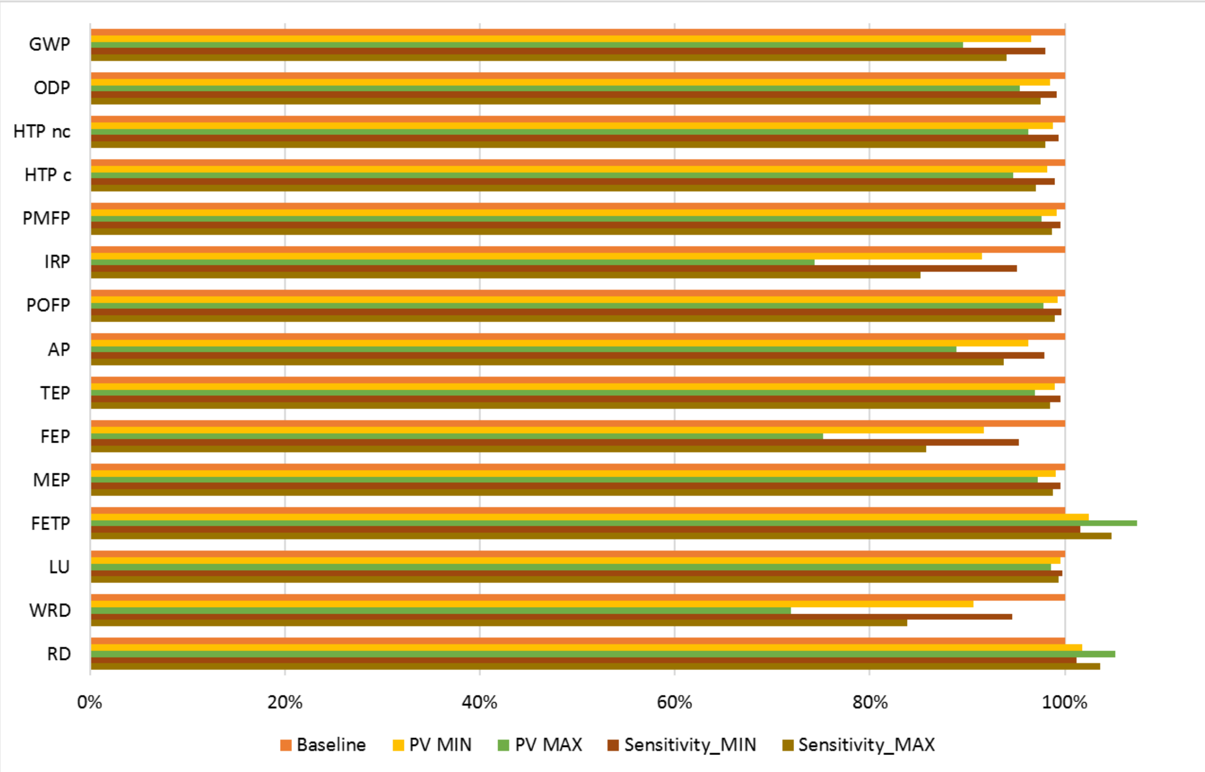


Table 100. Results of the scenarios Sensitivity_MIN and Sensitivity_MAX compared to scenarios PV_MIN and PV_MAX and to the baseline

Impact category	**Unit**	**Baseline**	**PV_MIN**		**PV_MAX**		**Sens_MIN**		**Sens_MAX**	
Climate change	kg CO_2 eq	2.62E+03	2.53E+03	*-3.5%*	2.35E+03	*-10.5%*	2.57E+03	*-2.0%*	2.47E+03	*-5.9%*
Ozone depletion	kg CFC-11 eq	3.33E-04	3.28E-04	*-1.5%*	3.17E-04	*-4.6%*	3.30E-04	*-0.8%*	3.25E-04	*-2.5%*
Human toxicity, non-cancer effects	CTUh	2.70E-04	2.67E-04	*-1.2%*	2.60E-04	*-3.7%*	2.68E-04	*-0.7%*	2.65E-04	*-2.0%*
Human toxicity, cancer effects	CTUh	3.48E-05	3.41E-05	*-1.8%*	3.29E-05	*-5.3%*	3.44E-05	*-1.0%*	3.37E-05	*-2.9%*
Particulate matter	kg $PM_{2.5}$ eq	2.90E+00	2.88E+00	*-0.8%*	2.83E+00	*-2.4%*	2.89E+00	*-0.4%*	2.86E+00	*-1.3%*
Ionizing radiation, effects on human health	kBq U^{235} eq	2.05E+02	1.87E+02	*-8.5%*	1.52E+02	*-25.6%*	1.95E+02	*-4.9%*	1.75E+02	*-14.8%*
Photochemical ozone formation	kg NMVOC eq	6.11E+00	6.07E+00	*-0.7%*	5.98E+00	*-2.2%*	6.09E+00	*-0.3%*	6.05E+00	*-1.0%*
Acidification	molc H+ eq	1.34E+01	1.29E+01	*-3.7%*	1.19E+01	*-11.1%*	1.31E+01	*-2.1%*	1.26E+01	*-6.3%*
Terrestrial eutrophication	molc N eq	1.84E+01	1.83E+01	*-1.0%*	1.79E+01	*-3.1%*	1.84E+01	*-0.5%*	1.82E+01	*-1.5%*
Freshwater eutrophication	kg P eq	1.48E-01	1.36E-01	*-8.3%*	1.12E-01	*-24.8%*	1.41E-01	*-4.7%*	1.27E-01	*-14.3%*
Marine eutrophication	kg N eq	1.68E+00	1.66E+00	*-0.9%*	1.63E+00	*-2.8%*	1.67E+00	*-0.4%*	1.66E+00	*-1.3%*
Freshwater ecotoxicity	CTUe	1.14E+03	1.17E+03	*2.5%*	1.22E+03	*7.4%*	1.16E+03	*1.6%*	1.19E+03	*4.8%*
Land use	kg C deficit	4.84E+03	4.82E+03	*-0.5%*	4.78E+03	*-1.4%*	4.83E+03	*-0.2%*	4.81E+03	*-0.6%*
Water resource depletion	m^3 water eq	1.51E+02	1.37E+02	*-9.4%*	1.08E+02	*-28.1%*	1.43E+02	*-5.4%*	1.26E+02	*-16.2%*
Resource depletion	kg Sb eq	1.18E-01	1.20E-01	*1.7%*	1.24E-01	*5.2%*	1.19E-01	*1.2%*	1.22E-01	*3.6%*
ADP – fossil resources	MJ	4.84E+04	4.61E+04	*-4.9%*	4.14E+04	*-14.6%*	4.71E+04	*-2.8%*	4.44E+04	*-8.4%*
ADP – minerals and metals	kg Sb eq	5.13E-03	5.61E-03	*9.4%*	6.57E-03	*28.2%*	5.42E-03	*5.8%*	6.02E-03	*17.5%*

9 Summary of main findings from the scenario analysis

Table 101 represents a summary of the results of the scenarios assessed for the BoP housing, as variation (%) of impact compared to the baseline scenario. Results that show an increase compared to the baseline are highlighted in red, whereas results that show a reduction are highlighted in green.

Table 101. Summary of results of the scenarios analysed. Results are expressed as variation (%) compared to the baseline (1)

	GWP	ODP	HTP nc	HTP c	PMFP	IRP	POFP	AP	TEP	FEP	MEP	FETP	LU	WRD	RD
SC.1: Night attenuation	-9.9%	-10.5%	-10.0%	-4.9%	-13.1%	-5.9%	-9.5%	-8.2%	-8.2%	-4.7%	-8.3%	-7.9%	-11.8%	-4.6%	-1.7%
SC.2: External wall insulation - increased thickness	-10.7%	-11.4%	-11.1%	-5.5%	-13.8%	-6.3%	-10.1%	-9.0%	-8.7%	-5.4%	-8.9%	-8.8%	-12.6%	-4.6%	-4.2%
SC.3: External wall insulation - bio-based materials	-10.7%	-12.0%	-10.4%	-5.5%	-13.8%	-6.3%	-10.8%	-9.0%	-8.2%	-5.4%	-8.3%	-8.8%	-12.4%	-5.3%	-1.7%
SC.4: Solar collector for domestic hot water	-2.3%	-2.7%	-0.7%	0.9%	-1.7%	-2.0%	-1.8%	-1.5%	-1.6%	0.0%	-1.8%	-0.9%	-2.1%	-2.6%	0.0%
SC.5: Floor finishing with bio-based materials	-0.8%	-0.9%	-0.7%	-1.4%	-4.1%	-1.5%	-0.3%	-0.7%	0.0%	-1.4%	-0.6%	-1.8%	0.6%	-2.0%	-16.4%
SC.6: Timber frame - bio-based scenario	-15.3%	-4.3%	-56.6%	-6.0%	-22.7%	-9.5%	-10.9%	-6.8%	-12.6%	-11.9%	-11.1%	-45.7%	33.2%	-10.2%	-0.4%
SC.7a: Smart windows - refurbishment rate 1	-0.5%	-0.7%	-0.3%	-0.5%	-0.9%	0.0%	-0.4%	-0.9%	0.0%	-0.8%	0.0%	0.3%	-0.5%	-0.5%	1.9%
SC.7b: Smart windows - refurbishment rate 2	0.0%	-0.7%	-0.3%	-0.5%	-0.5%	0.0%	-0.2%	0.0%	0.0%	-0.8%	0.0%	0.1%	-0.3%	0.0%	0.9%
SC.9: Combination of energy-related scenarios	-20.6%	-21.9%	-19.6%	-8.0%	-26.6%	-13.2%	-19.3%	-17.9%	-16.8%	-9.5%	-17.3%	-15.7%	-24.4%	-10.6%	-4.2
SC.10a: Installation of PV systems MIN	-3.5%	-1.5%	-1.2%	-1.8%	-0.8%	-8.5%	-0.7%	-3.7%	-1.0%	-8.3%	-0.9%	2.5%	-0.5%	-9.4%	1.7%
SC.10b: Installation of PV systems MAX	-10.5%	-4.6%	-3.7%	-5.3%	-2.4%	-25.6%	-2.2%	-11.1%	-3.1%	-24.8%	-2.8%	7.4%	-1.4%	-28.1%	5.2%

(1) Abbreviations: GWP (Climate change), ODP (Ozone depletion), HTP nc (Human toxicity, non-cancer effects), HTP c (Human toxicity, cancer effects), PMFP (Particulate matter), IRP (Ionizing Radiation HH), POFP (Photochemical ozone formation), AP (Acidification), TEP (Terrestrial eutrophication), FEP (Freshwater eutrophication), MEP (Marine eutrophication), FETP (Freshwater ecotoxicity), LU (Land use), WRD (Water resource depletion), RD (Resource depletion).

The assessment of the seven scenarios on eco-innovations related to the BoP housing revealed that in general a reduction of about 5 to 15% can be achieved for each of these.

The **first scenario on night attenuation** resulted in a reduction of all impact categories and hence does not lead to any increase due to the additional materials needed to allow for the night attenuation. The additional impacts related to these additional materials are all compensated by the energy reduction for heating.

Per EU citizen, per year, the highest reductions have been achieved for the SFH in the moderate climate and the smallest reductions for the MFH in the cold climate (taking into account the number of buildings in the BoP housing of each dwelling type). Due to the differences in achievements obtained over the various dwelling types, a slight change in relative importance of the various dwelling types in the overall impact of the BoP housing is noticed.

For an average EU housing, the reduction due to this eco-innovation is highest for particulate matter (13% reduction), followed by land use (12%) and climate change, ozone depletion and human toxicity-cancer effects (all three 10% reduction). The lowest reduction is achieved for the impact category resource depletion (1% reduction).

Although the impact of the use phase has reduced due to a reduction in heating demand, the use phase remains the most important life cycle stage in the impact of the BoP housing when night attenuation is assumed.

The **second scenario on increased wall insulation** resulted in a reduction of all impact categories and, hence, does not lead to any increase due to the additional insulation materials applied. The impacts related to these additional materials are all compensated by the energy reduction for heating.

Per EU citizen, per year, the highest reductions have been achieved (for most impact categories) for the SFH in the moderate climate and the smallest reductions for the SFH in the warm climate (taking into account the number of buildings in the BoP housing of each dwelling type). Due to the differences in achievements obtained over the various dwelling types, a slight change in relative importance of the various dwelling types in the overall impact of the BoP housing is noticed.

For an average EU housing, the reduction due to this eco-innovation is highest for particulate matter (14% reduction), followed by land use (12%) and climate change, ozone depletion and human toxicity-cancer effects (all three 11% reduction). The lowest reduction is achieved for the impact category resource depletion (4% reduction). This is similar as for the first scenario on night attenuation.

Although the impact of the use phase has reduced due to a reduction in space heating demand, the use phase remains the most important life cycle stage in the impact of the BoP housing when increased wall insulation is assumed.

As the increase in insulation level is quite limited for some of the dwelling types in this scenario, it is expected that higher benefits can be achieved by applying higher insulation levels than the ones assumed in this scenario.

The **third scenario on increased wall insulation with recycled and bio-based insulation materials** resulted in a reduction of all impact categories and hence does not lead to any increase due to the additional insulation materials applied. The additional impacts related to these additional materials are all compensated by the energy reduction for heating.

Per EU citizen, per year, the highest reductions have been achieved (for most impact categories) for the SFH in the moderate climate and the smallest reductions for the SFH in the warm climate (taking into account the number of buildings in the BoP housing of each dwelling type). Due to the differences in achievements obtained over the various dwelling types, a slight change in relative importance of the various dwelling types in the overall impact of the BoP housing is noticed.

For an average EU housing, the reduction due to this eco-innovation is highest for particulate matter (13% reduction), followed by land use (12%), ozone depletion (11%) and climate change, human toxicity-cancer effects and photochemical ozone formation (all three 10% reduction). The lowest reduction is achieved for the impact category resource depletion (2% reduction).

Although the impact of the use phase has reduced due to a reduction in space heating demand, the use phase remains the most important life cycle stage in the impact of the BoP housing when increased bio-based wall insulation is assumed.

Similar as for the second scenario, it is expected that higher benefits can be achieved when higher insulation levels would be applied as the increase in insulation level is quite limited for some of the dwelling types in this scenario.

The **fourth scenario on installing a solar collector for the production of domestic hot water** resulted in a reduction of all impact categories except for human toxicity – cancer effects (0,9% increase) and resource depletion (0,2% increase). These are due to the components needed for the solar collector system. The reduction in impacts for the reduced impact categories is rather small compared to the previous three scenarios, which can be explained by the lower relative contribution of DHW production compared to space heating.

Per EU citizen, per year, the highest reductions have been achieved (for most impact categories) for the SFH in the warm climate and the smallest reductions for the MFH in the cold climate (taking into account the number of buildings in the BoP housing of each dwelling type). Due to the differences in achievements obtained over the various dwelling types, a slight change in relative importance of the various dwelling types in the overall impact of the BoP housing is noticed.

For an average EU housing, the reduction due to this eco-innovation is highest for ozone depletion (2.5%), climate change (2.4%), water resource depletion (2.3%) and ionizing radiation (2.1%).

Although the impact of the use phase has reduced due to a reduction in heating demand for the production of domestic hot water, the use phase remains the most important life cycle stage in the impact of the BoP housing when a solar collector is assumed.

The **fifth scenario on using bio-based floor finishing** resulted in a reduction of all impact categories except for land use (0.7% increase). The reductions vary from nearly 0.3% to 16.4% (resource depletion) over the various impact categories. It is important to note that no changes have been made to the MFH and SFH in the cold climate in this scenario as a bio-based floor finishing was already applied in the baseline model in this climatic zone. This hence explains the relatively small impact reductions percentages.

Per EU citizen, per year, the highest reductions have been achieved (for most impact categories) for the MFH in the warm climate and the smallest reductions for the SFH in the warm climate (taking into account the number of buildings in the BoP housing of each dwelling type). Due to the differences in achievements obtained over the various dwelling types, a slight change in relative importance of the various dwelling types in the overall impact of the BoP housing is noticed.

For an average EU housing, the reduction due to this eco-innovation is highest for resource depletion (16.4%). followed by particulate matter (3.9%).

The **sixth scenario on using a timber frame instead of a more traditional one**, made by concrete and reinforced steel, resulted in a reduction of impact for all the impact categories with the exception of *land use* for which the use of biomass has a relevant role. Since the inventory of each component of the specific case study includes more details with regard to the correspondent one into the BoP model, which had to cope with macro-scale objectives, the comparative results gave also some important information for BoP models validation and suggestions for potential improvements of the baseline model.

The **seventh scenario on smart windows** highlighted potential benefits for all the impact categories, with the exception of *freshwater ecotoxicity* and *resource depletion*. The increase of the impact in the resource depletion is partly related to the higher impact of the materials used for the "smart windows" and partly due to the more accurate model used for smart window than the one used for windows within the BoP baseline.

The **eighth scenario** represents a combination of the energy-related scenarios discussed before (namely scenario 1, scenario 2 and scenario 4). It highlight that the combination of several energy-related measures can ensure a larger reduction of impacts compared to the implementation of the single measures. Results of the eighth scenario show a reduction of 15-20% for the majority of the impact categories, and of less than 10% for only two impact categories (human toxicity, cancer effects and abiotic resource depletion).

The **ninth scenario** simulated the installation of PV system as an additional source of electricity. Although results can vary in absolute terms, depending on the assumption made about the roof surface potentially available for the installation, some conclusions can be drawn about the potential effect of this installation. Results of the scenario and of the related sensitivity analyses showed a reduction of impact for all impact categories except freshwater ecotoxicity and resource depletion. The increase in resource depletion impact is due to the materials, and especially metals, used to produce the PV panel and mounting structures. This impact is only partially compensated by the reduced impact from energy carriers, coming from the reduced use of electricity from the grid.

10 Conclusions

The Basket of Product housing represents a model of the European building stock, based on archetypes. Twenty-four representative dwellings were selected, based on the type of building, the year of construction and the climatic zone in which they are located. The use of archetypes allows for modelling the entire building stock of large areas, such as nations or transnational territories. Compared to building-by-building approaches, the use of archetypes introduces some simplifications and uncertainties; however, the building-by-building approach is usually not applicable to large areas, because it is demanding for what concern data collection and modelling. Moreover, the use of archetypes is useful when modelling scenarios (Mastrucci et al., 2017).

According to the results of the hotspot analysis run on the baseline scenario, the use phase is dominating all impact categories, with a contribution that is higher than 80% for most of them. Only for human toxicity, cancer effects and for resource depletion the relevance is shared with the production phase (40% in human toxicity, cancer effects and 18% in resource depletion). The production of electricity (used in the use phase, but also in background processes of other phases) plays a relevant role for most of the impact categories. Heating, and especially wood heating, is also contributing to some impact categories: e.g., in the case of human toxicity, the emission of zinc to soil is coming mainly from the ashes of the wood burned for space heating. Regarding the relevance of impact categories, human toxicity, cancer effects is responsible for 18.9% of the impacts. This is mainly due to the production of reinforcing steel and electricity distribution network. Among the representative dwellings that compose the BoP, the single-family houses and the multi-family houses in cold climate are the one contributing the most to the overall impact. This is especially due to the higher needs of energy for space heating in that climate.

From the assessment of the scenarios, we can conclude that the reduction in impact for each of the eco-innovation scenarios is relatively limited. This is not surprising, because in the case of energy saving measures, it is well known that a combination of actions is needed to achieve significant improvements. Moreover, in the case of scenarios acting on the substitution of specific components of the building, the potential improvement is proportional to the relative importance of the substituted component in the baseline scenario. For instance, the impact of ceramic tiles on resource depletion corresponds to about 60% of the impact of the production phase of an average building in the baseline scenario. The production phase itself contributes to around 20% of the total impact of the baseline scenario in terms of resource depletion. This means that the production of ceramic tiles contributes for 10% to the overall impact of the BoP housing to resource depletion. Therefore, when substituting part of the ceramic tiles in an average building, the impact reduction due to the use of wood is around 55% in the production phase (because wood's abiotic depletion impact is less than 5%). Anyway, when this contribution is scaled to the overall BoP housing, the reduction becomes lower (16%).

The same applies for all the scenarios evaluated. Therefore, a combination of several actions, both for energy saving and for material efficiency, is needed to achieve a significant reduction in environmental impact of the overall BoP housing. It can hence be concluded from the assessment that an integrated policy is important in order to achieve significant impact reductions of the EU Building stock.

A preliminary modelling of combination of energy-related measures (scenario 8) proved to be a good way to enlarge the potential benefits coming from the selected improvements of the building stock. The same approach could be adopted for different kinds of improvements, combining also energy-related and non-energy-related measures.

Furthermore, two more scenarios were identified as potentially important ones without further assessment in this study as these were seen as lower priorities, i.e. solar screens in the warm climatic zone to reduce space cooling and rainwater collection and reuse. It could be insightful to look at their potential in a further reduction of the environmental impact of the BoP housing.

When interpreting the results of the scenarios, some limitations due to data sources and modelling choices have to be taken into account. The most important ones are the following:

- As discussed before, the use of archetypes is useful for analysing the effects of scenarios acting at the European level, but implies also a certain degree of approximation at the building level, compared to the building-by building approach. In fact, there is a trade-off between the data granularity of the model, which is higher at the small scale and lower at the large scale, and the relevance of the results obtained in support to policy decisions, which is of course higher when the model is built at a larger scale.
- With reference to the previous point, the uncertainty due to the use of average values instead of specific ones referred to real buildings may arise from the variability of service life of buildings, construction materials used, morphological features of the buildings, etc.
- Another limitation of the BoP baseline model is that the building stock is modelled in a static way and does not take into account stock dynamics over time. The effect of the European Energy Efficiency Directive is not captured in the basket of products housing (BoP-housing), because its baseline year (2010) is the first year of implementation of the Directive. It should also be pointed out that the construction of new buildings (that are adapted to the new regulation) suffered a setback due to the economic crisis of 2009, and existing buildings continue to be upgraded at a very low rate. It is estimated that the existing European building stock is currently being retrofitted at a rate of only approximately 1-3% of the total needed per year (Ascione et al., 2011).
- Finally, as for all the LCA studies, the use of background databases (in this specific case, the ecoinvent database 3.2), is a source of uncertainty because background data are not directly referred to the system under study. In the BoP housing this aspect was partially addressed by adjusting the background datasets to the European average conditions as far as possible.

On the contrary, some specific features of the BoP housing allow for detailed and reliable estimation of the impact of baseline and scenarios, especially for what concern the use phase, i.e. the most relevant one. Firstly, the energy consumption of the use phase of buildings is modelled with a top-down approach using data from the Intelligent Energy Europe Project ODYSSEE, which provides detailed data about energy consumption for space heating, space cooling, domestic hot water heating, lighting and use of appliances for each member state.

This level of detail allowed for a detailed modelling of the effects of the scenarios on specific energy uses (e.g. thanks to the contribution of solar panels to domestic water heating or the PV system to the provision of electricity). Moreover, the scenarios on energy efficiency were modelled with input data coming from dynamic energy simulation models, based on the specific features of the representative dwellings in the basket.

Therefore, the main conclusions that can be drawn from the results obtained are considered reliable and potentially relevant in support to several policies for energy and resource efficiency in the building sector.

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List of abbreviations and definitions

BIPV	Building Integrated Photovoltaics
BoP	Basket of Products
CDW	Construction and Demolition Waste
DHW	Domestic Hot Water
EoL	End of Life
FSC	Forest Stewardship Council
FU	Functional Unit
HDD	Heating Degree Days
HVAC	Heating, Ventilation and Air Conditioning
IEE	Intelligent Energy Europe
IFD	Industrial, Flexible and Demountable
ILCD	International Life Cycle Data System
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MFH	Multi Family House
MS	Member State
PM	Particulate Matter
PCM	Phase Changing Materials
PEF	Product Environmental Footprint
PEFC	Programme for the Endorsement of Forest Certification
PET	Polyethylene terephthalate
PS	Polystyrene
PVC	Polyvinylchloride
PVPS	Photovoltaic Power System Programme
SFH	Single Family House
VOC	Volatile Organic Compound

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Annexes

ANNEX 1 – Datasets used to model end of life processes

Table 102 summarizes all the assumptions that have been made in the definition of the EoL scenario for BoP housing. It must be highlighted that a certain rate of uncertainty is introduced while defining the recyclability rate of the construction materials. Data on this topic are not always available and when available they are characterized by a certain rate of uncertainty that is different according with the different sources of data (statistics at EU level. producer associations. case studies from literature). It must be also noted that the amount of recycling and reuse of CDW varies between under 10 and above 90 percent among the 28 states of the EU. Denmark. Germany. Ireland and the Netherlands recycled over 80 percent of CDW generation, while the Czech Republic, Finland, Hungary and Poland recycled between 15 and 30 percent (ETC/SCP. 2009). Concrete and masonry materials contribute from 40 to 84 percent of the composition of CDW. For sake of transparency, a summary of the information available in literature for the final destination of each material included in the system boundary follows:

Concrete: Väntsi and Kärki (2015) and EC-DG ENV (2011) report that current EU recycling rate is not available. We decided to make the same assumption made by the ecoinvent dataset (40% landfill and 60% recycled). Since recycling into aggregates for road construction or backfilling could absorb 75% of waste. It is assumed that the benefits in Module R are derived from the avoided production of gravel.

Mineral plaster: Since no data were available, we decided to make the same assumption made in the ecoinvent dataset.

Brick: EC-DG ENV (2011) reports that current EU recycling rate is not available. Since no data were available we decided to make the same assumption made in the ecoinvent dataset.

Wood: Diyamandoglu and Fortuna (2015) reports that currently 31% of wood waste is recycled into derived timber products and 34% goes to energy recovery processes, like energy generation. We decided to implement these data in the EoL scenario. Based on EC-DG ENV (2011) and Krajnc (2015) we assumed that mixed wood generates 14.40 MJ per kg.

Glass pane: Glass for Europe (2010) reports that "In Europe, each year, approximately 1.2 million tonnes of glass waste are generated by Construction and Demolition (C&D) of buildings, and by building refurbishment both internal and external. Glass represents 0.66% of the construction and demolition waste stream. Flat glass waste from this source, when not sorted and mixed with other demolition waste, is "unclean" and cannot be used as cullet for float glass melting, without treatment. This waste glass requires considerable cleaning/ processing before it reaches the quality criteria needed to be used as post-consumer cullet by the flat glass industry, by the container glass industry or by the manufacturers of insulating glass fibre. As a consequence, a significant part of CDW glass is used as an aggregate substitute or ends up as landfill inert material". We assumed that 90% of glass from glass panes goes to landfill.

Mineral wool: Väntsi and Kärki (2015) report that very little information on the separation of mineral wool waste from CDW streams can be found in the literature. Collecting mineral wool waste from the C&D stream is challenging due to limitations in waste separation technologies. At least one example exists, however. A case study by the BRE Group (2008) demonstrates that it was possible to use a shredder apparatus to separate mineral wool waste from steel–mineral wool composite wall panels recovered from refurbishment of an industrial building. Both the recovered mineral wool waste and steel waste were successfully reused in production of new steel–mineral wool composite panels, resulting in zero waste going to landfill. Current methods for recycling mineral wool waste include reuse in ceramics, cement or fiber-based composites, tiles, and soilless cultures. Since no data are available on the mineral wool recycling rate, we assumed 100% landfill.

Polyvinylchloride: Vinylplus (2012) reports that in 2012, 354.173 tonnes of recycled PVC were registered and certified by Recovinyl and the annual European consumption of PVC resin totals 6.5 million tonnes - 15% of all plastics used in Europe. Since 354.173 tonnes represent 5.4% of PVC production, we assumed this value for the recycling rate. Moreover. since PVC has a calorific value similar to that of brown coal (approximately 19 MJ/kg) , the material contributes positively to energy balance when incinerated in household waste (approximately 11 MJ/kg).

Table 102. EoL Inventory: Module S and Module R for each construction waste

	EoL treatment rate			Waste treatment –Module S		Module R	
Material	**% to landfill**	**% to incineration**	**% to recycling**	**ecoinvent process (waste treatment Sorting plant + Landfill)**	**ecoinvent process (waste treatment - incineration)**	**ecoinvent process (burdens from recycling)**	**ecoinvent process Avoided products (benefits from recycling)**
Reinforced concrete	38.8		61.2	Waste reinforced concrete {CH}| treatment of. sorting plant | Alloc Def. U			Gravel. crushed {CH}| production | Alloc Def. U
Non-reinforced concrete	40		60	Waste concrete. not reinforced {CH}| treatment of. sorting plant | Alloc Def. U			Gravel. crushed {CH}| production | Alloc Def. U
Mineral plaster	85		15	Waste mineral plaster {CH}| treatment of. sorting plant | Alloc Rec. U			Gravel. crushed {CH}| production | Alloc Def. U
Brick	40		60	Waste brick {CH}| treatment of. sorting plant | Alloc Def. U			Gravel. crushed {CH}| production | Alloc Def. U
Wood	35	34	31	Waste wood. treatment of. sorting plant	Waste wood. untreated {RoW}| heat production. untreated waste wood. at furnace 1000-5000 kW. state-of-the-art 2014 | Alloc Def. U		Log. energy wood. split. measured as solid wood under bark {GLO}| log. energy wood. split. measured as solid wood under bark. Recycled Content cut-off | Alloc Rec. U
				Waste wood. untreated {RoW}| treatment of. sanitary landfill | Alloc Def. U	Electricity. high voltage {Europe without Switzerland}| market group for | Alloc Def. U		
Glass pane	90		10	Waste glass sheet {CH}| treatment of. sorting plant | Alloc Def. U		Glass cullet. sorted {RER}| treatment of waste glass from unsorted public collection. sorting | Alloc Def. U	Packaging glass. green {CH}| production | Alloc Rec. U
Gypsum plasterboard	85		15	Waste gypsum plasterboard {CH}|		Gypsum plasterboard {RoW}|	Gypsum. mineral {GLO}|

	EoL treatment rate			Waste treatment –Module S		Module R	
Material	**% to landfill**	**% to incineration**	**% to recycling**	**ecoinvent process (waste treatment Sorting plant + Landfill)**	**ecoinvent process (waste treatment - incineration)**	**ecoinvent process (burdens from recycling)**	**ecoinvent process Avoided products (benefits from recycling)**
				treatment of. sorting plant | Alloc Rec. U		production | Alloc Def. U	market for | Alloc Def. U
Mineral wool	100			Waste mineral wool {CH}| treatment of. sorting plant | Alloc Def. U			
Metal - Reinforcement steel			100	Waste reinforcement steel {CH}| treatment of. sorting plant | Alloc Def. U			Pig iron {GLO}| production | Alloc Def. U
Metal - Iron			100	Waste bulk iron. excluding reinforcement {RoW}| treatment of. sorting plant | Alloc Def. U			Pig iron {GLO}| production | Alloc Def. U
Metal - Copper			100	Waste bulk iron. excluding reinforcement {RoW}| treatment of. sorting plant | Alloc Def. U		Copper {RER}| treatment of scrap by electrolytic refining | Alloc Rec. U	Copper {RER}| production. primary | Alloc Def. U
Metal - Aluminium			100	Aluminium scrap. post-consumer {RER}| treatment of. by collecting. sorting. cleaning. pressing | Alloc Def. U		Aluminium scrap. post-consumer. prepared for melting {RER}| treatment of aluminium scrap. post-consumer. prepared for recycling. at refiner | Alloc Def. U	Aluminium. primary. ingot {RoW}| market for | Alloc Def. U
Metal - Steel unalloyed			100	Waste bulk iron. excluding reinforcement {RoW}| treatment of. sorting plant | Alloc Def. U			Pig iron {GLO}| production | Alloc Def. U
Polyvinylchloride	74.6	15	5.4	Waste polyvinylchloride/sorting plant	Waste polyvinylchloride {CH}| treatment of. municipal incineration with fly ash extraction | Alloc Def. U	Extrusion. plastic pipes {RER}| production | Alloc Def. U	Polyvinylchloride. suspension polymerised {RER}| polyvinylchloride production. suspension polymerisation | Alloc Def. U
				Waste polyvinylchloride {CH}| treatment of. inert landfill	Electricity. high voltage {Europe without Switzerland}| market group for | Alloc Def. U		

	EoL treatment rate			Waste treatment –Module S		Module R	
Material	**% to landfill**	**% to incineration**	**% to recycling**	**ecoinvent process (waste treatment Sorting plant + Landfill)**	**ecoinvent process (waste treatment - incineration)**	**ecoinvent process (burdens from recycling)**	**ecoinvent process Avoided products (benefits from recycling)**
Polyethylene/polypropylene	90	10		Waste polyethylene/polypropylene product treatment of. sorting plant	Waste polyethylene {CH}| treatment of. municipal incineration with fly ash extraction | Alloc Def. U		
				Waste polyethylene/polypropylene product (waste treatment) {treatment of. sanitary landfill | Alloc Def. U	Electricity. high voltage {Europe without Switzerland}| market group for | Alloc Def. U		
Polystyrene isolation. flame-retardant	100			Waste polystyrene isolation. flame-retardant (waste treatment) {CH}.treatment of waste polystyrene isolation. flame-retardant . collection for final disposal Alloc Def. U			
Waste polyurethane foam	64	36		Waste polyurethane treatment of. sorting plant	Waste polyurethane {CH}| treatment of. municipal incineration with fly ash extraction | Alloc Def. U		
				Waste polyurethane {RoW}| treatment of. inert material landfill | Alloc Def. U	Electricity. high voltage {Europe without Switzerland}| market group for | Alloc Def. U		
Paint on wood	66	34		Waste paint on wood| treatment of. sorting plant	Waste paint {CH}| treatment of. municipal incineration with fly ash extraction | Alloc Def. U		
				Waste paint {CH}| treatment of. sanitary landfill | Alloc Def. U	Electricity. high voltage {Europe without Switzerland}| market group for | Alloc Def. U		
Paint on wall	91.6	1.9	6.5	Waste paint on wall {CH}| treatment of. sorting plant	Waste paint {CH}| treatment of. municipal		Clinker {Europe without Switzerland}|

	EoL treatment rate			Waste treatment –Module S		Module R	
Material	**% to landfill**	**% to incineration**	**% to recycling**	**ecoinvent process (waste treatment Sorting plant + Landfill)**	**ecoinvent process (waste treatment - incineration)**	**ecoinvent process (burdens from recycling)**	**ecoinvent process Avoided products (benefits from recycling)**
					incineration with fly ash extraction | Alloc Def. U		production | Alloc Def. U
				Waste paint {CH}| treatment of. sanitary landfill | Alloc Def. U	Electricity. high voltage {Europe without Switzerland}| market group for | Alloc Def. U		
Bitumen sheet	50	50		Waste bitumen sheet| treatment of. sorting plant	Waste bitumen sheet {CH}| treatment of. municipal incineration with fly ash extraction | Alloc Def. U		
				Waste bitumen {CH}| treatment of. sanitary landfill | Alloc Def. U	Electricity. high voltage {Europe without Switzerland}| market group for | Alloc Def. U		
Cellulose fibers-insulation material	28.3		71.7	Waste paper.| treatment of sorting		Waste paper. sorted – Recycling burdens	Cellulose fibre. production
				Waste paper. unsorted			

ANNEX 2 – Results of the sensitivity analysis on the electricity mix

As shown in the results per life cycle stage, the environmental impacts from BoP Housing baseline are dominated by the use phase. Within this phase, electricity is the main responsible for all the impact categories. The only exceptions are Particulate Matter and Terrestrial Eutrophication, for which an important role is also played by the light fuel oil, and Land Use and Human Toxicity, non-cancer effects, for which the main responsibility is attributed to the wood based heating.

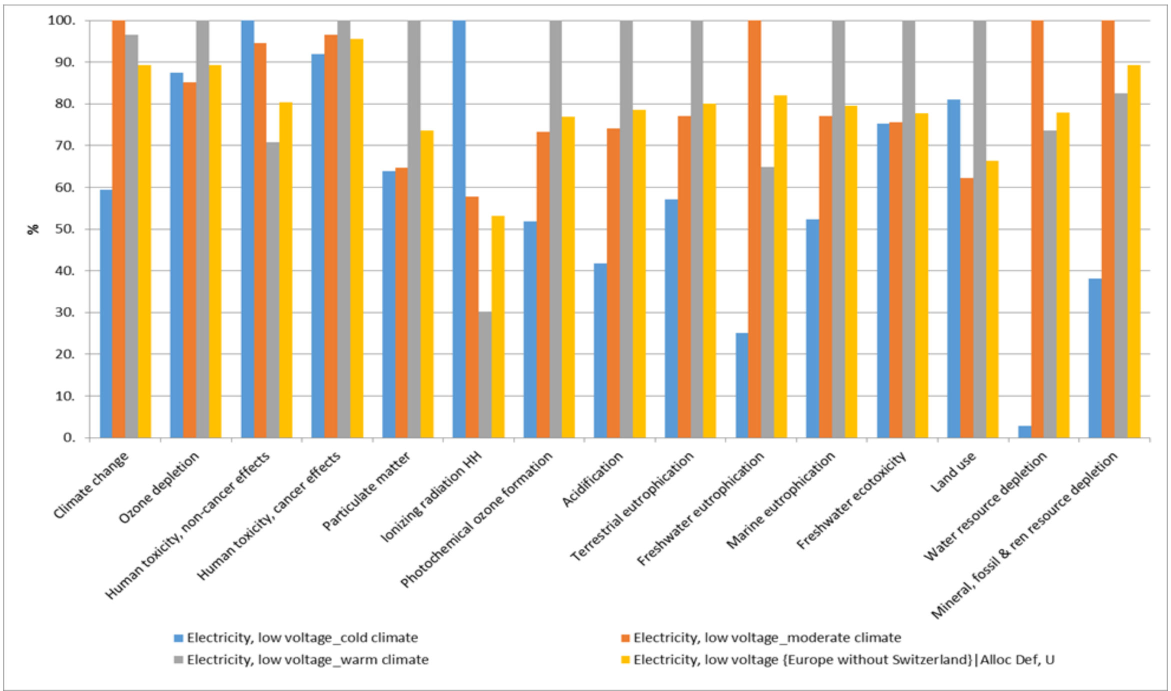
In order to better understand the variability of hotspots with specific reference to the electricity and thus to all electricity consuming functions, a "zone" electricity mix has been calculated for each of the three climatic zones and compared to the European one used in the BoP (Electricity, low voltage {Europe without Switzerland} market group for | Alloc Def, U). In the electricity mix of each zone, the contribution of each country mix is proportional to the number of dwellers in that country (Table 103), to reproduce in a way as consistent as possible, the consumption pattern within each zone.

Table 103. Composition of the electricity mix for the warm, moderate and cold zone. The contribution of country mix to 1 kWh from zone mix is proportional to the number of dwellers.

Electricity mix	Dwellers	Dwellers, % on the total zone	Contribution to 1 kWh
Malta	414027	0.32	0.003218
Cyprus	819140	0.64	0.006366
Portugal	10573479	8.22	0.082177
Greece	11183516	8.69	0.086918
Spain	46486619	36.13	0.361294
Italy	59190143	46.00	0.460026
Zone 1 - Warm	128666924	100	1
France	64658856	18.52	0.185192
Slovenia	2046976	0.59	0.005863
Belgium	10839905	3.10	0.031047
Hungary	10014324	2.87	0.028682
Romania	20294683	5.81	0.058127
Ireland	4549428	1.30	0.01303
Netherlands	16574989	4.75	0.047473
Bulgaria	7421766	2.13	0.021257
Luxembourg	502066	0.14	0.001438
United Kingdom	62510197	17.90	0.179038
Slovakia	5390410	1.54	0.015439
Germany	81802257	23.43	0.234293
Austria	8375290	2.40	0.023988
Czech Rep.	10462088	3.00	0.029965
Poland	38167329	10.93	0.109316
Denmark	5534738	1.59	0.015852
Zone 2 - Moderate	349145302	100.00	1
Lithuania	3141976	14.76	0.147595
Latvia	2120504	9.96	0.099611
Estonia	1333290	6.26	0.062631
Sweden	9340682	43.88	0.438779
Finland	5351427	25.14	0.251384
Zone 3 - Cold	21287879	100	1

When the European electricity mix is used instead of the one for the Warm Zone one, impacts on several impact categories are underestimated (Figure 38).

Figure 38. Comparison between impacts of electricity from European mix (Electricity, low voltage {Europe without Switzerland} |market group for | Alloc Def, U – ecoinvent) and electricity from warm, moderate and cold mix (calculated on ecoinvent).



The major underestimations are on the land use, freshwater ecotoxicity, acidification, photochemical ozone formation, marine eutrophication, particulate matter, freshwater eutrophication, for which the differences are higher than 20% (Table 104). On the contrary, other impact categories are overestimated, in particular ionizing radiation HH, freshwater eutrophication, ionizing radiation E (interim), where the difference is higher than -20% (Table 104).

Table 104. Impacts difference between 1 kWh electricity provided by the Warm zone mix (calculated on ecoinvent) and the European mix (Electricity, low voltage {Europe without Switzerland} |market group for | Alloc Def, U – ecoinvent).

Impact category	**Unit**	**Difference (absolute value)**	**Difference (%)**
Climate change	kg CO_2 eq	4.00E-02	8%
Ozone depletion	kg CFC-11 eq	6.76E-09	12%
Human toxicity, non-cancer effects	CTUh	-4.43E-09	-12%
Human toxicity, cancer effects	CTUh	2.14E-10	5%
Particulate matter	kg PM2.5 eq	7.09E-05	36%
Ionizing radiation HH	kBq U^{235} eq	-3.00E-02	-43%
Photochemical ozone formation	kg NMVOC eq	3.15E-04	30%
Acidification	molc H^+ eq	7.82E-04	27%
Terrestrial eutrophication	molc N eq	9.33E-04	25%
Freshwater eutrophication	kg P eq	-1.15E-05	-21%
Marine eutrophication	kg N eq	8.80E-05	26%
Freshwater ecotoxicity	CTUe	4.00E-02	29%
Land use	kg C deficit	2.50E-01	51%
Water resource depletion	m^3 water eq	-3.00E-03	-5%
Resource depletion	kg Sb eq	-1.88E-06	-8%

When the European electricity mix is used instead of a Cold Zone one, the major underestimations are on Ionizing radiation HH, land use, ionizing radiation E (interim) and human toxicity, non-cancer effects, for which differences are always higher than 20% and can also reach the 88%. Several other categories are overestimated, among all pop up water resource depletion, freshwater eutrophication and resource depletion, for which the difference is higher than 50% (Table 105).

Table 105. Impacts difference between 1 kWh electricity provided by the Cold zone mix (calculated on ecoinvent) and the European mix (Electricity, low voltage {Europe without Switzerland} |market group for | Alloc Def, U – ecoinvent).

Impact category	Unit	Difference (unit)	Difference (%)
Climate change	kg CO_2 eq	-1.67E-01	-33%
Ozone depletion	kg CFC-11 eq	-1.18E-09	-2%
Human toxicity, non-cancer effects	CTUh	9.02E-09	24%
Human toxicity, cancer effects	CTUh	-1.76E-10	-4%
Particulate matter	kg PM2.5 eq	-2.63E-05	-13%
Ionizing radiation HH	kBq U^{235} eq	6.65E-02	88%
Photochemical ozone formation	kg NMVOC eq	-3.43E-04	-33%
Acidification	molc H^+ eq	-1.35E-03	-47%
Terrestrial eutrophication	molc N eq	-1.06E-03	-28%
Freshwater eutrophication	kg P eq	-3.83E-05	-69%
Marine eutrophication	kg N eq	-1.18E-04	-34%
Freshwater ecotoxicity	CTUe	-4.29E-03	-3%
Land use	kg C deficit	1.13E-01	22%
Water resource depletion	m^3 water eq	-5.91E-02	-96%
Resource depletion	kg Sb eq	-1.42E-05	-57%

As far as the impacts from the moderate electricity mix is concerned, just in the case of the Water resource depletion and Freshwater eutrophication using the European mix instead of the moderate zone mix produces an underestimation slightly above the 20% (Table 106). On the contrary, the most evident overestimation is for the particulate matter, where the difference is up to 12% (Table 106).

Results show that difference exist between the European electricity mix and the zone electricity mix. Differences are evident for warm and cold zone, whereas are smaller for the moderate zone. It can be concluded that, the environmental impacts arising from the building stock in warm and cold zone vary by changing the electricity mix, in particular by using for these zone their specific mix as built in this exercise. For the moderate zone, the variation is quite small. However, the sensitivity of results from the overall BoP Housing baseline to the electricity mix is limited, due to the minor weight of cold and warm zone compared to the moderate zone, in term of inhabitants (Table 107).

Table 106. Impacts difference between 1 kWh electricity provided by the Moderate zone mix (calculated on ecoinvent) and European mix (Electricity, low voltage {Europe without Switzerland} |market group for | Alloc Def, U – ecoinvent).

Impact category	Unit	Difference (unit)	Difference (%)
Climate change	kg C deficit	6.02E-02	12%
Ozone depletion	kg CO_2 eq	-2.66E-09	-5%
Human toxicity, non-cancer effects	CTUe	6.54E-09	18%
Human toxicity, cancer effects	kBq U^{235} eq	4.88E-11	1%
Particulate matter	m^3 water eq	-2.38E-05	-12%
Ionizing radiation HH	molc N eq	6.61E-03	9%
Photochemical ozone formation	molc H^+ eq	-5.07E-05	-5%
Acidification	kg NMVOC eq	-1.69E-04	-6%
Terrestrial eutrophication	kg N eq	-1.37E-04	-4%
Freshwater eutrophication	kg $PM_{2.5}$ eq	1.21E-05	22%
Marine eutrophication	kg P eq	-1.10E-05	-3%
Freshwater ecotoxicity	kg Sb eq	-3.58E-03	-3%
Land use	kg CFC-11 eq	-3.04E-02	-6%
Water resource depletion	CTUh	1.74E-02	28%
Resource depletion	CTUh	2.97E-06	12%

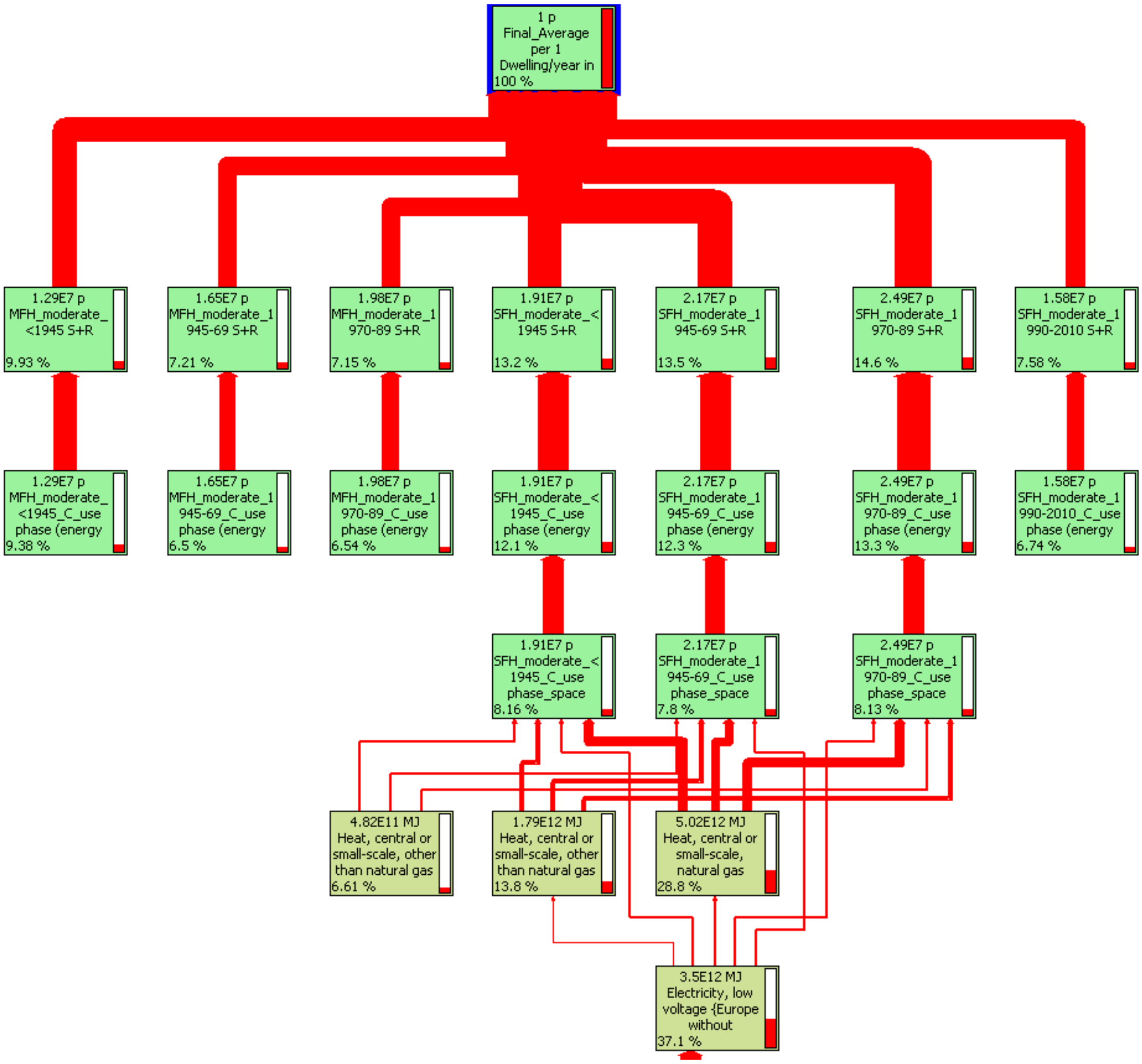
Table 107. Contribution of the single zone to the total amount of dwellers.

	Dwellers	Dwellers % on the total
Zone 1 - warm	128,666,924	26
Zone 2 - moderate	349,145,302	70
Zone 3 - cold	21,287,879	4
Total	499,100,105	100

ANNEX 3 – Network graphs of the inventory of most contributing elementary flows

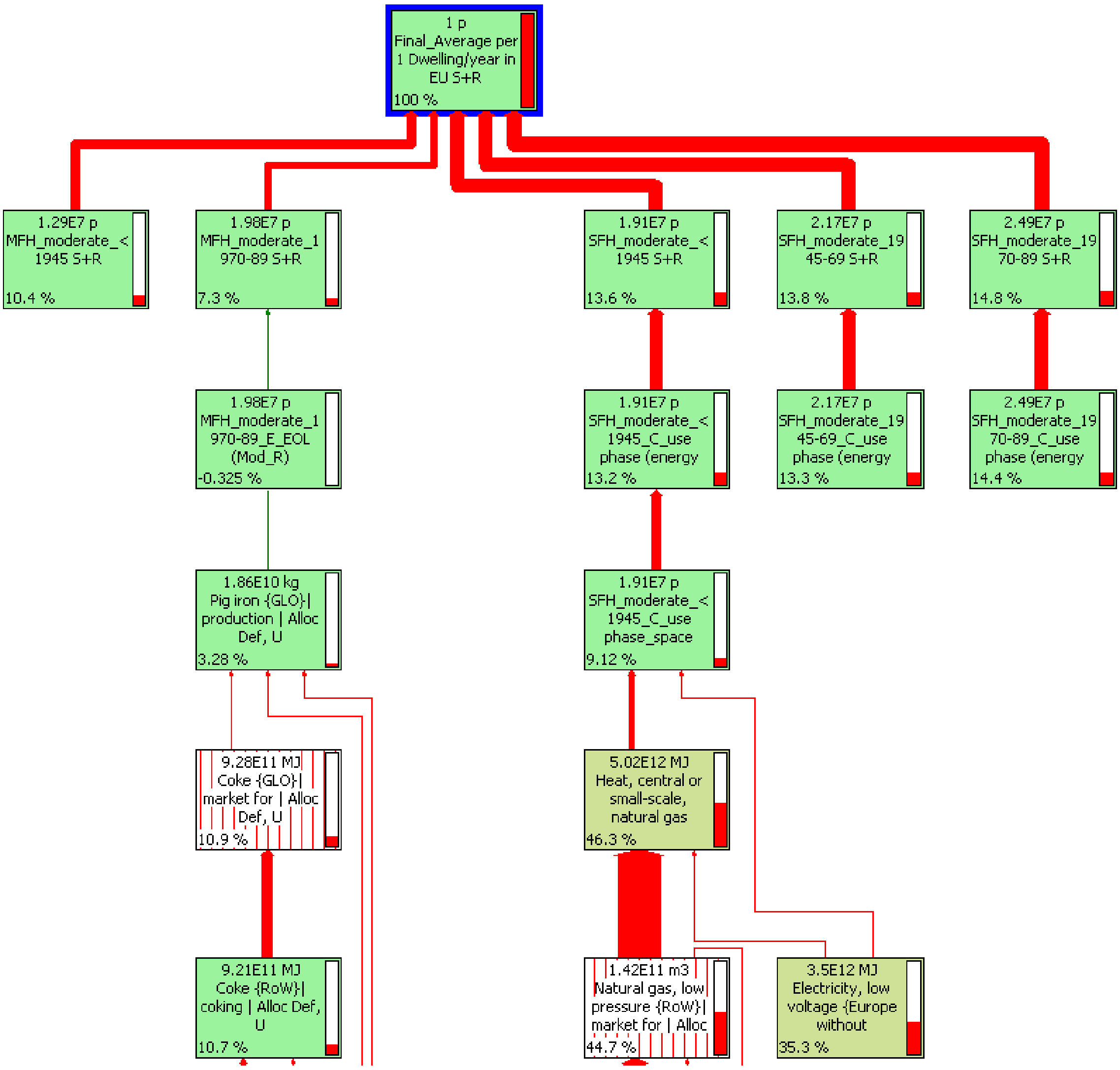
The inventory networks of the most important flow(s) (Table 22) are reported below. The larger the depth of the red arrow going from one process to the related one(s), the larger the contribution of that process to the total amount of the analysed flow in the inventory (e.g., which are the activities that entail higher emissions of carbon dioxide to air).

Carbon dioxide, fossil (92.2% of Climate change):



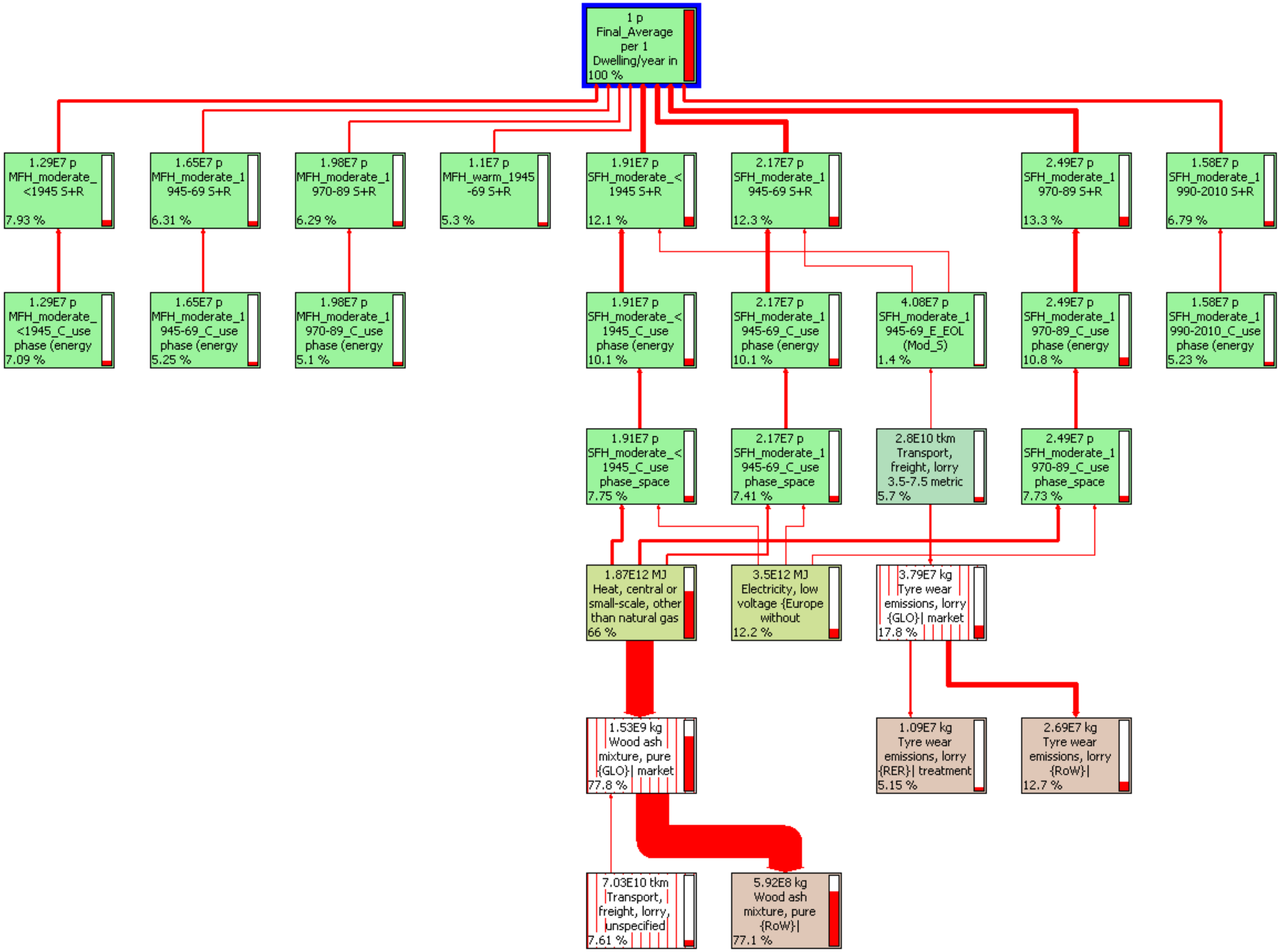
cut-off 9 %

Methane, fossil (6.45% of Climate change):

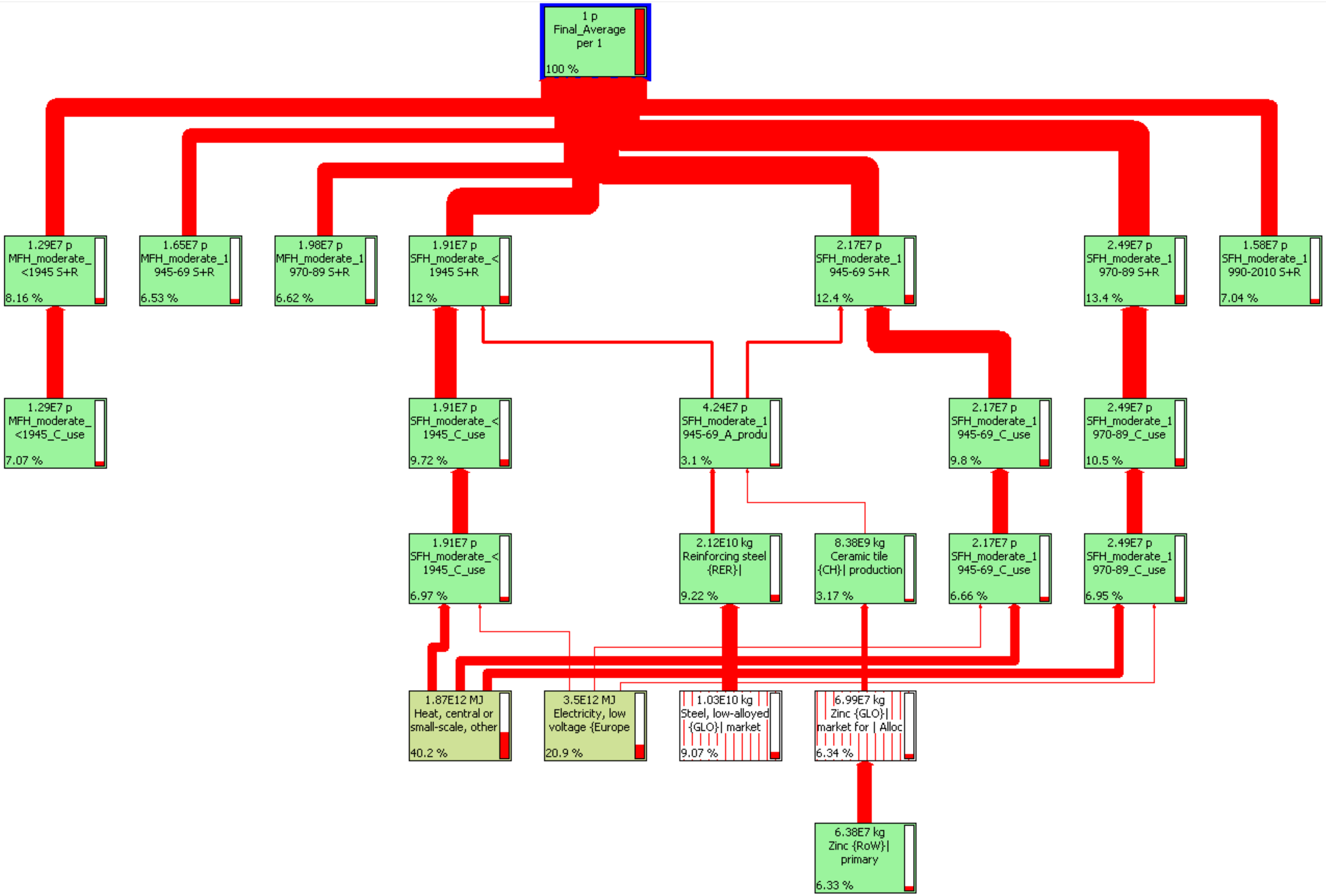


cut-off 10 %

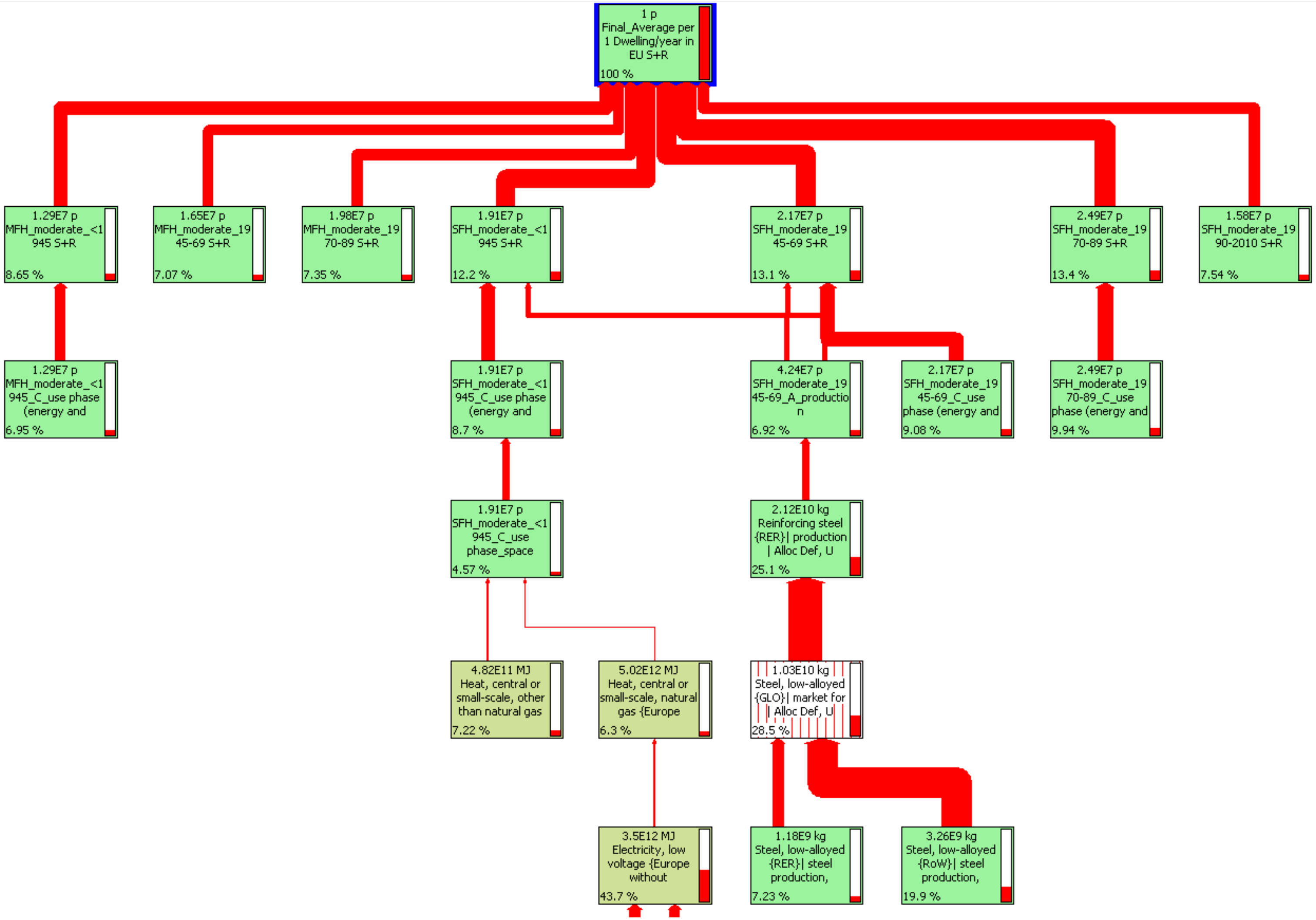
Zinc to soil (32.40% of Human tox. non-cancer effects):



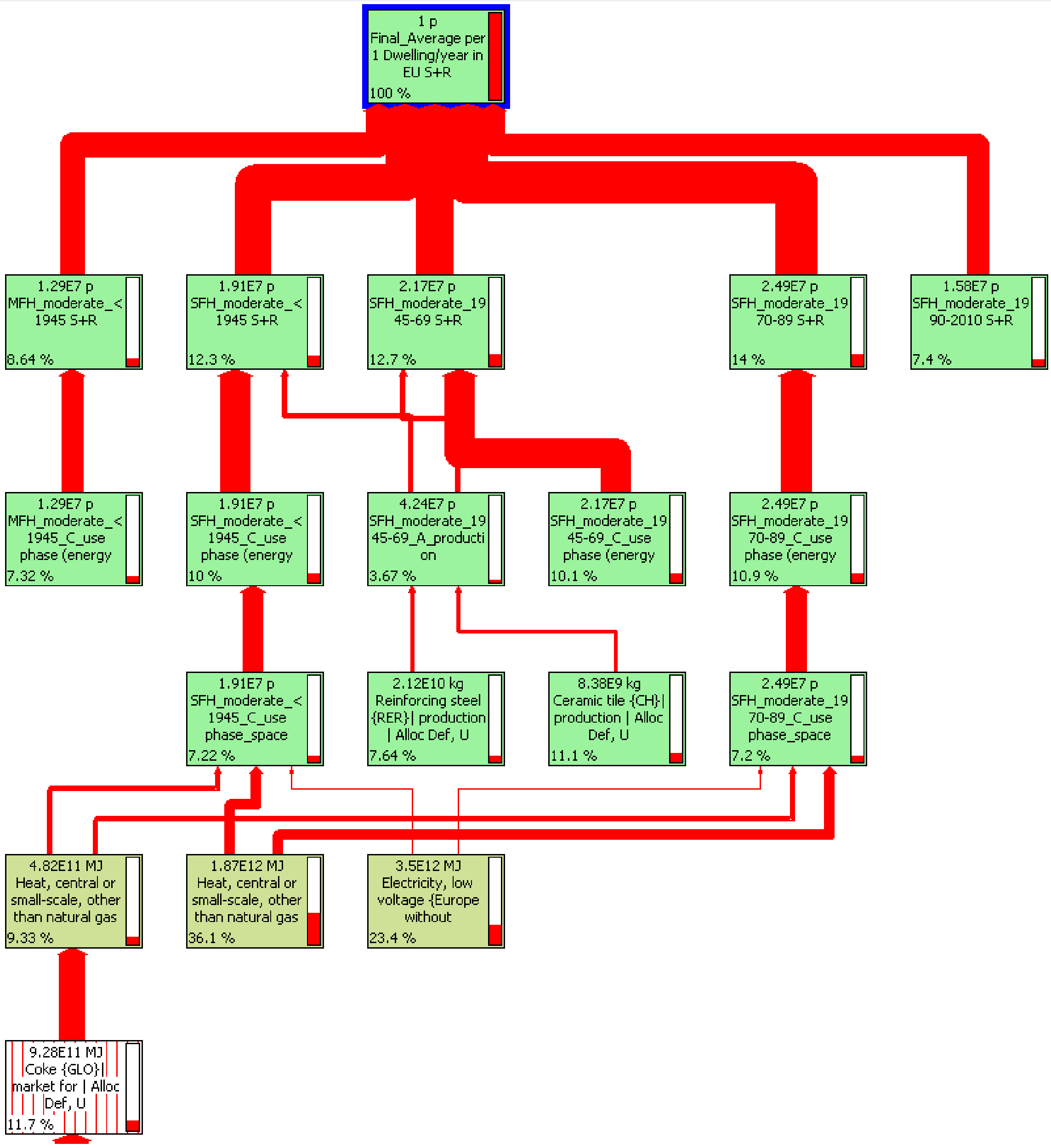
Zinc to air (23.70% of Human tox. non-cancer effects):



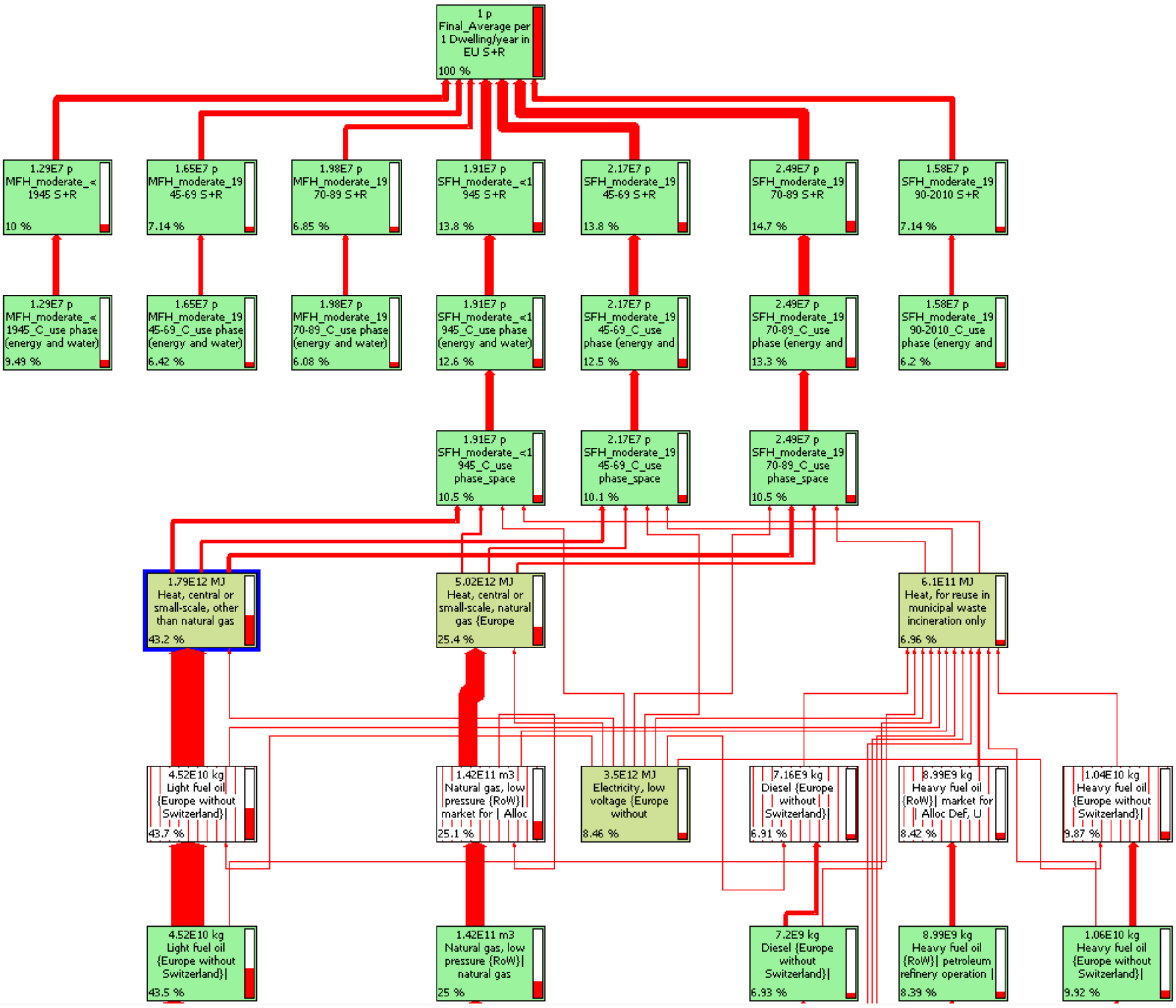
Mercury to air (23.30% of Human tox. non-cancer effects):



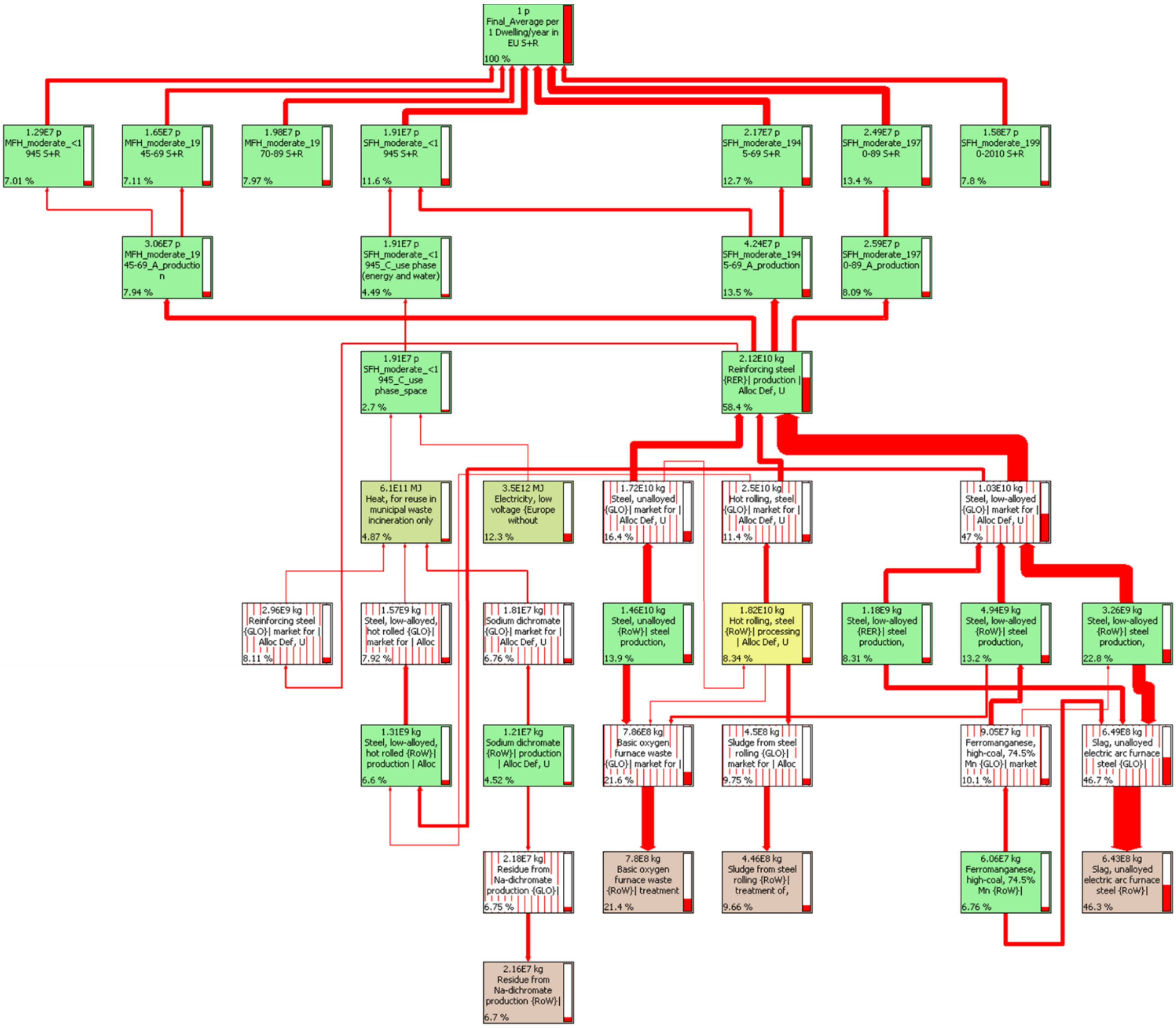
Particulates < 2.5 um (81.8% of Particulate matter):



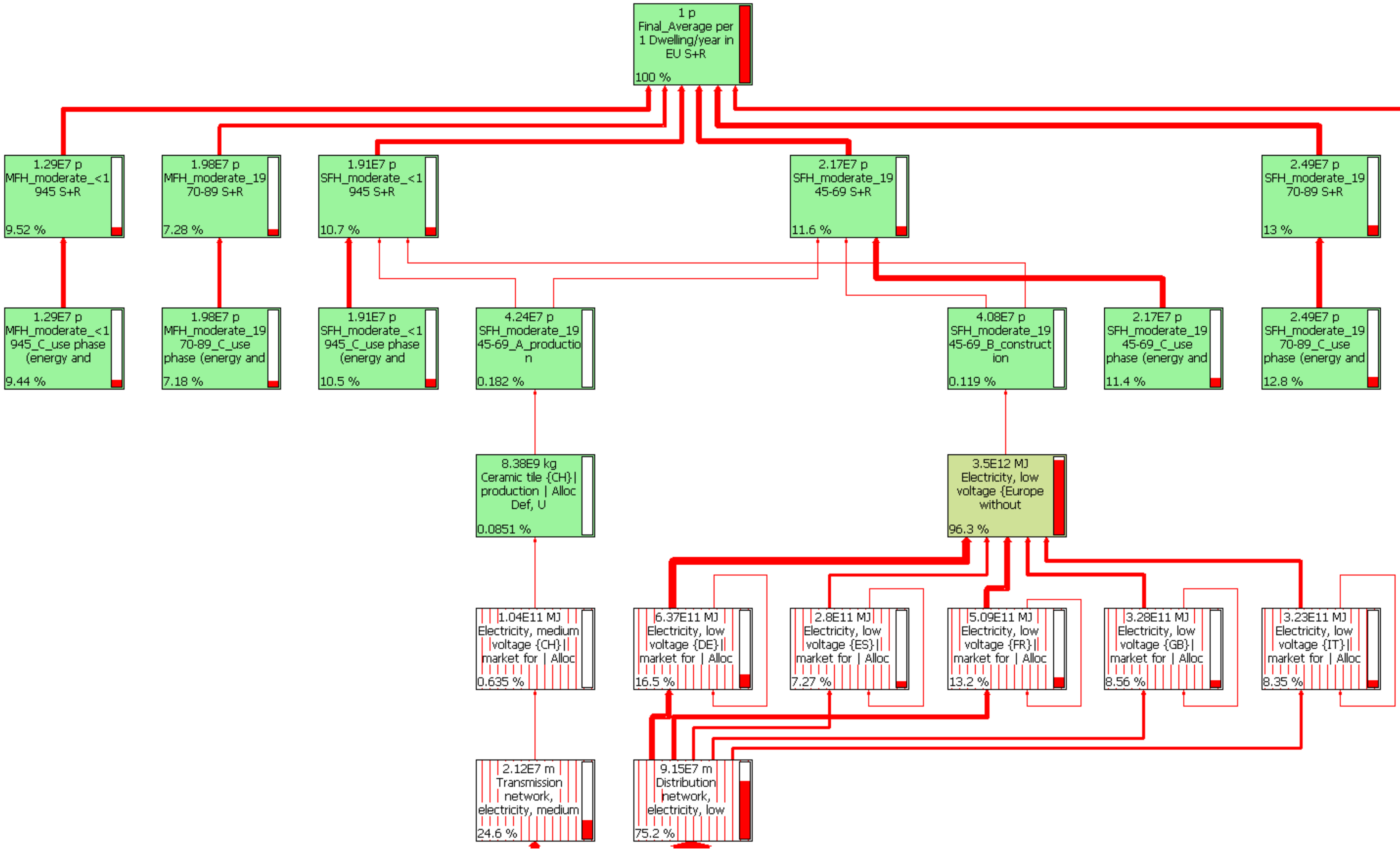
Methane, bromotrifluoro-, Halon 1301 (42.80% of Ozone depletion):



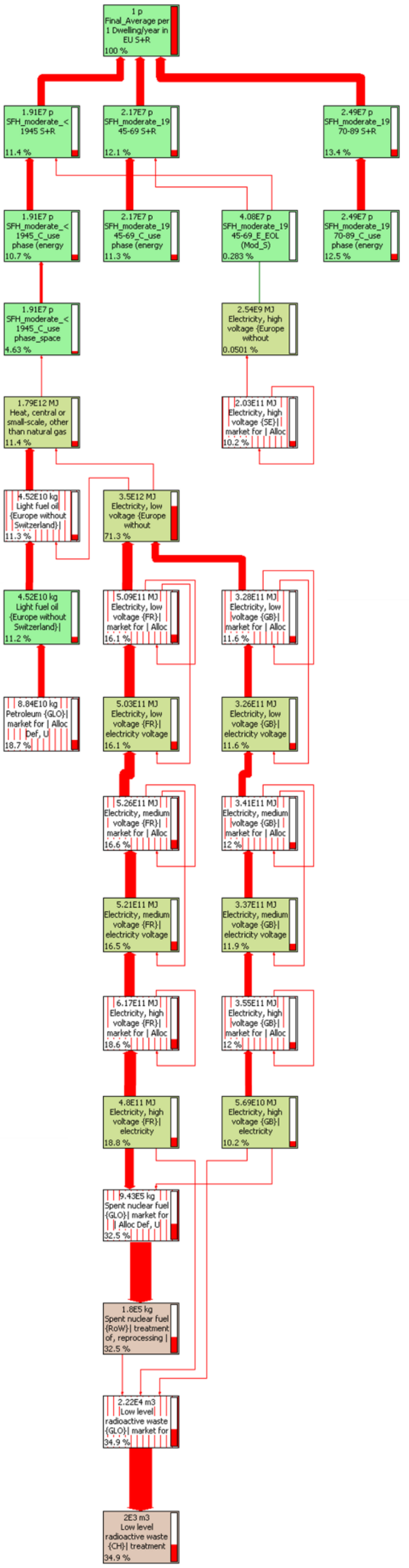
Chromium VI to water (54.20% of Human toxicity, cancer effects and 16.4% of Freshwater ecotoxicity):



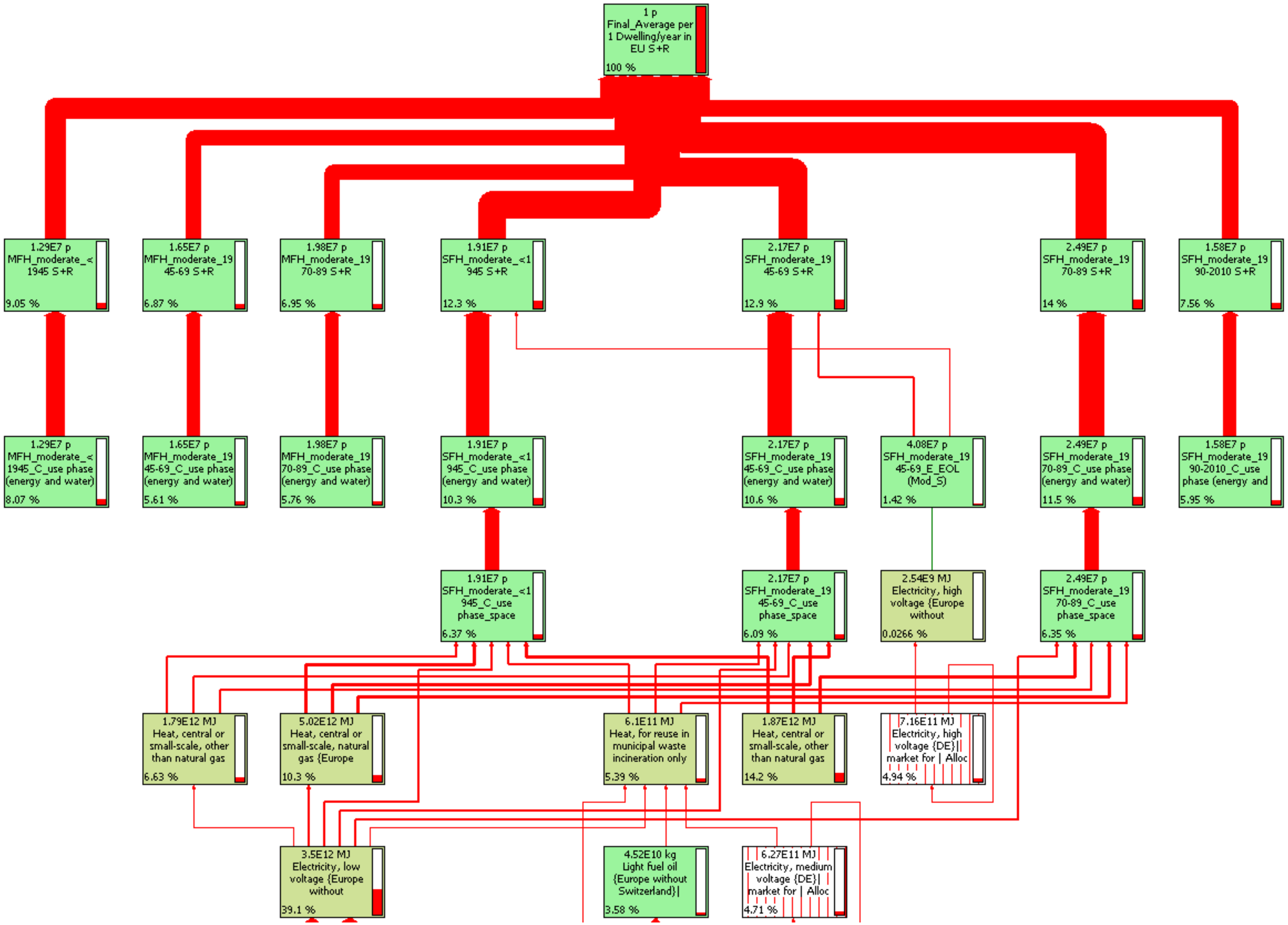
Chromium VI to soil (15.10% of Human toxicity, cancer effects):



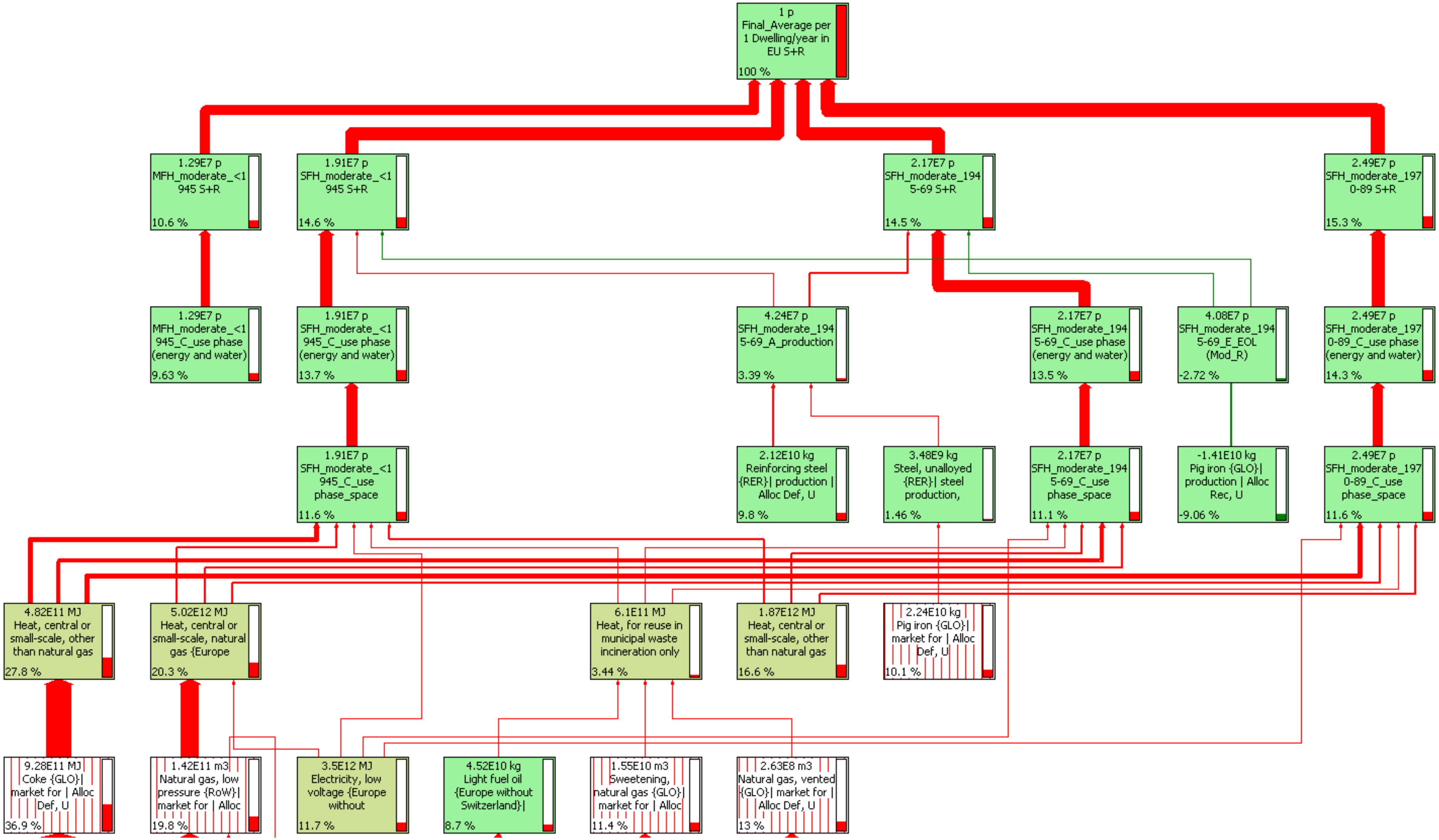
Carbon-14 to air (94.10% of Ionizing radiation HH):



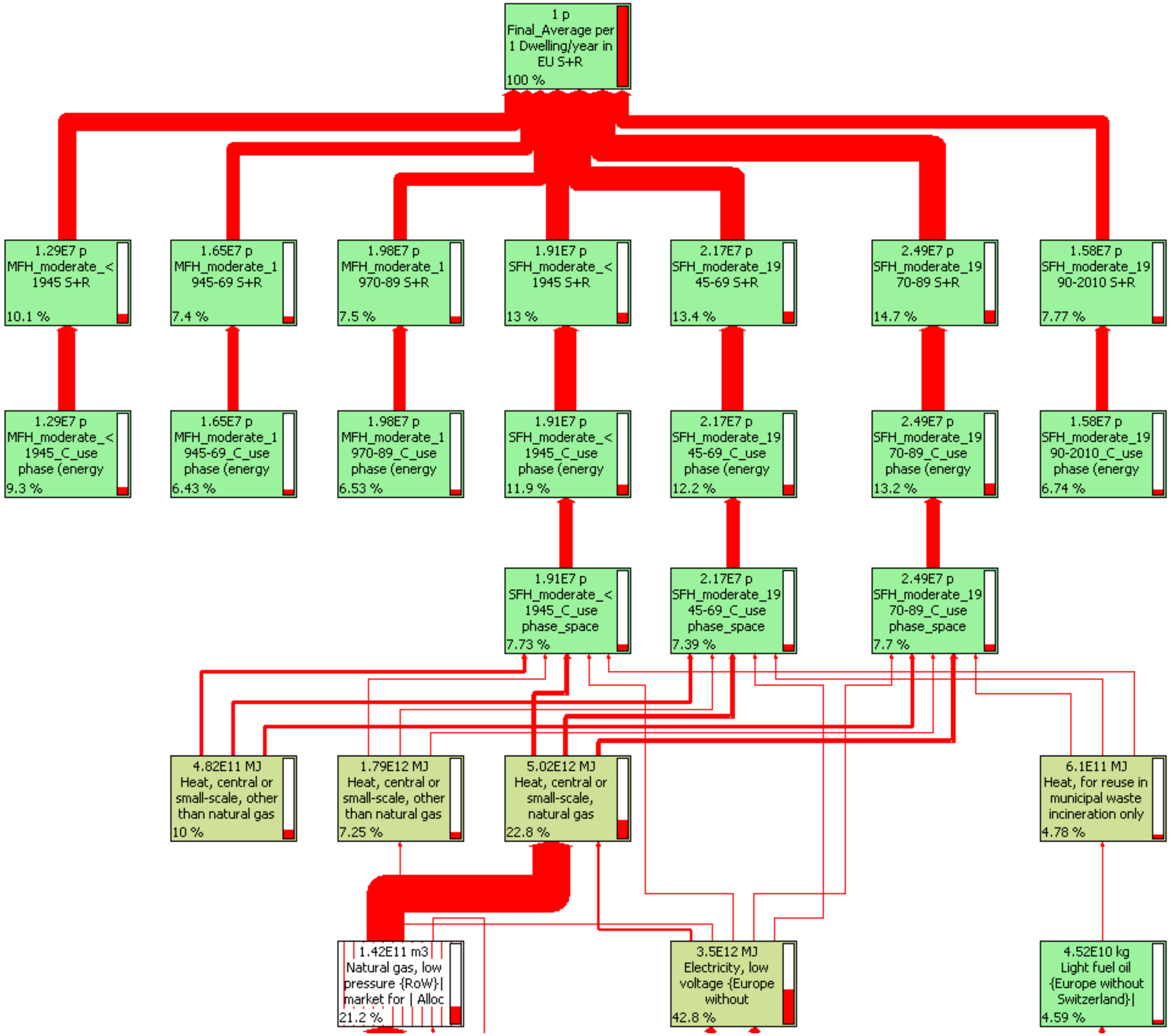
Nitrogen oxides (67.40% of Photochemical ozone formation. 95.50% of Marine eutrophication. 22.70% of Acidification and 95.20% of Terrestrial eutrophication):



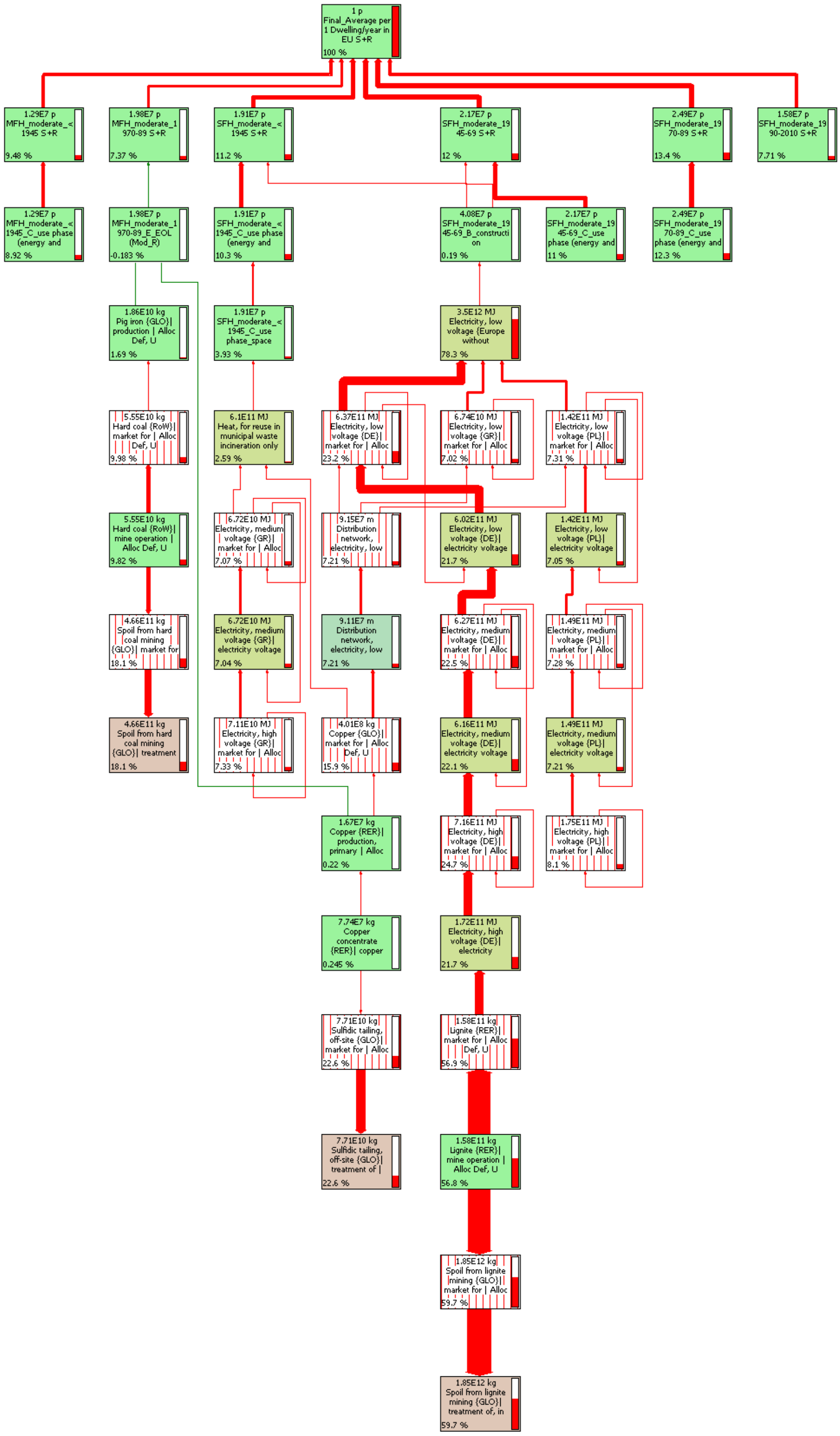
NMVOC, non-methane volatile organic compounds, unspecified origin (18.10% of Photochemical ozone formation):



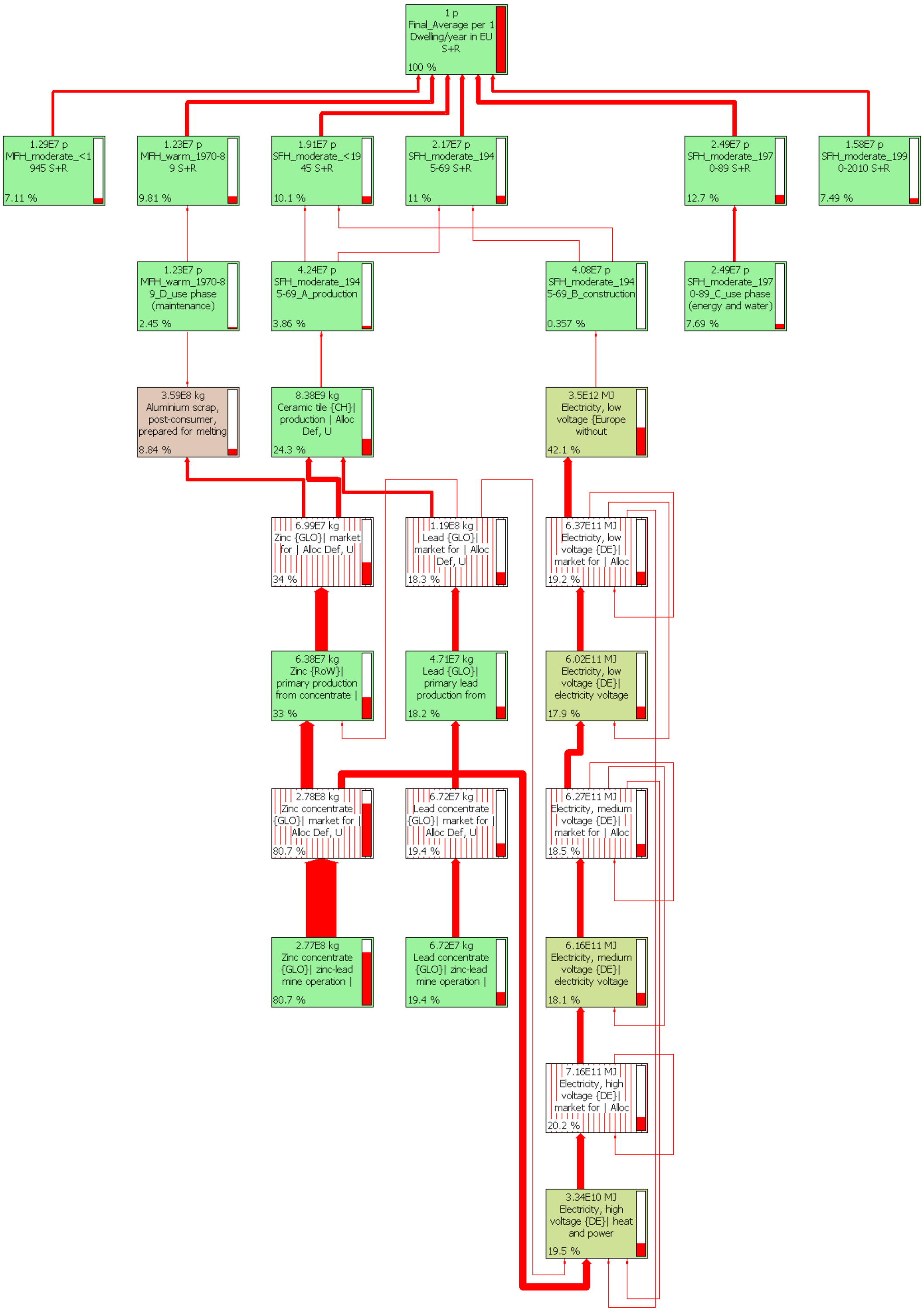
Sulfur dioxide (75.80% of Acidification. 10.30% of Photochemical ozone formation and 16.7% of Particulate matter):



Phosphate to water (91.20% of Freshwater eutrophication):

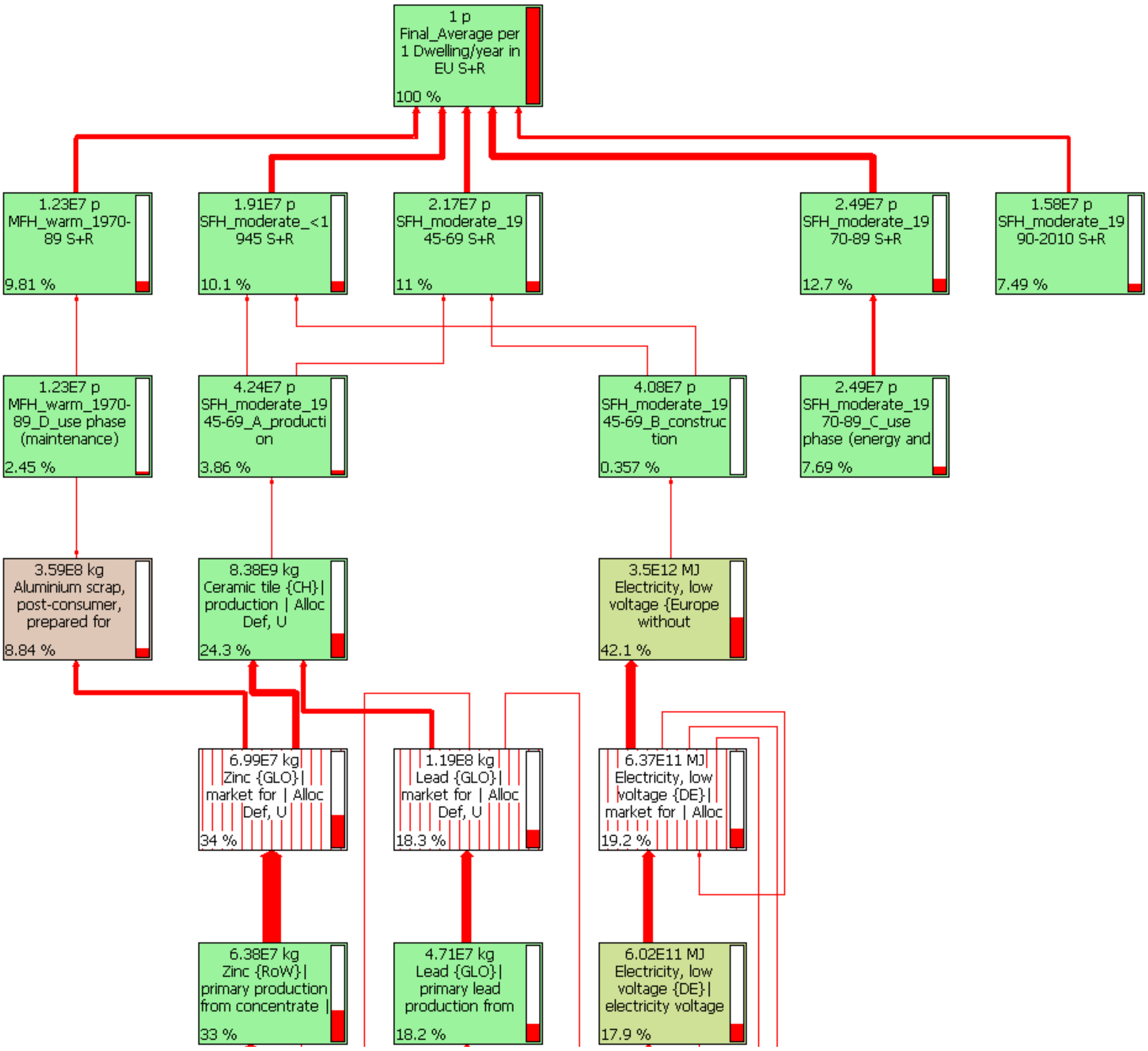


Indium (70.90% of Resource depletion):

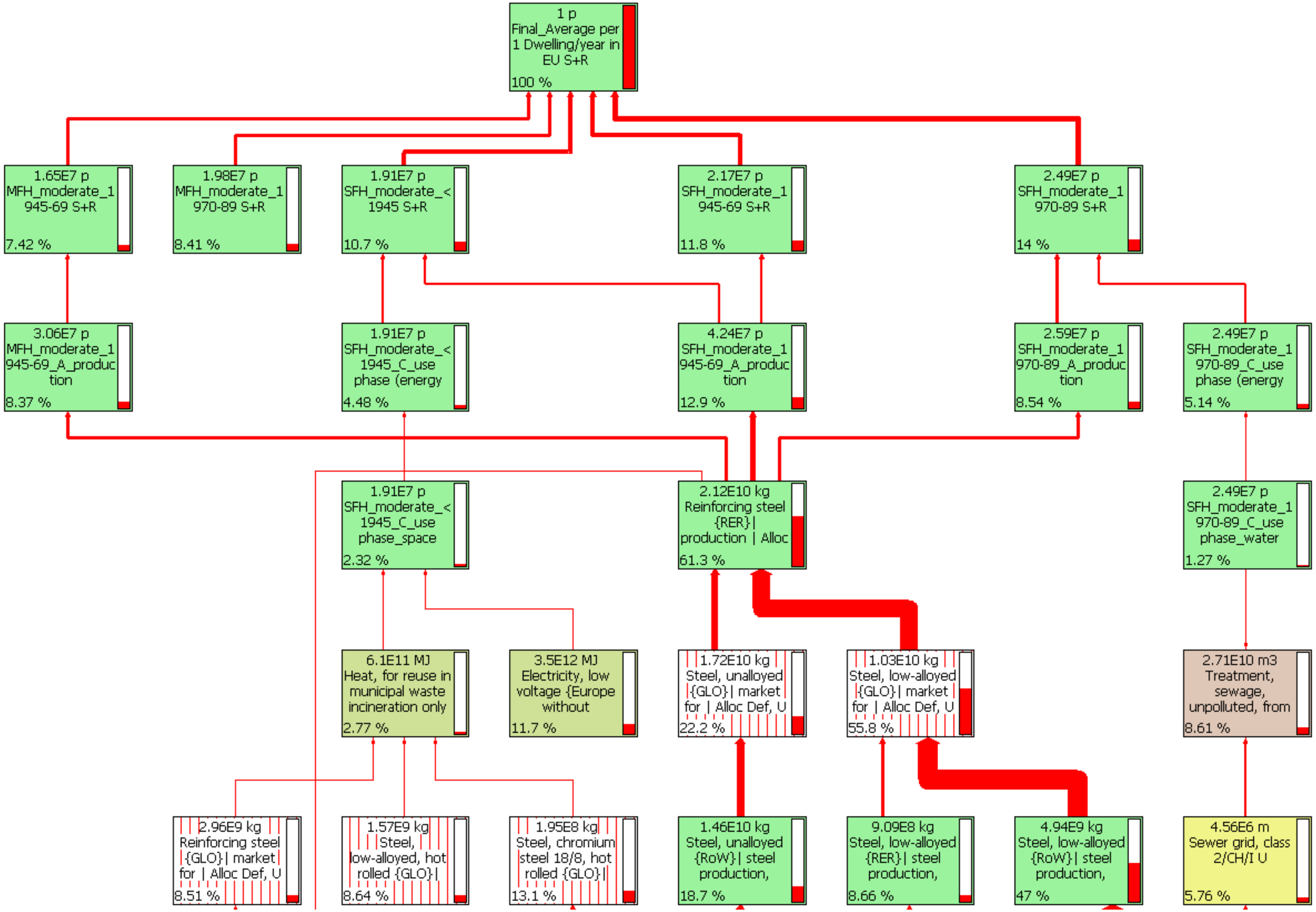


The relevance of Indium, associated to zinc production is due to the economic allocation of the inventory related to mining. For this reason, we evaluated also the distribution of Cadmiun, second in the relevance list for Mineral resources, within the inventory of BoP housing.

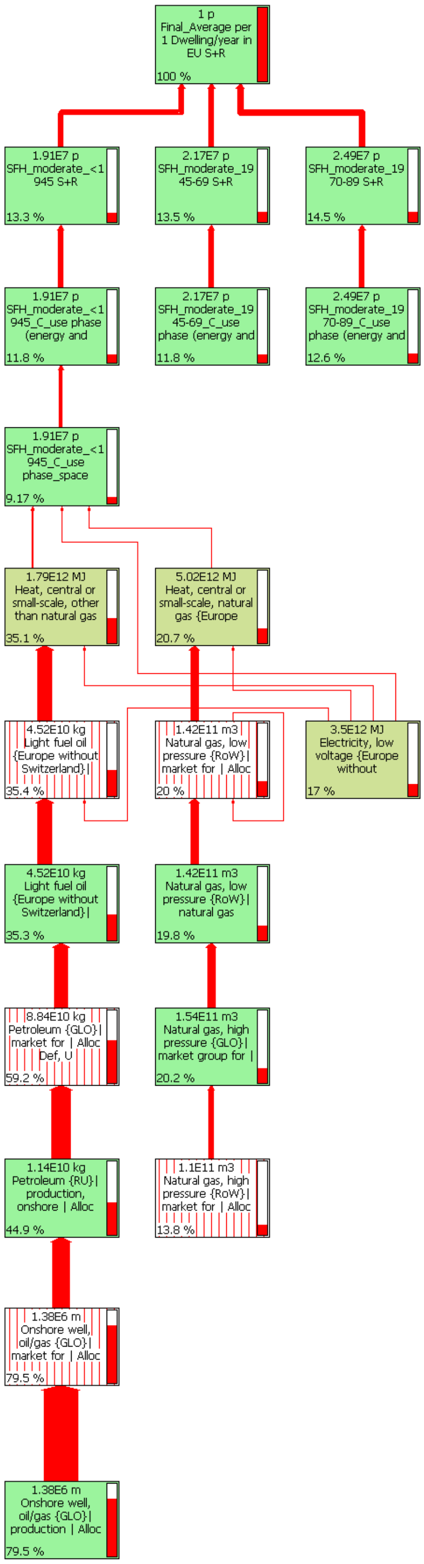
Cadmium (8.51% of Resource depletion):


1 p
Final_Average per 1 Dwelling/year in EU S+R
100 %
1.23E7 p
MFH_warm_1970-89 S+R
9.81 %
1.91E7 p
SFH_moderate_<1945 S+R
10.1 %
2.17E7 p
SFH_moderate_1945-69 S+R
11 %
2.49E7 p
SFH_moderate_1970-89 S+R
12.7 %
1.58E7 p
SFH_moderate_1990-2010 S+R
7.49 %
1.23E7 p
MFH_warm_1970-89_D_use phase (maintenance)
2.45 %
4.24E7 p
SFH_moderate_1945-69_A_production
3.86 %
4.08E7 p
SFH_moderate_1945-69_B_construction
0.357 %
2.49E7 p
SFH_moderate_1970-89_C_use phase (energy and
7.69 %
3.59E8 kg
Aluminium scrap, post-consumer, prepared for
8.84 %
8.38E9 kg
Ceramic tile {CH}| production | Alloc Def, U
24.3 %
3.5E12 MJ
Electricity, low voltage {Europe without
42.1 %
6.99E7 kg
Zinc {GLO}| market for | Alloc Def, U
34 %
1.19E8 kg
Lead {GLO}| market for | Alloc Def, U
18.3 %
6.37E11 MJ
Electricity, low voltage {DE}| market for | Alloc
19.2 %
6.38E7 kg
Zinc {RoW}| primary production from concentrate |
33 %
4.71E7 kg
Lead {GLO}| primary lead production from
18.2 %
6.02E11 MJ
Electricity, low voltage {DE}| electricity voltage
17.9 %

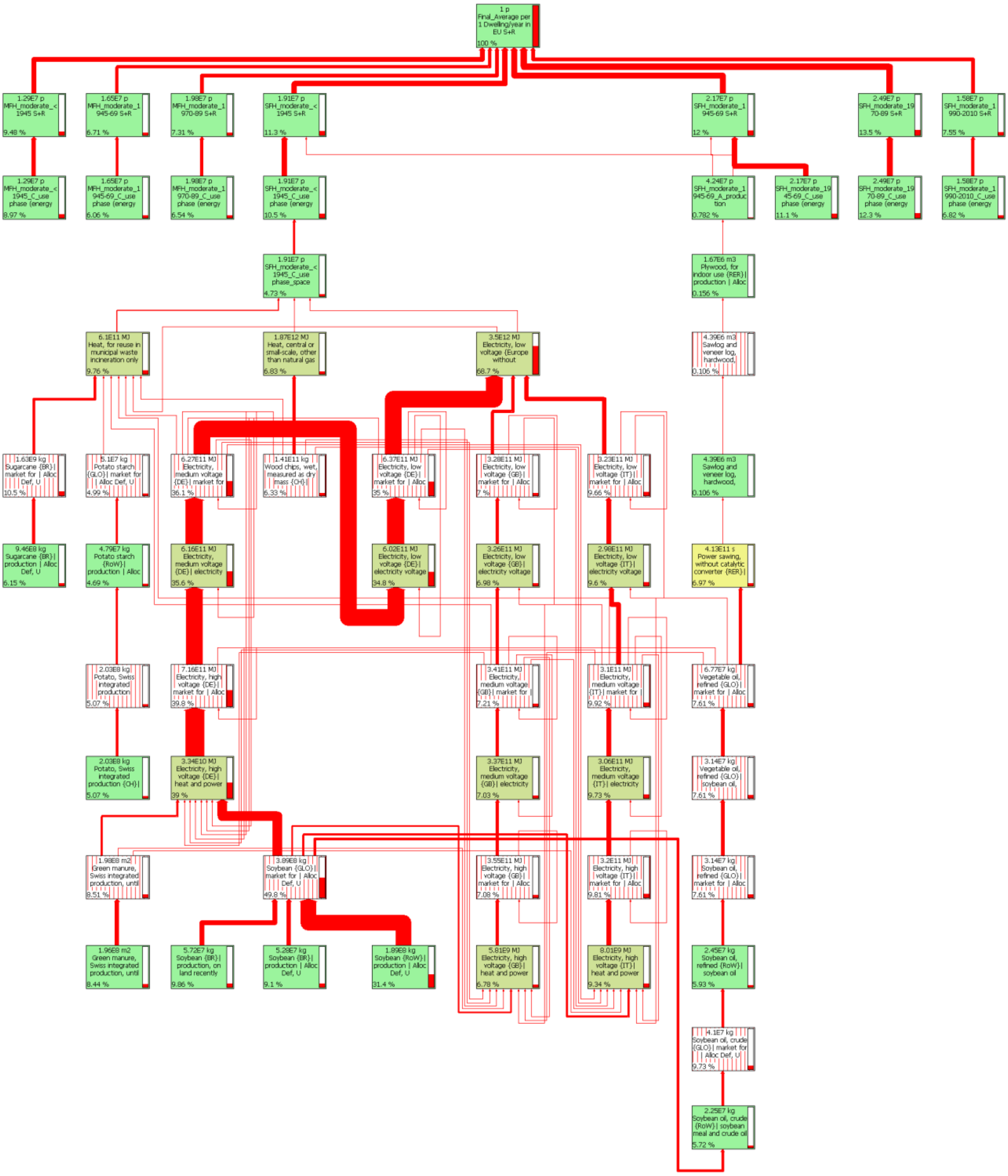
Nickel (5.94% of Resource depletion)



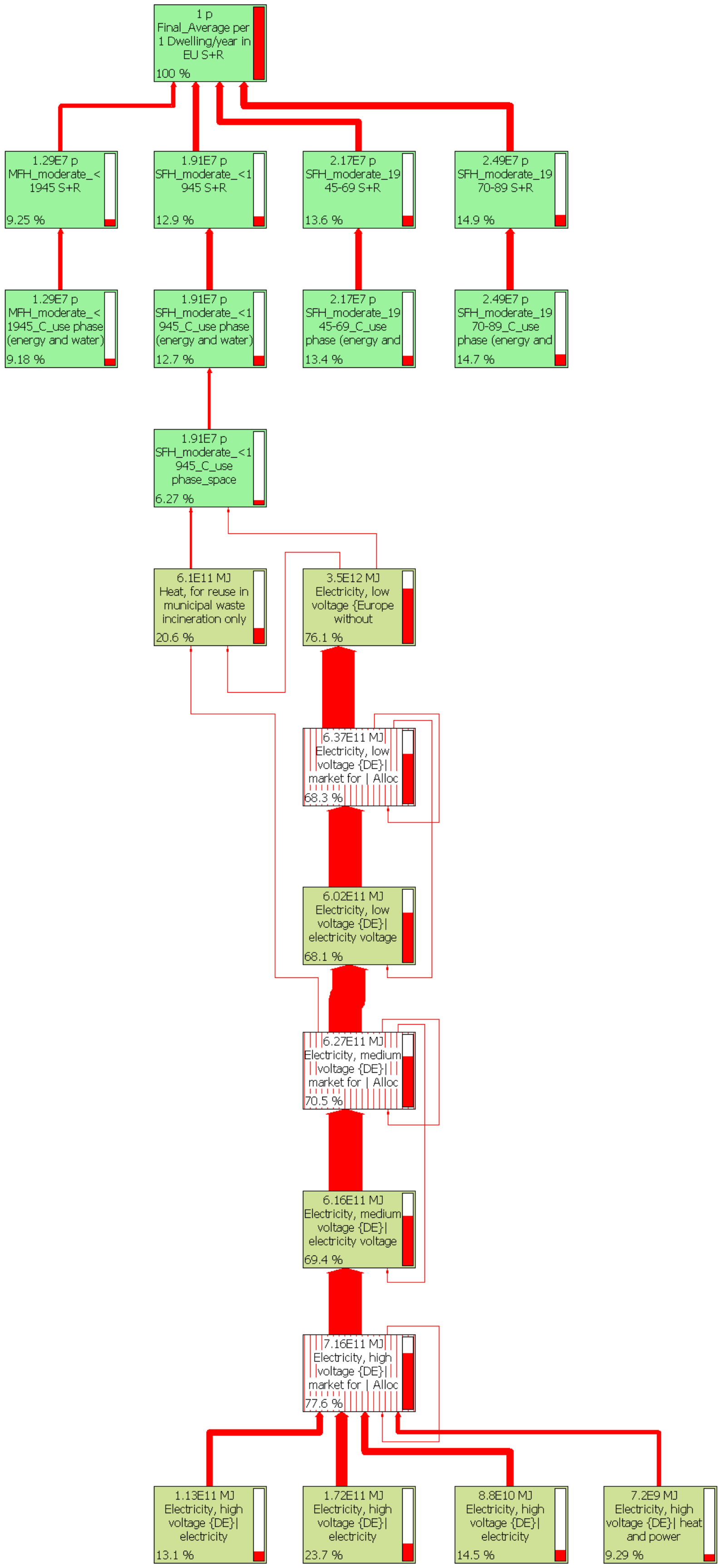
Transformation to mineral extraction site (49.0% of Land Use)



Transformation, to arable, non-irrigated, intensive (47.4% of Land Use)



Water, cooling, unspecified natural origin, DE (25.30% of Water Depletion)



ANNEX 4 – Details of the LCI models for the scenarios analysed

The LCI model of the scenarios follows the same structure as used for the model of the BoP Housing baseline. In consequence, each model of the scenarios is composed by the following life cycle phases (in red, the modifications made for the modelling of the scenarios, in black, the phases as they were already included in the baseline):

- Production of materials (baseline scenario)
- *Production of additional materials (new scenario)*
- Construction phase (baseline scenario)
- *Construction phase – additional products/processes (new scenario)*
- Use phase – energy and water consumption (new scenario)
- Use phase – maintenance of the building and its components (baseline scenario)
- *Use phase – maintenance of the additional components (new scenario)*
- End of Life (baseline scenario)
- *End of life of additional materials (new scenario)*

The model of the fifth scenario (biobased floor finishing) differs from the above structure as this scenario does not only include an addition of materials (biobased floor finishing) but also includes a reduction in use of the original floor covering. For the modelling of this fifth scenario, the following structure is followed:

- Production of materials (new scenario)
- Construction phase (new scenario)
- Use phase – energy and water consumption (baseline scenario as these do not change)
- Use phase – maintenance (new scenario)
- End of life (new scenario)

The BoP housing overall model is composed of 24 representative dwellings, identified according to the year of construction and climatic condition of their location. This is fully in line with the BoP housing baseline.

In the subsequent paragraphs, the LCI modelling of each of the scenarios is explained in detail.

Scenario 1 – Night Attenuation

The following changes have been made to the BoP Housing baseline LCI model for the modelling of this scenario.

Production phase

The following technical components have to be added in order to allow for night attenuation: room thermostat, outdoor temperature sensor, cable to connect room thermostat with the boiler.

It is assumed that in each bedroom a room thermostat is being placed, which results in 3 room thermostats per dwelling for the SFH and 2 room thermostats per dwelling for the MFH. The ecoinvent LCI datasets listed in Table 108 have been used for the modelling of these components. Table 109 summarizes the amounts of each of these components per dwelling.

Table 108. LCI datasets for scenario 1

Technical component	ecoinvent record
Room thermostat	Electronics, for control units {RER}| production | Alloc Def. U
Cable to connect room thermostat with the boiler	Cable, network cable, category 5, without plugs {GLO}| production | Alloc Def. U
Manifold (brass)	Brass {CH}| production | Alloc Def. U
Circulation pump	Pump, 40W {CH}| production | Alloc Def. U
Ducts for second circuit (night) - PE pipes. outer dia 16 mm. thickness 2 mm	Own modelling (see excel file) - Weight aluminium/PE based on: www.henco.be/web/assets/downloads/Brochures/DO04-0000DU02.pdf

Table 109. Bill of quantities for each of the LCI datasets

Technical component	amount	unit	Source
Room thermostat	1 x 0.200	kg	www.karwei.nl/assortiment/plieger-klokthermostaat-milton/p/B454842 (0.150 kg); Honeywell klokthermostaat Chronotherm Touch TH8200G1004 (0.300 kg)
Cable to connect room thermostat with boiler	SFH: 13 MFH: 6	m	Estimation based on own expertise
Manifold	2.889	kg	www.uponorengineering.com/~/media/uponor%20engineering/submittal%20packages/package_4a.ashx?version=092020140134 + calculation to kg (see excel file)
Circulation pump	1	p	
Ducts for second circuit (night) - PE pipes. outer dia 16 mm. thickness 2 mm	SFH: 26 MFH: 12	m	Estimation based on own expertise

The same amounts have been assumed for each of the 12 SFH and for each of the 12 MFH in the BoP housing.

Construction phase

In line with the assumptions in the baseline scenario, it is assumed that 4% of the materials become "construction waste".

For the transport from plant to building site of the additional materials, the same assumptions were taken as in the baseline scenario, with a distance of 50 km from production to construction site with a lorry of 3.5-7.5 t. For the weight of the additional components, the following is taken into account:

- SFH
  - room thermostat: 0.200 kg
  - ducts: 3.822 kg
  - manifold: 2.889 kg
  - cable: 0.036 kg/m x 13 m = 0.468 kg
- MFH
  - room thermostat: 0.200 kg
  - ducts: 1.764 kg
  - manifold: 2.889 kg
  - cable: 0.036 kg/m x 6 m = 0.216 kg

No additional energy use is assumed for the installation of the additional components.

Use phase – energy and water consumption

This scenario only affects the energy use during this phase and has no influence on the water consumption. The latter hence remains unchanged compared to the BoP housing baseline scenario.

The reduced energy consumption for this scenario has been summarized in Table 32 (SFH) and Table 33 (MFH) in the chapter 8.2. For the LCI modelling, these total yearly energy consumption had to be distributed over the various energy sources. As only the control system has been changed in this scenario, the same percentage distribution of energy sources has been assumed. This results in the total yearly amounts of energy for each of the dwellings (expressed in kWh/year), and for the different energy sources. For each of the energy sources, the same LCI datasets have been assumed as in the BoP housing baseline scenario.

As for the baseline scenario, the total lifetime of the buildings is assumed to be 100 years.

Table 110. Scenario 1 – space heating in zone 1 (warm climate) for SFH.

zone 1	SFH	<1945				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	69	100	6911	0.4	28.85	Coal
				20.2	1396.91	Oil
				44.7	3090.28	Gas
				0.5	35.06	District heating
				30.6	2115.27	Wood
				3.5	244.56	Electricity

zone 1	SFH	1945-1969				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	65	100	6541	0.4	27.30	Coal
				20.2	1322.15	Oil
				44.7	2924.89	Gas
				0.5	33.18	District heating
				30.6	2002.05	Wood
				3.5	231.47	Electricity

zone 1	SFH	1970-1989				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	46	100	4633	0.4	19.34	Coal
				20.2	936.54	Oil
				44.7	2071.85	Gas
				0.5	23.51	District heating
				30.6	1418.16	Wood
				3.5	163.96	Electricity

zone 1	SFH	1990-2010				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	40	130	5152	0.4	21.50	Coal
				20.2	1041.35	Oil
				44.7	2303.70	Gas
				0.5	26.14	District heating
				30.6	1576.86	Wood
				3.5	182.31	Electricity

Table 111. Scenario 1 – space heating in zone 2 (moderate climate) for SFH.

zone 2	SFH	<1945				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	176	90	15880	6.6	1055.99	Coal
				16.8	2672.38	Oil
				47.6	7560.00	Gas
				8.8	1399.01	District heating
				14.1	2242.62	Wood
				6.0	950.42	Electricity

zone 2	SFH	1945-1969				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	148	90	13305	6.6	884.74	Coal
				16.8	2239.00	Oil
				47.6	6334.00	Gas
				8.8	1172.13	District heating
				14.1	1878.94	Wood
				6.0	796.29	Electricity

zone 2	SFH	1970-1989				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	120	100	11972	6.6	796.11	Coal
				16.8	2014.70	Oil
				47.6	5699.49	Gas
				8.8	1054.71	District heating
				14.1	1690.71	Wood
				6.0	716.52	Electricity

zone 2	SFH	1990-2010				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	79	100	7944	6.6	528.24	Coal
				16.8	1336.81	Oil
				47.6	3781.75	Gas
				8.8	699.83	District heating
				14.1	1121.83	Wood
				6.0	475.43	Electricity

Table 112. Scenario 1 – space heating in zone 3 (cold climate) for SFH.

zone 3	SFH	<1945				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	162	100	16211	0.6	97.03	Coal
				5.2	848.05	Oil
				2.2	355.92	Gas
				39.8	6456.38	District heating
				33.3	5398.32	Wood
				18.8	3055.22	Electricity

zone 3	SFH	1945-1969				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	150	100	14964	0.6	89.56	Coal
				5.2	782.80	Oil
				2.2	328.53	Gas
				39.8	5959.64	District heating
				33.3	4982.99	Wood
				18.8	2820.16	Electricity

zone 3	SFH	1970-1989				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	128	120	15415	0.6	92.27	Coal
				5.2	806.43	Oil
				2.2	338.45	Gas
				39.8	6139.54	District heating
				33.3	5133.40	Wood
				18.8	2905.29	Electricity

zone 3	SFH	1990-2010				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	99	120	11847	0.6	70.91	Coal
				5.2	619.76	Oil
				2.2	260.11	Gas
				39.8	4718.36	District heating
				33.3	3945.12	Wood
				18.8	2232.77	Electricity

Table 113. Scenario 1 – space heating in zone 1 (warm climate) for MFH.

zone 1	MFH	<1945				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	74	90	6631	0.4	27.68	Coal
				20.2	1340.40	Oil
				44.7	2965.26	Gas
				0.5	33.64	District heating
				30.6	2029.69	Wood
				3.5	234.66	Electricity

zone 1	MFH	1945-1969				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	71	90	6429	0.4	26.84	Coal
				20.2	1299.52	Oil
				44.7	2874.82	Gas
				0.5	32.62	District heating
				30.6	1967.79	Wood
				3.5	227.50	Electricity

zone 1	MFH	1970-1989				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	47	90	4238	0.4	17.69	Coal
				20.2	856.66	Oil
				44.7	1895.13	Gas
				0.5	21.50	District heating
				30.6	1297.20	Wood
				3.5	149.97	Electricity

zone 1	MFH	1990-2010				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	37	90	3353	0.4	14.00	Coal
				20.2	677.74	Oil
				44.7	1499.32	Gas
				0.5	17.01	District heating
				30.6	1026.27	Wood
				3.5	118.65	Electricity

Table 114. Scenario 1 – space heating in zone 2 (moderate climate) for MFH.

zone 2	MFH	<1945				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	151	60	9077	6.6	603.56	Coal
				16.8	1527.43	Oil
				47.6	4321.00	Gas
				8.8	799.62	District heating
				14.1	1281.79	Wood
				6.0	543.22	Electricity

zone 2	MFH	1945-1969				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	151	60	9035	6.6	600.78	Coal
				16.8	1,520.39	Oil
				47.6	4,301.10	Gas
				8.8	795.93	District heating
				14.1	1,275.89	Wood
				6.0	540.72	Electricity

zone 2	MFH	1970-1989				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	110	60	6604	6.6	439.16	Coal
				16.8	1111.39	Oil
				47.6	3144.05	Gas
				8.8	581.82	District heating
				14.1	932.66	Wood
				6.0	395.26	Electricity

zone 2	MFH	1990-2010				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	83	60	4996	6.6	332.24	Coal
				16.8	840.81	Oil
				47.6	2378.60	Gas
				8.8	440.17	District heating
				14.1	705.60	Wood
				6.0	299.03	Electricity

Table 115. Scenario 1 – space heating in zone 3 (cold climate) for MFH.

zone 3	MFH	<1945				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	138	60	8300	0.6	49.68	Coal
				5.2	434.23	Oil
				2.2	182.24	Gas
				39.8	3305.87	District heating
				33.3	2764.11	Wood
				18.8	1564.37	Electricity

zone 3	MFH	1945-1969				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	147	60	8798	0.6	52.66	Coal
				5.2	460.23	Oil
				2.2	193.15	Gas
				39.8	3503.82	District heating
				33.3	2929.62	Wood
				18.8	1658.04	Electricity

zone 3	MFH	1970-1989				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	130	60	7803	0.6	46.70	Coal
				5.2	408.20	Oil
				2.2	171.32	Gas
				39.8	3107.69	District heating
				33.3	2598.41	Wood
				18.8	1470.59	Electricity

zone 3	MFH	1990-2010				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	113	60	6802	0.6	40.71	Coal
				5.2	355.84	Oil
				2.2	149.34	Gas
				39.8	2709.13	District heating
				33.3	2265.16	Wood
				18.8	1281.98	Electricity

Use phase – maintenance of the building and its components

For the replacement of the additional components, the same assumptions as for the systems in the baseline scenario have been taken. This means that a life span of 50 years (replacement of 50% of the systems every 25 years) has been assumed.

As for the baseline scenario, the total lifetime of the buildings is assumed to be 100 years, leading to one replacement of the additional components during the lifetime of the building.

The LCI model takes into account the production, transport to construction phase, transport to EoL and EoL processes of the replaced materials. We refer to the relevant sections for the details on the LCI modelling of each of these aspects.

End of Life

The system boundaries include the dismantling process, transport to sorting plants, final disposal of waste materials; and benefits from materials recycling and energy recovery (incineration). In line with the baseline scenario, the modelling consists of two modules: S and R.

- Module S includes deconstruction (dismantling and demolition), transportation of the discarded product to the sorting plant, handling in the sorting plant, transport of part of the waste processing from the sorting plant to landfill and physical pre-treatment and management of the disposal site, transport of part of the waste processed from the sorting plant to the incineration plant, incineration burdens and benefits from energy recovery;
- Module R includes the burdens from recycling processes and benefits from avoided products and raw material extraction.

Table 116 shows in details what the two modules include and which are the assumptions made on the EoL treatment rate for each of the materials considered in this scenario.

Table 116. EoL inventory: Module S and Module R for the additional construction waste in scenario 1 (night attenuation)

	EoL treatment rate			Waste treatment – Module S		Waste treatment – module R	
Material	% to landfill	% to incineration	% to recycling	ecoinvent process (waste treatment Sorting plant + landfill)	ecoinvent process (waste treatment – incineration)	ecoinvent process (burdens from recycling)	ecoinvent process avoided products (benefits from recycling)
Manifold (Metal – Brass)			100	Waste bulk iron, excluding reinforcement {ROW} |treatment of, sorting plant | Alloc def, U		Copper {RER}|treatment of scrap by electrolytic refining | Alloc Rec, U	Zinc {RoW}| primary production from concentrate | Alloc Def, U
Electricity cable (Metal – copper)			100	Waste bulk iron, excluding reinforcement {ROW} |treatment of, sorting plant | Alloc def, U		Copper {RER}|treatment of scrap by electrolytic refining | Alloc Rec, U	Copper {RER} | production, primary | Alloc Def, U

Heating pipes and room thermostat (PE/PP)	90	10		Waste polyethylene/polypropylene product treatment of sorting plant	Waste polyethylene {CH} | treatment of municipal incineration with fly ash extraction | Alloc Def, U		
				Waste polyethylene {CH}| treatment of, sanitary landfill | Alloc Def, U	Electricity, high voltage {Europe without Switzerland} | market group for | Alloc Def, U		

For the transport (in module S) the same assumptions are considered as in the baseline scenario: all additional materials needed for the scenario are assumed to be transported over a distance of 50 km with a lorry of 3.5-7.5 metric ton (EURO 3). The calculation is in line with the modelling of the baseline (transport during construction phase).

For the calculation of the energy recovery due to incineration of the room thermostat and heat distribution pipes, a caloric value of PE of 42.47 MJ/kg has been assumed based on the ecoinvent information and validation through other sources (http://www.slideshare.net/shahanambadi1/recyclying-and-recovery-routes-of).

Scenario 2 – External wall insulation – increased insulation thickness

The following changes have been made to the BoP Housing baseline LCI model for the modelling of this scenario.

Production phase

Stone wool is added as (additional) insulation of the external walls. The new insulation levels as mentioned in Table 40 are assumed in this scenario in order to obtain a lower heating demand during the use phase. For the calculation of the insulation thickness, it is assumed that the lambda value of stone wool equals 0.036 W/m²K.

To calculate the amount of insulation material in kg, the same assumptions are used as for the baseline scenario: i.e. insulation density of 50 kg/m³.

These lead to the amounts of additional kg of stone wool as mentioned in Table 117 and Table 118 for the modelling of this scenario. For stone wool, the same ecoinvent record has been used as was used in the baseline scenario, i.e. Rock wool {CH}| production | Alloc Def. U.

Table 117. Single Family House: amount of additional external wall insulation

		Single Family House											
		SFH_warm_ <1945	SFH_warm_ 1945-69	SFH_warm_ 1970-89	SFH_warm_ 1990-2010	SFH_mod_ <1945	SFH_mod_ 1945-69	SFH_mod_ 1970-89	SFH_mod_19 90-2010	SFH_cold_ <1945	SFH_cold_ 1945-69	SFH_cold_ 1970-89	SFH_cold_19 90-2010
Basis Scenario	Uvalue_walls (W/m²K)	1.71	1.71	1.47	0.82	1.54	1.54	0.98	0.50	0.64	0.64	0.52	0.39
	Insulation thickness_walls (m)	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.05	0.04	0.04	0.05	0.06
	Heating energy consumption (kWh/m².yr)	108	102	76	62	220	184	151	100	190	175	150	115
Scenario 2	Uvalue_walls (W/m²K)	0.86	0.86	0.74	0.41	0.77	0.77	0.49	0.25	0.32	0.32	0.26	0.195
	Insulation thickness_walls (m)	0.02	0.02	0.02	0.06	0.02	0.02	0.04	0.12	0.10	0.10	0.12	0.15
	Heating energy consumption (kWh/m².yr)	86	81	55	49	163	136	123	85	170	157	129	101
Scenario 2	Additional insulation (m)	0.02	0.02	0.02	0.04	0.02	0.02	0.04	0.07	0.06	0.06	0.07	0.09
	Additional insulation (kg/m² wall)	1.05	1.05	1.22	2.20	1.17	1.17	1.84	3.60	2.81	2.81	3.46	4.62
	m² wall insulation/dwelling (see baseline scenario)	146	146	146	146	119	119	119	119	123	123	123	124
	Additional insulation (kg/dwelling)	153.68	153.68	178.78	320.49	138.86	138.86	218.20	427.68	345.01	345.01	424.63	573.23
	Additional insulation (kg/dwelling, year)	1.54	1.54	1.79	3.20	1.39	1.39	2.18	4.28	3.45	3.45	4.25	5.73

Table 118. Multi Family House: amount of additional external wall insulation

		Multi Family House											
		MFH_warm_ <1945	MFH_warm _1945-69	MFH_warm _1970-89	MFH_warm_ 1990-2010	MFH_mod _<1945	MFH_mod _1945-69	MFH_mod _1970-89	MFH_mod_1 990-2010	MFH_cold _<1945	MFH_cold _1945-69	MFH_cold _1970-89	MFH_cold_ 1990-2010
Basis Scenario	Uvalue_walls (W/m²K)	1.76	1.76	1.47	0.81	1.55	1.55	0.98	0.54	0.71	0.71	0.54	0.58
	Insulation thickness_walls (m)	0.00	0.00	0.00	0.02	0.00	0.00	0.02	0.04	0.03	0.03	0.03	0.03
	Heating energy consumption (kWh/m².yr)	101	98	63	52	182	182	133	98	168	168	148	129
Scenario 2	Uvalue_walls (W/m²K)	0.88	0.88	0.74	0.41	0.775	0.775	0.49	0.27	0.355	0.355	0.27	0.29
	Insulation thickness_walls (m)	0.02	0.02	0.02	0.06	0.02	0.02	0.06	0.11	0.08	0.08	0.10	0.09
	Heating energy consumption (kWh/m².yr)	73	71	41	35	134	134	102	74	140	140	125	106
Scenario 2	Additional insulation (m)	0.0204545	0.0204545	0.024490	0.044444	0.023226	0.023226	0.0367347	0.0666667	0.050704	0.05	0.066667	0.062069
	Additional insulation (kg/m² wall)	1.02	1.02	1.22	2.22	1.16	1.16	1.84	3.33	2.54	2.54	3.33	3.10
	m² wall insulation/building (see baseline scenario)	900.5000	900.50	901	901	690.5000	690.5000	690.5000	691.0000	685.6800	686	686	686
	Additional insulation (kg/building)	920.97	920.97	1102.65	2001.11	801.87	801.87	1268.27	2303.33	1738.34	1738.34	2285.60	2127.97
	Additional insulation (kg/apartment)	57.56	57.56	68.92	125.07	50.12	50.12	79.27	143.96	108.65	108.65	142.85	133.00
	Additional insulation (kg/dwelling, year)	0.576	0.58	0.69	1.25	0.50	0.50	0.79	1.44	1.09	1.09	1.43	1.33

Construction phase

In line with the assumptions in the baseline scenario, it is assumed that 4% of the materials become "construction waste".

For the transport from plant to building site of the additional materials, the same assumptions were taken as in the baseline scenario, with a distance of 50 km from production to construction site with a lorry of 3.5-7.5 t. These assumptions lead to the amount of tkm transport per dwelling*year as mentioned in Table 119 and Table 120.

Table 119. Single Family House: amount of tkm transport of the additional external wall insulation (production to construction site)

Single Family House, tkm/dwelling,year											
SFH_warm_ <1945	SFH_warm_ 1945-69	SFH_warm_ 1970-89	SFH_warm_ 1990-2010	SFH_mod_ <1945	SFH_mod_ 1945-69	SFH_mod_ 1970-89	SFH_mod_19 90-2010	SFH_cold_ <1945	SFH_cold_ 1945-69	SFH_cold_ 1970-89	SFH_cold_19 90-2010
0.077	0.077	0.089	0.160	0.069	0.069	0.109	0.214	0.173	0.173	0.212	0.287

Table 120. Multi Family House: amount of tkm transport of the additional external wall insulation (production to construction site)

Multi Family House, tkm/dwelling, year											
MFH_warm_ <1945	MFH_warm _1945-69	MFH_warm _1970-89	MFH_warm_ 1990-2010	MFH_mod _<1945	MFH_mod _1945-69	MFH_mod _1970-89	MFH_mod_1 990-2010	MFH_cold _<1945	MFH_cold _1945-69	MFH_cold _1970-89	MFH_cold_ 1990-2010
0.029	0.029	0.034	0.063	0.025	0.025	0.040	0.072	0.054	0.054	0.071	0.066

No additional energy use is assumed for the installation of the additional components.

Use phase – energy and water consumption

This scenario only affects the energy use during this phase and has no influence on the water consumption. The latter hence remains unchanged compared to the BoP housing baseline scenario.

The reduced energy consumption for this scenario has been summarized in Table 41 in the main text. For the LCI modelling, these total yearly energy consumption had to be distributed over the various energy sources. The same percentage distribution of energy sources has been assumed as in the baseline scenario. This results in the total yearly amounts of energy for each of the dwellings (expressed in kWh/year), and for the different energy sources as summarized in Table 121 to Table 126. For each of the energy sources, the same LCI datasets have been assumed as in the BoP housing baseline scenario.

As for the baseline scenario, the total lifetime of the buildings is assumed to be 100 years.

Table 121. Scenario 2 – space heating in zone 1 (warm climate) for SFH.

zone 1	SFH	<1945				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	86	100	8583	0.4	35.83	Coal
				20.2	1734.95	Oil
				44.7	3838.10	Gas
				0.5	43.54	District heating
				30.6	2627.14	Wood
				3.5	303.74	Electricity

zone 1	SFH	1945-1969				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	81	100	8106	0.4	33.84	Coal
				20.2	1638.56	Oil
				44.7	3624.87	Gas
				0.5	41.13	District heating
				30.6	2481.19	Wood
				3.5	286.86	Electricity

zone 1	SFH	1970-1989				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	55	100	5533	0.4	23.10	Coal
				20.2	1118.42	Oil
				44.7	2474.20	Gas
				0.5	28.07	District heating
				30.6	1693.56	Wood
				3.5	195.80	Electricity

zone 1	SFH	1990-2010				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	49	130	6324	0.4	26.40	Coal
				20.2	1278.32	Oil
				44.7	2827.93	Gas
				0.5	32.08	District heating
				30.6	1935.69	Wood
				3.5	223.79	Electricity

Table 122. Scenario 2 – space heating in zone 2 (moderate climate) for SFH.

zone 2	SFH	<1945				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	163	90	14682	6.6	976.33	Coal
				16.8	2470.78	Oil
				47.6	6989.70	Gas
				8.8	1293.47	District heating
				14.1	2073.45	Wood
				6.0	878.72	Electricity

zone 2	SFH	1945-1969				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	136	90	12280	6.6	816.56	Coal
				16.8	2066.47	Oil
				47.6	5845.93	Gas
				8.8	1081.81	District heating
				14.1	1734.15	Wood
				6.0	734.93	Electricity

zone 2	SFH	1970-1989				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	123	100	12338	6.6	820.44	Coal
				16.8	2076.29	Oil
				47.6	5873.70	Gas
				8.8	1086.95	District heating
				14.1	1742.39	Wood
				6.0	738.42	Electricity

zone 2	SFH	1990-2010				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	85	100	8490	6.6	564.53	Coal
				16.8	1428.65	Oil
				47.6	4041.57	Gas
				8.8	747.91	District heating
				14.1	1198.90	Wood
				6.0	508.09	Electricity

Table 123. Scenario 2 – space heating in zone 3 (cold climate) for SFH.

zone 3	SFH	<1945				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	170	100	16997	0.6	101.73	Coal
				5.2	889.16	Oil
				2.2	373.17	Gas
				39.8	6769.40	District heating
				33.3	5660.04	Wood
				18.8	3203.34	Electricity

zone 3	SFH	1945-1969				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	157	100	15655	0.6	93.70	Coal
				5.2	818.96	Oil
				2.2	343.71	Gas
				39.8	6234.97	District heating
				33.3	5213.19	Wood
				18.8	2950.45	Electricity

zone 3	SFH	1970-1989				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	129	120	15432	0.6	92.37	Coal
				5.2	807.30	Oil
				2.2	338.81	Gas
				39.8	6146.13	District heating
				33.3	5138.91	Wood
				18.8	2908.41	Electricity

zone 3	SFH	1990-2010				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	101	120	12107	0.6	72.46	Coal
				5.2	633.34	Oil
				2.2	265.81	Gas
				39.8	4821.79	District heating
				33.3	4031.60	Wood
				18.8	2281.71	Electricity

Table 124. Scenario 2 – space heating in zone 1 (warm climate) for MFH.

zone 1	MFH	<1945				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	73	90	6559	0.4	27.38	Coal
				20.2	1325.88	Oil
				44.7	2933.14	Gas
				0.5	33.28	District heating
				30.6	2007.70	Wood
				3.5	232.12	Electricity

zone 1	MFH	1945-1969				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	71	90	6365	0.4	26.57	Coal
				20.2	1286.49	Oil
				44.7	2846.01	Gas
				0.5	32.29	District heating
				30.6	1948.07	Wood
				3.5	225.23	Electricity

zone 1	MFH	1970-1989				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	41	90	3713	0.4	15.50	Coal
				20.2	750.56	Oil
				44.7	1660.40	Gas
				0.5	18.84	District heating
				30.6	1136.53	Wood
				3.5	131.40	Electricity

zone 1	MFH	1990-2010				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	35	90	3147	0.4	13.13	Coal
				20.2	636.03	Oil
				44.7	1407.05	Gas
				0.5	15.96	District heating
				30.6	963.11	Wood
				3.5	111.35	Electricity

Table 125. Scenario 2 – space heating in zone 2 (moderate climate) for MFH.

zone 2	MFH	<1945				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	134	60	8035	6.6	534.31	Coal
				16.8	1352.18	Oil
				47.6	3825.25	Gas
				8.8	707.88	District heating
				14.1	1134.73	Wood
				6.0	480.90	Electricity

zone 2	MFH	1945-1969				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	134	60	8035	6.6	534.31	Coal
				16.8	1,352.18	Oil
				47.6	3,825.25	Gas
				8.8	707.88	District heating
				14.1	1,134.73	Wood
				6.0	480.90	Electricity

zone 2	MFH	1970-1989				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	102	60	6138	6.6	408.13	Coal
				16.8	1032.85	Oil
				47.6	2921.89	Gas
				8.8	540.71	District heating
				14.1	866.76	Wood
				6.0	367.33	Electricity

zone 2	MFH	1990-2010				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	74	60	4424	6.6	294.18	Coal
				16.8	744.48	Oil
				47.6	2106.10	Gas
				8.8	389.74	District heating
				14.1	624.76	Wood
				6.0	264.77	Electricity

Table 126. Scenario 2 – space heating in zone 3 (cold climate) for MFH.

zone 3	MFH	<1945				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	140	60	8388	0.6	50.21	Coal
				5.2	438.82	Oil
				2.2	184.17	Gas
				39.8	3340.84	District heating
				33.3	2793.35	Wood
				18.8	1580.92	Electricity

zone 3	MFH	1945-1969				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	140	60	8388	0.6	50.21	Coal
				5.2	438.82	Oil
				2.2	184.17	Gas
				39.8	3340.84	District heating
				33.3	2793.35	Wood
				18.8	1580.92	Electricity

zone 3	MFH	1970-1989				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	125	60	7477	0.6	44.76	Coal
				5.2	391.17	Oil
				2.2	164.17	Gas
				39.8	2978.05	District heating
				33.3	2490.01	Wood
				18.8	1409.24	Electricity

zone 3	MFH	1990-2010				
	kWh/m2/y	m2	kWh/y	%	kWh/y	
	106	60	6343	0.6	37.96	Coal
				5.2	331.81	Oil
				2.2	139.26	Gas
				39.8	2526.16	District heating
				33.3	2112.18	Wood
				18.8	1195.40	Electricity

Use phase – maintenance of the building and its components

For the replacement of the additional insulation, the same assumptions as for the insulation in the baseline scenario have been taken. This means that a life span of 30 years is assumed for the mineral insulation, within a building life span of 100 years, it means that the insulation is replaced two times, i.e. at age 30 and 60. At year 90, no replacement will take place anymore as this is 10 years before the end of the life span of the building.

The LCI model takes into account the production, transport to construction phase, transport to EoL and EoL processes of the replaced materials. We refer to the relevant sections for the details on the LCI modelling of each of these aspects.

End of Life

The system boundaries include the dismantling process, transport to sorting plants, final disposal of waste materials; and benefits from materials recycling and energy recovery (incineration). In line with the baseline scenario, the modelling consists of two modules: S and R.

- Module S includes deconstruction (dismantling and demolition), transportation of the discarded product to the sorting plant, handling in the sorting plant, transport of part of the waste processing from the sorting plant to landfill and physical pre-treatment and management of the disposal site, transport of part of the waste processed from the sorting plant to the incineration plant, incineration burdens and benefits from energy recovery;
- Module R includes the burdens from recycling processes and benefits from avoided products and raw material extraction.

Table 127 shows in details what the two modules include and which are the assumptions made on the EoL treatment rate for the stone wool considered in this scenario (and fully in line with the BoP baseline scenario).

Table 127. EoL inventory: Module S and Module R for the stone wool in scenario 2 (increased wall insulation)

	EoL treatment rate			Waste treatment – Module S		Waste treatment – module R	
Material	% to landfill	% to incineration	% to recycling	ecoinvent process (waste treatment Sorting plant + landfill)	ecoinvent process (waste treatment – incineration)	ecoinvent process (burdens from recycling)	ecoinvent process avoided products (benefits from recycling)
Mineral wool	100			Waste mineral wool {CH}| treatment of. sorting plant | Alloc Def. U			

For the transport (in module S) the same assumptions are considered as in the baseline scenario: the additional mineral wool needed for this second scenario is assumed to be transported over a distance of 50 km with a lorry of 3.5-7.5 metric ton (EURO 3). The calculation is in line with the modelling explained in section 0 (transport during construction phase).

Scenario 3 – External wall insulation – recycled or bio-based insulation materials

The following changes have been made to the BoP Housing baseline LCI model for the modelling of this scenario.

Production phase

Cellulose is added as (additional) insulation of the external walls for the cold climate (timber frame structure) and wood fiber board for the warm and moderate climate (brick walls). The new insulation levels are identical as for scenario 2 and are mentioned in Table 40. For the calculation of the insulation thickness, it is assumed that the lambda values of cellulose and wood fibre board equal 0.038 W/m²K. As the cellulose is blown in between the studs of the timber frame, the lambda-value of the layer composed of timber and cellulose has to be considered. It is assumed that the layer consists of 20% timber and 80% cellulose. With a lambda value of wood of 0.13 W/m²K, this results in a lambda value of the whole layer of 0.056 W/m²K.

To calculate the amount of kg cellulose insulation, it is assumed that cellulose has a density of 45 kg/m³. For wood fibre, the declared unit of the ecoinvent record is m³. Hence a calculation in kg is not necessary for this second insulation material.

These lead to the amounts of additional kg and m³ of insulation as mentioned in Table 128 and Table 129 for the modelling of this scenario. For cellulose, the ecoinvent record "Cellulose fibre, inclusive blowing in {RoW}| production | Alloc Def. U" has been used and for wood fiber board, the ecoinvent record "Fibreboard, soft, latex bonded {RoW}| production | Alloc Def. U" has been used.

Table 128. Single Family House: amount of additional external wall insulation

		Single Family House											
		SFH_warm_<1945	SFH_warm_1945-69	SFH_warm_1970-89	SFH_warm_1990-2010	SFH_mod_<1945	SFH_mod_1945-69	SFH_mod_1970-89	SFH_mod_1990-2010	SFH_cold_<1945	SFH_cold_1945-69	SFH_cold_1970-89	SFH_cold_1990-2010
Basis Scenario	Uvalue_walls (W/m²K)	1.71	1.71	1.47	0.82	1.54	1.54	0.98	0.50	0.64	0.64	0.52	0.39
	Insulation thickness_walls (m)	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.05	0.04	0.04	0.05	0.06
	Heating energy consumption (kWh/m².yr)	108	102	76	62	220	184	151	100	190	175	150	115
Scenario 3	Uvalue_walls (W/m²K)	0.86	0.86	0.74	0.41	0.77	0.77	0.49	0.25	0.32	0.32	0.26	0.195
	Insulation thickness_walls (m)	0.03	0.03	0.04	0.09	0.04	0.04	0.06	0.16	0.13	0.13	0.16	0.20
	Heating energy consumption (kWh/m².yr)	86	81	55	49	163	136	123	85	170	157	129	101
Scenario 3	Additional insulation (m)	0.03298	0.03298	0.03837	0.06878	0.03662	0.03662	0.05755	0.11280	0.08813	0.08813	0.10846	0.14462
	Additional cellulose insulation (kg/m² wall)	-	-	-	-	-	-	-	-	3.17	3.17	3.90	5.21
	Additional wood fiber insulation (m³/m² wall)	0.03	0.03	0.04	0.07	0.04	0.04	0.06	0.11	-	-	-	-
	m² wall insulation/dwelling (see baseline scenario)	146	146	146	146	119	119	119	119	123	123	123	124
	Additional cellulose insulation (kg/dwelling)	-	-	-	-	-	-	-	-	389.17	389.17	478.98	646.60
	Additional wood fiber insulation (m³/dwelling)	4.82	4.82	5.60	10.04	4.35	4.35	6.84	13.40	-	-	-	-
	Additional cellulose insulation (kg/dwelling, year)	-	-	-	-	-	-	-	-	3.89	3.89	4.79	6.47
	Additional wood fiber insulation (m³/dwelling, year)	0.05	0.05	0.06	0.10	0.04	0.04	0.07	0.13	-	-	-	-

Table 129. Multi Family House: amount of additional external wall insulation

		Multi Family House											
		MFH_warm_<1945	MFH_warm_1945-69	MFH_warm_1970-89	MFH_warm_1990-2010	MFH_mod_<1945	MFH_mod_1945-69	MFH_mod_1970-89	MFH_mod_1990-2010	MFH_cold_<1945	MFH_cold_1945-69	MFH_cold_1970-89	MFH_cold_1990-2010
Basis Scenario	Uvalue_walls (W/m²K)	1.76	1.76	1.47	0.81	1.55	1.55	0.98	0.54	0.71	0.71	0.54	0.58
	Insulation thickness_walls (m)	0.00	0.00	0.00	0.02	0.00	0.00	0.02	0.04	0.03	0.03	0.03	0.03
	Heating energy consumption (kWh/m².yr)	101	98	63	52	182	182	133	98	168	168	148	129
Scenario 3	Uvalue_walls (W/m²K)	0.88	0.88	0.74	0.41	0.775	0.775	0.49	0.27	0.355	0.355	0.27	0.29
	Insulation thickness_walls (m)	0.02	0.02	0.03	0.07	0.02	0.02	0.06	0.11	0.11	0.11	0.13	0.13
	Heating energy consumption (kWh/m².yr)	73	71	41	35	134	134	102	74	140	140	125	106
Scenario 3	Additional insulation (m)	0.02	0.02	0.03	0.05	0.02	0.02	0.04	0.07	0.08	0.08	0.10	0.10
	Additional cellulose insulation (kg/m² wall)	-	-	-	-	-	-	-	-	2.86	2.86	3.76	3.50
	Additional wood fiber insulation (m³/m² wall)	0.02	0.02	0.03	0.05	0.02	0.02	0.04	0.07	-	-	-	-
	m² wall insulation/building (see baseline scenario)	901	901	901	901	691	691	691	691	686	686	686	686
	Additional cellulose insulation (kg/building)	-	-	-	-	-	-	-	-	1961	1961	2578	2400
	Additional wood fiber insulation (m³/building)	19.44	19.44	23.28	42.25	16.93	16.93	26.77	48.63	-	-	-	-
	Additional cellulose insulation (kg/apartment)	-	-	-	-	-	-	-	-	123	123	161	150
	Additional wood fiber insulation (m³/apartment)	1.22	1.22	1.45	2.64	1.06	1.06	1.67	3.04				
	Additional celllulose insulation (kg/dwelling, year)	-	-	-	-	-	-	-	-	1.23	1.23	1.61	1.50
	Additional wood fiber insulation (m³/dwelling, year)	0.01	0.01	0.01	0.03	0.01	0.01	0.02	0.03	-	-	-	-

Construction phase

In line with the assumptions in the baseline scenario, it is assumed that 4% of the materials become "construction waste".

For the transport from plant to building site of the additional materials, the same assumptions were taken as in the baseline scenario, with a distance of 50 km from production to construction site with a lorry of 3.5-7.5 t. These assumptions lead to the amount of tkm transport per dwelling*year as mentioned in Table 130 and Table 131.

Table 130. Single Family House: amount of tkm transport of the additional external wall insulation (production to construction site)

Single Family House, tkm/dwelling, year											
SFH_warm_ <1945	SFH_warm_ 1945-69	SFH_warm_ 1970-89	SFH_warm_ 1990-2010	SFH_mod_ <1945	SFH_mod_ 1945-69	SFH_mod_ 1970-89	SFH_mod_19 1990-2010	SFH_cold_ <1945	SFH_cold_ 1945-69	SFH_cold_ 1970-89	SFH_cold_19 1990-2010
0.120	0.120	0.140	0.251	0.109	0.109	0.171	0.335	0.195	0.195	0.239	0.323

Table 131. Multi Family House: amount of tkm transport of the additional external wall insulation (production to construction site)

Multi Family House, tkm/dwelling, year											
MFH_warm_ <1945	MFH_warm _1945-69	MFH_warm _1970-89	MFH_warm_ 1990-2010	MFH_mod _<1945	MFH_mod _1945-69	MFH_mod _1970-89	MFH_mod_1 1990-2010	MFH_cold _<1945	MFH_cold _1945-69	MFH_cold _1970-89	MFH_cold_ 1990-2010
0.030	0.030	0.036	0.066	0.026	0.026	0.042	0.076	0.061	0.061	0.081	0.075

No additional energy use is assumed for the installation of the additional components.

Use phase – energy and water consumption

This scenario only affects the energy use during this phase and has no influence on the water consumption. The latter hence remains unchanged compared to the BoP housing baseline scenario.

The reduced energy consumption for this scenario is identical to the second scenario and has been summarized in Table 41 in the main text. For the LCI modelling, these total yearly energy consumption had to be distributed over the various energy sources. The same percentage distribution of energy sources has been assumed as in the baseline scenario. This results in the total yearly amounts of energy for each of the dwellings (expressed in kWh/year), and for the different energy sources are identical as to the second scenario and are summarized in Table 121 to Table 126. For each of the energy sources, the same LCI datasets have been assumed as in the BoP housing baseline scenario.

As for the baseline scenario, the total lifetime of the buildings is assumed to be 100 years.

Use phase – maintenance of the building and its components

For the replacement of the additional insulation, the same assumptions as for the insulation in the baseline scenario have been taken. This means that a life span of 30 years is assumed for both the cellulose and wood fiber board insulation. Within a building life span of 100 years, it means that the insulation is replaced two times, i.e. at age 30 and 60. At year 90 no replacement will take place anymore as this is 10 years before the end of the life span of the building.

The LCI model takes into account the production, transport to construction phase, transport to EoL and EoL processes of the replaced insulation materials. We refer to the relevant sections for the details on the LCI modelling of each of these aspects.

End of Life

The system boundaries include the dismantling process, transport to sorting plants, final disposal of waste materials; and benefits from materials recycling and energy recovery (incineration). In line with the baseline scenario, the modelling consists of two modules: S and R.

- Module S includes deconstruction (dismantling and demolition), transportation of the discarded product to the sorting plant, handling in the sorting plant, transport of part of the waste processing from the sorting plant to landfill and physical pre-treatment and management of the disposal site, transport of part of the waste processed from the sorting plant to the incineration plant, incineration burdens and benefits from energy recovery;
- Module R includes the burdens from recycling processes and benefits from avoided products and raw material extraction.

Table 132 shows in details what the two modules include and which are the assumptions made on the EoL treatment rate for the cellulose and wood fiberboard insulation considered in this scenario. For cellulose insulation, the scenario is in line with the scenario of the BoP baseline model and for the wood fiberboard insulation, the EoL scenario is based on own expertise.

Table 132. EoL inventory: Module S and Module R for the insulation materials in scenario 3 (biobased wall insulation)

	EoL treatment rate			Waste treatment – Module S		Waste treatment – module R	
Material	% to landfill	% to incineration	% to recycling	ecoinvent process (waste treatment Sorting plant + landfill)	ecoinvent process (waste treatment – incineration)	ecoinvent process (burdens from recycling)	ecoinvent process avoided products (benefits from recycling)
Cellulose insulation	28.3		71.7	Waste paper. unsorted {Europe without Switzerland}| treatment of sorting | Alloc Def. U			Cellulose fibre. production Module D (from BoP baseline study – scenario biobased)
				Waste graphical paper {RoW}| treatment of. sanitary landfill | Alloc Def. U			
Wood fiber board insulation	15	85		Waste wood{CH}| treatment of sorting plant | Alloc Def. U	Waste wood. untreated {RoW}| heat production. untreated waste wood. at furnace 1000-5000 kW. state-of-the-art 2014 | Alloc Def. U		
				Waste wood. untreated {CH}| treatment of sanitary landfill | Alloc Def. U	Electricity. high voltage {Europe without Switzerland} | market group for | Alloc Def. U		

For cellulose, the same assumptions for the EoL scenario (% landfill. incineration and recycling) are taken as in the report of Sala et al. 2016 (page 175).

For wood fiberboard insulation, the EoL scenario is based on expert judgement.

For the transport (in module S) the same assumptions are considered as in the baseline scenario: the additional insulation needed for this second scenario is assumed to be transported over a distance of 50 km with a lorry of 3.5-7.5 metric ton (EURO 3). The calculation is in line with the modelling explained for the baseline (transport during construction phase).

For the calculation of the energy recovery due to incineration of the wood fiberboard, a caloric value of wood of 14 MJ/kg has been assumed.

Scenario 4 – Solar collector for domestic hot water

The following changes have been made to the BoP Housing baseline LCI model for the modelling of this scenario.

Production phase

A solar boiler system is added to the dwellings in order to produce part of the domestic hot water (DHW). For the single family houses, one solar boiler system is added per dwelling, while for the multi-family houses a collective system is selected for the whole building. One sixteenth of the complete system is allocated to each apartment in the building.

For the single family houses, the ecoinvent dataset "Solar system, flat plate collector, one-family house, hot water/CH/I U" is used as a base, but adaptations have been made in line with the assumptions described in the main text. The following adaptations have been made:

- Storage tank has been reduced in size from 600 litres to the sizes mentioned in Table 57;
- Flat plate collector: size has been adjusted from 4 m² to the sizes mentioned in Table 56.

For the multi-family houses, the ecoinvent dataset "Solar system, flat plate collector, multiple dwelling, hot water/CH/I U", is used as a base, but adaptations have been made in line with the assumptions described in the main text. The following adaptations have been made:

- Storage tank has been reduced in size from 2000 litres to the sizes mentioned in Table 57;
- Flat plate collector: size has been adjusted from 58.3 m² to the sizes mentioned in Table 56.

The original datasets of the solar collector system include the transportation to the construction site with a van (<3.5 t). For this transport a distance of 50 km is assumed and a load of 440 kg per m² solar collector. In order to be in line with the modular approach of the BoP this transport has been deleted in the datasets and added in the modelling of the construction phase.

The original datasets of the solar collector system moreover include the EoL treatment. In order to be in line with the modular approach of the BoP, these EoL processes have been deleted in the datasets and added in the modelling of the EoL phase (both in module S and module R). We refer to that section for a description of the modelling assumptions of the EoL stage.

Construction phase

In line with the assumptions in the baseline scenario, it is assumed that 4% of the materials become "construction waste".

For the transport of the solar collector system from plant to building site, a distance of 50 km is assumed with a van of less than 3.5 tonnes (ecoinvent dataset: Transport, van <3.5t/RER U), in line with the assumptions of the ecoinvent dataset of the solar collector, a weight of 440 kg has been assumed. These assumptions lead to the amount of tkm transport per dwelling*year as mentioned in Table 133.

Table 133. Amount of transport of the solar boiler system (production to construction site). expressed in tkm/dwelling*year

	solar collector (tkm)/dwelling,year							
	SFH				MFH			
	<1945	1945-1969	1970-1989	1990-2010	<1945	1945-1969	1970-1989	1990-2010
zone 1	0.91	0.91	0.91	0.91	0.54	0.54	0.54	0.54
zone 2	0.72	0.72	0.72	0.72	0.54	0.54	0.54	0.54
zone 3	0.75	0.75	0.75	0.75	0.44	0.44	0.44	0.44

No additional energy use is assumed for the installation of the solar collector system.

Use phase – energy and water consumption

This scenario only affects the energy use during this phase, i.e. for the production of domestic hot water, and has no influence on the amount of water consumption. The latter hence remains unchanged compared to the BoP housing baseline scenario.

The reduced energy consumption for this scenario has been calculated based on dynamic energy simulations by Baldinelli (2016) and are summarized in Table 59 in the main text. For the LCI modelling, the remaining total yearly energy consumption for domestic hot water production had to be distributed over the various energy sources. The same percentage distribution of energy sources has been assumed as in the baseline scenario. This results in the total yearly amounts of energy for each of the dwellings (expressed in kWh/year), and for the different energy sources as presented in Table 134 to Table 139. For each of the energy sources, the same LCI datasets have been assumed as in the BoP housing baseline scenario.

As for the baseline scenario, the total lifetime of the buildings is assumed to be 100 years.

Table 134. Scenario 4 – DHW in zone 1 (warm climate) for SFH.

zone 1	SFH	<1945				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	151	3.43	516	0.2	0.98	Coal
				21.3	109.85	Oil
				55.1	284.58	Gas
				0.0	0.00	District heating
				4.9	25.35	Wood
				18.5	95.67	Electricity

zone 1	SFH	1945-1969				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	151	3.43	516	0.2	1	Coal
				21.3	110	Oil
				55.1	285	Gas
				0.0	0	District heating
				4.9	25	Wood
				18.5	96	Electricity

zone 1	SFH	1970-1989				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	151	3.43	516	0.2	1	Coal
				21.3	110	Oil
				55.1	285	Gas
				0.0	0	District heating
				4.9	25	Wood
				18.5	96	Electricity

zone 1	SFH	1990-2010				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	151	3.43	516	0.2	1	Coal
				21.3	110	Oil
				55.1	285	Gas
				0.0	0	District heating
				4.9	25	Wood
				18.5	96	Electricity

Table 135. Scenario 4 – DHW in zone 2 (moderate climate) for SFH.

zone 2	SFH	<1945				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	886	2.71	2403	0.8	19.54	Coal
				10.2	244.49	Oil
				47.7	1146.38	Gas
				6.3	151.20	District heating
				15.1	363.30	Wood
				19.9	477.92	Electricity

zone 2	SFH	1945-1969				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	886	2.71	2403	0.8	20	Coal
				10.2	244	Oil
				47.7	1146	Gas
				6.3	151	District heating
				15.1	363	Wood
				19.9	478	Electricity

zone 2	SFH	1970-1989				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	886	2.71	2403	0.8	20	Coal
				10.2	244	Oil
				47.7	1146	Gas
				6.3	151	District heating
				15.1	363	Wood
				19.9	478	Electricity

zone 2	SFH	1990-2010				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	886	2.71	2403	0.8	20	Coal
				10.2	244	Oil
				47.7	1146	Gas
				6.3	151	District heating
				15.1	363	Wood
				19.9	478	Electricity

Table 136. Scenario 4 – DHW in zone 3 (cold climate) for SFH.

zone 3	SFH	<1945				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	1,008	2.83	2850	0.6	16.00	Coal
				5.6	158.28	Oil
				3.1	88.67	Gas
				53.1	1513.72	District heating
				15.8	449.23	Wood
				21.9	624.45	Electricity

zone 3	SFH	1945-1969				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	1,008	2.83	2850	0.6	16	Coal
				5.6	158	Oil
				3.1	89	Gas
				53.1	1514	District heating
				15.8	449	Wood
				21.9	624	Electricity

zone 3	SFH	1970-1989				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	1,008	2.83	2850	0.6	16	Coal
				5.6	158	Oil
				3.1	89	Gas
				53.1	1514	District heating
				15.8	449	Wood
				21.9	624	Electricity

zone 3	SFH	1990-2010				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	1,008	2.83	2850	0.6	16	Coal
				5.6	158	Oil
				3.1	89	Gas
				53.1	1514	District heating
				15.8	449	Wood
				21.9	624	Electricity

Table 137. Scenario 4 – DHW in zone 1 (warm climate) for MFH.

zone 1	MFH	<1945				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	180	2.03	365	0.2	0.69	Coal
				21.3	77.71	Oil
				55.1	201.32	Gas
				0.0	0.00	District heating
				4.9	17.93	Wood
				18.5	67.68	Electricity

zone 1	MFH	1945-1969				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	180	2.03	365	0.2	1	Coal
				21.3	78	Oil
				55.1	201	Gas
				0.0	0	District heating
				4.9	18	Wood
				18.5	68	Electricity

zone 1	MFH	1970-1989				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	180	2.03	365	0.2	1	Coal
				21.3	78	Oil
				55.1	201	Gas
				0.0	0	District heating
				4.9	18	Wood
				18.5	68	Electricity

zone 1	MFH	1990-2010				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	180	2.03	365	0.2	1	Coal
				21.3	78	Oil
				55.1	201	Gas
				0.0	0	District heating
				4.9	18	Wood
				18.5	68	Electricity

Table 138. Scenario 4 – DHW in zone 2 (moderate climate) for MFH.

zone 2	MFH	<1945				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	854	2.05	1747	0.8	14.21	Coal
				10.2	177.74	Oil
				47.7	833.37	Gas
				6.3	109.92	District heating
				15.1	264.11	Wood
				19.9	347.43	Electricity

zone 2	MFH	1945-1969				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	854	2.05	1747	0.8	14.21	Coal
				10.2	177.74	Oil
				47.7	833.37	Gas
				6.3	109.92	District heating
				15.1	264.11	Wood
				19.9	347.43	Electricity

zone 2	MFH	1970-1989				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	854	2.05	1747	0.8	14	Coal
				10.2	178	Oil
				47.7	833	Gas
				6.3	110	District heating
				15.1	264	Wood
				19.9	347	Electricity

zone 2	MFH	1990-2010				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	854	2.05	1747	0.8	14	Coal
				10.2	178	Oil
				47.7	833	Gas
				6.3	110	District heating
				15.1	264	Wood
				19.9	347	Electricity

Table 139. Scenario 4 – DHW in zone 3 (cold climate) for MFH.

zone 3	MFH	<1945				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	980	1.67	1642	0.6	9.22	Coal
				5.6	91.16	Oil
				3.1	51.07	Gas
				53.1	871.79	District heating
				15.8	258.73	Wood
				21.9	359.64	Electricity

zone 3	MFH	1945-1969				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	980	1.67	1642	0.6	9.22	Coal
				5.6	91.16	Oil
				3.1	51.07	Gas
				53.1	871.79	District heating
				15.8	258.73	Wood
				21.9	359.64	Electricity

zone 3	MFH	1970-1989				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	980	1.67	1642	0.6	9.22	Coal
				5.6	91.16	Oil
				3.1	51.07	Gas
				53.1	871.79	District heating
				15.8	258.73	Wood
				21.9	359.64	Electricity

zone 3	MFH	1990-2010				
	kWh/person	People/dwelling	kWh/y	%	kWh/y	
	980	1.67	1642	0.6	9.22	Coal
				5.6	91.16	Oil
				3.1	51.07	Gas
				53.1	871.79	District heating
				15.8	258.73	Wood
				21.9	359.64	Electricity

Use phase – maintenance of the building and its components

For the replacement of the solar boiler system, the same assumptions as for the technical services in the baseline scenario have been taken. This means that a life span of 50 years is assumed for the whole system (replacement of 50% of the systems every 25 years). Within a building life span of 100 years, it means that the solar system is replaced once.

The LCI model takes into account the production, transport to construction phase, transport to EoL and EoL processes of the replaced insulation materials. We refer to the relevant sections for the details on the LCI modelling of each of these aspects.

End of Life

The system boundaries include the dismantling process, transport to sorting plants, final disposal of waste materials; and benefits from materials recycling and energy recovery (incineration). In line with the baseline scenario, the modelling consists of two modules: S and R.

- Module S includes deconstruction (dismantling and demolition), transportation of the discarded product to the sorting plant, handling in the sorting plant, transport of part of the waste processing from the sorting plant to landfill and physical pre-treatment and management of the disposal site, transport of part of the waste processed from the sorting plant to the incineration plant, incineration burdens and benefits from energy recovery;
- Module R includes the burdens from recycling processes and benefits from avoided products and raw material extraction.

Table 140 provides an overview of the inventory of the various components of the solar collector system with their respective amounts for end-of-life treatment. Table 141 shows in details what the module S and module R include and which are the assumptions made on the EoL treatment rate for the various components of the solar collector system considered in this scenario.

Table 140. EoL inventory for the components of the solar collector system (amounts per collector system)

Solar collector component	EoL process	amount	Module
Glycol	Treatment, heat carrier liquid, 40% C3H8O2, to wastewater treatment, class 2/CH U	SFH: 0.0311 m³ MFH: 0.44 m³	S
Tube insulation, elastomere	EoL Polyethylene/polypropylene (see Table 141)	SFH: 4 x 0.0748 kg MFH: 18 x 0.0748 kg	S
	Treatment, sewage, from residence, to wastewater treatment, class 2/CH U	SFH: 4 x 0.00134 m³ MFH: 18 x 0.00134 m³	S
Pump 40W, at plant/CH/I U	Plastics, mixture => Polyethylene/polypropylene (see Table 141)	SFH: 1 x 0.007 kg MFH: 5 x 0.007 kg	S
	EoL polyvinyl chloride (see Table 141)	SFH: 1 x 0.03 kg MFH: 5 x 0.03 kg	S and R
	EoL metal iron (see Table 141)	SFH: 1 x 2.12 kg MFH: 5 x 2.12 kg	S and R
Expansion vessel 25l, at plant/CH/I U	Plastics, mixture => Polyethylene/polypropylene (see Table 141)	SFH: 1 x 0.77 kg	S
	EoL Polyethylene/polypropylene (see Table 141)	SFH: 1 x 0.025 kg	S
	EoL metal iron (see Table 141)	SFH: 1 x 4.7 kg	S and R
Expansion vessel 80l, at plant/CH/I U	Plastics, mixture => Polyethylene/polypropylene (see Table 141)	MFH: 1 x 1.6 kg	S

	EoL Polyethylene/polypropylene (see Table 141)	MFH: 1 x 0.07 kg	S
	EoL metal iron (see Table 141)	MFH: 1 x 12.2 kg	S and R
Hot water tank 600l, at plant/CH/I U	Waste mineral wool {CH}| treatment of, sorting plant | Alloc Def, U	SFH_cold/moderate: 0.319 x 20 kg SFH_warm: 0.399 x 20 kg	S
	Plastics, mixture => Polyethylene/polypropylene (see Table 141)	SFH_cold/moderate: 0.319 x 3.86 kg SFH_warm: 0.399 x 3.86 kg	S
	EoL polyvinyl chloride (see Table 141)	SFH_cold/moderate: 0.319 x 2 kg SFH_warm: 0.399 x 2 kg	S and R
	Treatment, sewage, from residence, to wastewater treatment, class 2/CH U	SFH_cold/moderate: 0.319 x 0.617 m³ SFH_warm: 0.399 x 0.617 m³	S
	EoL metal iron (see Table 141)	SFH_cold/moderate: 0.319 x 220 kg SFH_warm: 0.399 x 220 kg	S and R
Heat storage 2000l, at plant/CH/I U	Waste mineral wool {CH}| treatment of, sorting plant | Alloc Def, U	MFH_cold: 0.459 x 25 kg MFH_moderate: 0.643 x 25 kg MFH_warm: 1.15 x 25 kg	S
	Plastics, mixture => Polyethylene/polypropylene (see Table 141)	MFH_cold: 0.459 x 5 kg MFH_moderate: 0.643 x 5 kg MFH_warm: 1.15 x 5 kg	S
	Treatment, sewage, from residence, to wastewater treatment, class 2/CH U	MFH_cold: 0.459 x 0.8 m³ MFH_moderate: 0.643 x 0.8 m³ MFH_warm: 1.15 x 0.8 m³	S
	EoL metal iron (see Table 141)	MFH_cold: 0.459 x 305 kg MFH_moderate: 0.643 x 305 kg MFH_warm: 1.15 x 305 kg	S and R
Flat plate collector, at plant/CH/I U	EoL glass pane (see Table 141)	amount of solar collector (m²) x 9.12 kg	S and R
	Waste mineral wool {CH}| treatment of, sorting plant | Alloc Def, U	amount of solar collector (m²) x 2.43 kg	S
	Eol aluminium (see Table 141)	amount of solar collector (m²) x 3.93 kg	S and R
	Eol metal copper (see Table 141)	amount of solar collector (m²) x 2.82 kg	S and R
	Eol metal iron (see Table 141)	amount of solar collector (m²) x 4.14 kg	S and R

	Plastics, mixture => Polyethylene/polypropylene (see Table 141)	amount of solar collector (m²) x 0.79 kg	S
	Treatment, sewage, from residence, to wastewater treatment, class 2/CH U	amount of solar collector (m²) x 0.0094 m³	S
	Treatment, heat carrier liquid, 40% C3H8O2, to wastewater treatment, class 2/CH U	amount of solar collector (m²) x 0.00239 m³	S

Table 141. EoL scenarios: Module S and module R for the components of the solar collector system (inventory per m² solar collector)

	EoL treatment rate			Waste treatment – Module S		Waste treatment – module R	
Material	% to landfill	% to incineration	% to recycling	ecoinvent process (waste treatment Sorting plant + landfill)	ecoinvent process (waste treatment – incineration)	ecoinvent process (burdens from recycling)	ecoinvent process avoided products (benefits from recycling)
Polyvinyl chloride	74.6	15	5.4	Waste polyethylene/ polypropylene product treatment of, sorting plant | Module C	Waste Polyvinylchloride {CH}| treatment of, municipal incineration with fly ash extraction | Alloc Def, U	Extrusion, plastic pipes {RER}| production | Alloc Def, U	Polyvinylchloride, suspension polymerised {RER}| polyvinylchloride production, suspension polymerisation | Alloc Def, U
				Waste polyvinylchloride {CH}| treatment of, sanitary landfill | Alloc Def, U	Electricity, high voltage {Europe without Switzerland}| market group for | Alloc Def, U		
Polyethylene/polypropylene	90	10		Waste polyethylene/ polypropylene product treatment of, sorting plant	Waste polyethylene {CH}| treatment of, municipal incineration with fly ash extraction | Alloc Def, U		
				Waste polyethylene/ polypropylene product (waste treatment) {treatment of, sanitary landfill | Alloc Def, U	Electricity, high voltage {Europe without Switzerland}| market group for | Alloc Def, U		
Metal - Iron			100	Waste bulk iron, excluding reinforcement {RoW}| treatment of,			Pig iron {GLO}| production | Alloc Def, U

	EoL treatment rate			Waste treatment – Module S		Waste treatment – module R	
Material	% to landfill	% to incineration	% to recycling	ecoinvent process (waste treatment Sorting plant + landfill)	ecoinvent process (waste treatment – incineration)	ecoinvent process (burdens from recycling)	ecoinvent process avoided products (benefits from recycling)
				sorting plant | Alloc Def, U			
Glass pane	90		10	Waste glass sheet {CH}| treatment of, sorting plant | Alloc Def, U		Glass cullet, sorted {RER}| treatment of waste glass from unsorted public collection, sorting | Alloc Def, U	Packaging glass, green {CH}| production | Alloc Def, U
Metal – Copper			100	Waste bulk iron, excluding reinforcement {RoW}| treatment of, sorting plant | Alloc Def, U		Copper {RER}| treatment of scrap by electrolytic refining | Alloc Rec, U	Copper {RER}| production, primary | Alloc Def, U
Metal - Aluminium			100	Aluminium scrap, post-consumer {RER}| treatment of, by collecting, sorting, cleaning, pressing | Alloc Def, U		Aluminium scrap, post-consumer, prepared for melting (waste treatment) {RER}| treatment of aluminium scrap, post-consumer, prepared for recycling, at refiner | Alloc Def, U	Aluminum, primary, ingot {RoW}| market for | Alloc Def, U

For the transport (in module S) the same assumptions are considered as in the baseline scenario: the additional components needed for this scenario are assumed to be transported over a distance of 50 km with a lorry of 3.5-7.5 metric ton (EURO 3). For the calculation of the energy recovery due to incineration of the materials, the following caloric values have been assumed:

- PVC: 19 MJ/kg
- PE/PP: 42.47 MJ/kg

Scenario 5 – Floor finishing with bio-based materials

Production phase

The ceramic tiles are replaced by hardwood parquet for the floor finishing in the dwellings in the moderate and warm climate. In the baseline model, parquet was already assumed in the cold climatic zone.

In the remodelled dwellings, ceramic tiles have been kept for staircases, garage and terraces. All other inner floors have hardwood parquet as finishing material in this fifth scenario. For the modelling of the parquet, hardwood (e.g. French Oak) is assumed with a thickness of 0.021 m. The ecoinvent dataset used is "Sawnwood, hardwood, dried (u=10%), planed {RER}| production | Alloc Def. U ".

In addition wood wax is used to treat the parquet. This is modelled with the ecoinvent dataset "Paraffin {RER}| production | Alloc Def. U".

The inventory is changed as follows:

MFH in the moderate climate

- reduction of ceramic tiles: from 14.936 kg/dwelling*year to 2.586 kg/dwelling*year
- addition of hardwood parquet: 0.013 m³ /dwelling*year (=9.077 kg/dwelling*year)
- addition of wood wax: 0.04 kg/m² floor => 0.025 kg/dwelling*year

MFH in the warm climate:

- reduction of ceramic tiles: from 20.825 kg/dwelling*year to 2.724 kg/dwelling*year
- addition of hardwood parquet: 0.019 m³/dwelling*year (=13.304 kg/dwelling*year)
- addition of wood wax: 0.04 kg/m² floor => 0.036 kg/dwelling*year

SFH in the moderate climate

- reduction of ceramic tiles: from 23.2 kg/dwelling*year to 7.244 kg/dwelling*year
- addition of hardwood parquet: 0.017 m/dwelling*year (=11.760 kg/dwelling*year)
- addition of wood wax: 0.04 kg/m² floor => 0.032 kg/dwelling*year

SFH in the warm climate:

- reduction of ceramic tiles: from 26 kg/dwelling*year to 7.644 kg/dwelling*year
- addition of hardwood parquet: 0.019 m³/dwelling*year (=13.524 kg/dwelling*year)
- addition of wood wax: 0.04 kg/m² floor => 0.037 kg/dwelling*year

Construction phase

In line with the assumptions in the baseline scenario, it is assumed that 4% of the materials become "construction waste". The replacement of the ceramic tiles have been reduced to the amounts calculated in the production phase (previous section) and the parquet and wood wax have been added. For the transport of the materials to the construction site, a distance of 50 km is assumed with a small truck (ecoinvent dataset: Transport, freight, lorry 3.5-7.5 metric ton. EURO3 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO3 | Alloc Def. U) in line with the assumptions of the baseline scenario. No additional energy use is assumed for the installation of the parquet.

Use phase – energy and water consumption

This scenario does not affect the energy and water consumption during the use phase.

Use phase – maintenance of the building and its components

For the replacement of the parquet, the same assumptions as for the floor finishes in the baseline scenario have been taken. This means that a life span of 50 years is assumed for the whole system (replacement of 50% of the systems every 25 years). Within a building life span of 100 years, it means that the parquet is replaced once.

The LCI model takes into account the production, transport to construction phase, transport to EoL and EoL processes of the replaced insulation materials. We refer to the relevant sections for the details on the LCI modelling of each of these aspects.

End of Life

The system boundaries include the dismantling process, transport to sorting plants, final disposal of waste materials; and benefits from materials recycling and energy recovery (incineration). In line with the baseline scenario, the modelling consists of two modules: S and R.

- Module S includes deconstruction (dismantling and demolition), transportation of the discarded product to the sorting plant, handling in the sorting plant, transport of part of the waste processing from the sorting plant to landfill and physical pre-treatment and management of the disposal site, transport of part of the waste processed from the sorting plant to the incineration plant. incineration burdens and benefits from energy recovery;
- Module R includes the burdens from recycling processes and benefits from avoided products and raw material extraction.

Table 142 shows in detail what the module S and module R include and which are the assumptions made on the EoL treatment rate for the parquet considered in this scenario.

Table 142. EoL inventory: Module S and Module R for the parquet in scenario 5

	EoL treatment rate			Waste treatment – Module S		Waste treatment – module R	
Material	% to landfill	% to incineration	% to recycling	ecoinvent process (waste treatment Sorting plant + landfill)	ecoinvent process (waste treatment – incineration)	ecoinvent process (burdens from recycling)	ecoinvent process avoided products (benefits from recycling)
Wood	35	34	31	Waste Wood| treatment of. sorting plant_Module C	Waste wood. untreated {RoW}| heat production. untreated waste wood. at furnace 1000-5000 kW. state-of-the-art 2014 | Alloc Def. U		Log. energy wood. split. measured as solid wood under bark {GLO}| log. energy wood. split. measured as solid wood under bark. Recycled Content cut-off | Alloc Rec. U
				Waste wood. untreated {RoW}| treatment of. sanitary landfill | Alloc Def. U	Electricity. high voltage {Europe without Switzerland}| market group for | Alloc Def. U		

Scenario 6 – Timber frame

Table 143 provide the inventory of the production phase of the two scenarios of the case-study used for the Timber frame scenario. Construction phase, use phase maintenance (System S and System R), use phase (energy and water consumption), end of life phase (System S and System R) have been also modelled in accordance with what has been done for each product of the BoP housing.

Table 143. Inventories for the common practice (reinforcing steel and concrete frame and bio-based (timber frame) scenarios.

			Amount/building	
		Unit	Common practice	Bio-based
ground floor m²	Excavation, hydraulic digger/RER U	m³	15.827	23.74
	Sand, at mine/CH U	kg	11466.2	2972
	Gravel, unspecified, at mine/CH U	kg		5522.2
	Concrete, normal, at plant/CH U	m³	7.843	
	Expanded clay, at plant/DE U	kg		13659.9
	Reinforcing steel, at plant/RER U	kg	555.1	
	Chromium steel 18/8, at plant/RER U	kg		48.9
	Adapted ecoinvent record PE/PP	kg	10.2	10.2
	Ceramic tiles, at regional storage/CH U	kg	1299	
	Cement mortar, at plant/CH U	kg	19.8	376.5
	Linoleum tiles_RER	m2		51.729
	Acrylic binder, 34% in H2O, at plant/RER U	kg		20.7
	Phenolic resin, at plant/RER U	kg	123.9	
	Tap water, at user/RER U	kg	629.1	921.8
	Portland cement, strength class Z 52.5, at plant/CH U	kg	1139.3	569.6
	Lime mortar, at plant/CH U	kg		1201.1
	Basalt_imported	kg		2252
	Polystyrene, extruded (XPS), at plant/RER U	kg	0.7	0.7
	Polyurethane, rigid foam, at plant/RER U	kg	118.9	
foundation m	Excavation, hydraulic digger/RER U	m³	3.452	4.027
	Concrete, normal, at plant/CH U	m³	3.382	
	Sand, at mine/CH U	kg		3189.6
	Sand-lime brick, at plant/DE U	kg		2807.1
	Cement mortar, at plant/CH U	kg		131.3
	Reinforcing steel, at plant/RER U	kg	422.7	
outer wall m²	Brick, at plant/RER U	kg	18061.1	
	Sand-lime brick, at plant/DE U	kg		432.7
	Cement mortar, at plant/CH U	kg	4854.3	68
	Sawn timber, hardwood, planed, kiln dried, u=10%, at plant/RER U	m³		0.228
	Sawn timber, softwood, planed, kiln dried, at plant/RER U	m³		3.57
	Biocides	kg		10.5
	Chromium steel 18/8, at plant/RER U	kg	3.8	13.8

		Unit	Amount/building	
			Common practice	Bio-based
	Isofloc - cellulose flakes for insulation	kg		328.5
	Woodfibre, for insulation board	m3		1.329
	Fibreboard - Houtflex	m³		3.072
	Gypsum fibre board, at plant/CH U	kg		844
	Finish duroskin	kg		11.7
	Fibreboard hard, at plant/RER U	m³		0.705
	Natural paint, water based, at plant/RER U	kg		17.2
	Polyvinylchloride, suspension polymerised, at plant/RER U	kg	0.8	
	Rock wool, packed, at plant/CH U	kg	350.5	
	Base plaster, at plant/CH U	kg	596.5	
	Tap water, at user/RER U	kg	48.9	94.6
	Acrylic varnish, 87.5% in H2O, at plant/RER U	kg	17.9	
loadbearing inner wall m²	Brick, at plant/RER U	kg	3829.4	
	Cement mortar, at plant/CH U	kg	862.1	
	Base plaster, at plant/CH U	kg	631.4	
	Tap water, at user/RER U	kg	51.8	
	Acrylic varnish, 87.5% in H2O, at plant/RER U	kg	18.9	
	Sawn timber, hardwood, planed, kiln dried, u=10%, at plant/RER U	m³		0.121
	Sawn timber, softwood, planed, kiln dried, at plant/RER U	m³		0.944
	Biocides	kg		5.6
	Tap water, at user/RER U	kg		50.1
	Chromium steel 18/8, at plant/RER U	kg		6.8
	Isofloc - cellulose flakes for insulation	kg		167.1
	Fibreboard hard, at plant/RER U	m³		1.134
	Finish duroskin	kg		6.3
	Natural paint, water based, at plant/RER U	kg		18.1
non-bearing inner wall m²	Brick, at plant/RER U	kg	4532	
	Cement mortar, at plant/CH U	kg	1199.3	
	Base plaster, at plant/CH U	kg	1039.9	
	Tap water, at user/RER U	kg	85.3	
	Acrylic varnish, 87.5% in H2O, at plant/RER	kg	31.2	
	Sawn timber, hardwood, planed, kiln dried, u=10%, at plant/RER U	m³		0.14
	Sawn timber, softwood, planed, kiln dried, u=10%, at plant/RER U	m³		1.163
	Chromium steel 18/8, at plant/RER U	kg		6.6
	Isofloc - cellulose flakes for insulation	kg		194.2
	Gypsum fibre board, at plant/CH U	kg		1485.5
	Finish duroskin	kg		10.3

		Unit	Amount/building Common practice	Bio-based
	Natural paint, water based, at plant/RER U	kg		29.8
floor m²	Concrete, normal, at plant/CH U	m³	7.4724	
	Reinforcing steel, at plant/RER U	kg	182.83	
	Chromium steel 18/8, at plant/RER U	kg		4.8
	Sawn timber, softwood, planed, kiln dried, at plant/RER U	m³		2.669
	Ceramic tiles, at regional storage/CH U	kg	1146.08	
	Cement mortar, at plant/CH U	kg	18.5	325
	Phenolic resin, at plant/RER U	kg	106.98	
	Tap water, at user/RER U	kg	321.6	
	Portland cement, strength class Z 52.5, at plant/CH U	kg	491.77	
	Sand, at mine/CH U	kg	2565.77	
	Polystyrene, extruded (XPS), at plant/RER U	kg	0.86	
	Base plaster, at plant/CH U	kg	427.63	
	Acrylic varnish, 87.5% in H2O, at plant/RER U	kg	19.24	
	Isofloc - cellulose flakes as insulation	kg		371.9
	Linoleum tiles_RER	m²		45.632
	Acrylic binder, 34% in H2O, at plant/RER U	kg		18.3
	Gypsum fibre board, at plant/CH U	kg		1229.4
	Finish duroskin	kg		8.6
	Woodfibre, for insulation board	m³		1.711
	Oriented strand board, at plant/RER U	m³		0.077
	Natural paint, water based, at plant/RER U	kg		12.3
pitched roof m² (horizontally projected)	Belgian mix_sawn timber, softwood, planed, kiln dried, at plant_U	m³	2.935	
	Sawn timber, softwood, planed, kiln dried, at plant/RER U	m³		5.692
	Biocides	kg	19.4	
	Tap water, at user/RER U	kg	175	
	Chromium steel 18/8, at plant/RER U	kg	57.7	56.9
	Isofloc - cellulose flakes as insulation	kg		513.8
	Belgian mix_sawn timber, hardwood, planed, kiln dried, at plant_U	m³	0.4	
	Rock wool, packed, at plant/CH U	kg	442.5	
	Gypsum plaster board, at plant/CH U	kg	734.8	
	Gypsum fibre board, at plant/CH U	kg		1006
	Finish duroskin	kg	7	6.998
	Acrylic varnish, 87.5% in H2O, at plant/RER U	kg	31.5	
	Natural paint, water based, at plant/RER U	kg		20.2

		Unit	Amount/building Common practice	Bio-based
	Woodfibre, for insulation board	m^3		1.6
	Fibreboard hard, at plant/RER U	m^3		1.6
	Roof tile, at plant/RER U	kg	3034.8	
	PP	kg	7.2	
	Steel, converter, unalloyed, at plant/RER U	kg	2.8	1.4
	PE/PP	kg	13.9	13.9
windows	Polyvinylchloride	kg	2268.5	
m^2	Sawn timber, hardwood, planed, kiln dried, at plant_U	m^3		6.1
	Steel, low alloyed	kg	2443	452.6
	Zinc	kg	28.4	25.3
	Aluminium	kg	165.2	337.6
	Flat glas	kg	4471.2	4531.7

Scenario 9 – PV system

This chapter describes the PV system model developed in the context of BoP Appliances and implemented in scenario 9 of the BoP housing.

The PV system model in the BoP appliances represents 1 m^2 of a residential 3 kWp PV system, which is the typical size in the residential sector. The system includes the PV panel, the electric installation and the mounting structure. The structure of the model is reported in Table 144.

Table 144. System boundaries, life cycle stages and activities included in the assessment of PV system in the BoP Appliances.

Life Cycle Stage	Activities included
Manufacturing of components	• Production of raw materials • Processing of raw materials • Transport of the materials to the factory
Manufacturing of the product	• Assembly of components (to the building site)
Packaging	• Manufacture of packaging • Transport of packaging to the factory • Final disposal of packaging (landfill, incineration and energy recovery, recycling)
Distribution and retail	• Transport of the packaged product from factory to Retail/Distribution Centre (for electric installation and mounting structure) or to the regional storage (for PV panel)
Use phase	• Electricity production (as avoided product)
Maintenance	• Manufacturing of components to be substituted (production of raw materials, processing of raw materials, transport of the materials to the factory)
EoL of the product	• Sorting of materials/components • Landfill • Incineration and energy recovery • Recycling

The modelled PV system is a technology mix and namely, includes the Multicrystalline-Si and Monocrystalline-Si technologies, which are the most used ones in the residential sector and cover the vast majority of the market (FHI-ISE, 2013). Based on data reported in FHI-ISE (2013), the Monocrystalline-Si (Mono-Si) covers the 40.4% of the market whereas the Multi-Si the 45.2%. In order to model the panel, the above mentioned market coverage percentage have been upscaled to cover the whole market. Thus, the PV panel in the BoP is composed by Mono-Si for 47% and Multi-Si for 53%.

The model of each PV technology is based on the information reported in the PEF screening report of electricity from photovoltaic panel version 24th April 2016, hereinafter PV PEF screening report (PEF screening Report, 2016). Both Mono-Si for and Multi-Si panels consumed in Europe, based on data reported in PV PEF screening report (PEF screening Report, 2016), are produced for 79% in China, for 6% in Asia and Pacific region, for 15% in Europe. Table 145 reports the Bill of Materials (BoM) for the two considered technologies, for 1 m^2 of panel. For each technology, the BoM is reported for both the framed (panel), which is typically mounted on roof, and the unframed (laminate), which is integrated on roof. Based on FHI-ISE (2013), the unframed PV represents only 5% of each technology. The manufacturing of panels includes the use of energy (electricity and diesel) and of several auxiliaries (water, hydrogen fluoride, propanol, isopropanol, potassium hydroxide and soap), the production of waste and wastewater, the emission of heat waste, NMVOC and carbon dioxide.

Table 145. Bill of Materials for the two different PV technologies constituting the PV panel used for the PV system model in the BoP. Data are reported for 1 m^2 of PV technology.

		Mono-Si PV		**Multi-Si PV**	
Materials/components	**Unit**	**Framed/ panel**	**Unframed /laminate**	**Framed/ panel**	**Unframed /laminate**
Photovoltaic cell, multi-Si wafer	m^2			9.35E-01	9.35E-01
Photovoltaic cell, single-Si wafer	m^2	9.35E-01	9.35E-0		
Aluminum alloy	kg	2.13E+00		2.13E+00	
Copper	kg	1.03E-01	1.03E-01	1.03E-01	1.03E-01
Diode, unspecified	kg	2.81E-03	2.81E-03	2.81E-03	2.81E-03
Silicon product	kg	1.22E-01	1.22E-01	1.22E-01	1.22E-01
Tin	kg	1.29E-02	1.29E-02	1.29E-02	1.29E-02
Lead	kg	7.25E-04	7.25E-04	7.25E-04	7.25E-04
Solar glass	kg	8.81E+00	8.81E+00	8.81E+00	8.81E+00
Glass fiber reinforced plastic	kg	2.95E-01	2.95E-01	2.95E-01	2.95E-01
Polyethylene Terephthalate	kg	3.46E-01	3.46E-01	3.46E-01	3.46E-01
Polyethylene (HDPE)	kg	2.38E-02	2.38E-02	2.38E-02	2.38E-02
Ethylvinylacetate foil	kg	8.75E-01	8.75E-01	8.75E-01	8.75E-01
Polyvinylfluoride film	kg	1.21E-01	1.21E-01	1.21E-01	1.21E-01

The BoM for the electric installation is reported in Table 146 and refers to a 3 kWp system, based on PV PEF screening report (PEF screening Report, 2016). Material inputs do not depend on the specific PV technology (Mono-Si/Multi-Si) or typology (framed/unframed).

Table 146. Bill of Materials for the electric installation of a 3 kWp system.

Materials/components	**Electric installation for a 3 kWp system - kg**
Copper	1.47E+01
Brass	2.00E-02
Zinc	4.00E-02
Steel	8.60E-01
Nylon	2.30E-01
Polyethylene (HDPE)	1.44E+01
Polyvinyl chloride	2.13E+00
Polycarbonate	2.00E-01
Epoxy resin	2.00E-03

On the contrary, the PV framed and unframed require different input material in the mounting structure (Table 147).

Table 147. Bill of Materials for the mounting structure. Data are reported for 1 m^2 of a 3 kWp system.

Materials/components	**Mounting structure for PV mounted on roof - kg**	**Mounting structure for PV integrated on roof - kg**
Aluminium alloy	2.84E+0	2.25E+0
Polyethylene (HDPE)	1.40E-3	2.82E-2
Polystyrene (HiPS)	7.02E-3	6.02E-3
Polyurethane, flexible foam		1.84E-2
Synthetic rubber		1.24E+0
Steel	1.50E+0	2.00E-1

As far as the transport is concerned, the same assumptions used in PEF screening report (PEF screening Report, 2016) are considered. Thus, for the PV, a road transport (lorry > 16 ton) of 100 km (500 km for cells) and a rail transport of 600 km are included. For the electric installation, a road transport (lorry 16-32ton) of 60 km and rail transport of 200 km are considered. The transport for the mounting structure include a road transport by lorry > 16ton for 60 km, a road transport by lorry between 3.5 and 7.5 ton for 100 km plus, a rail transport of 200 km.

Packaging is composed by corrugated board and flat pallet. It includes both the packaging of the PV panel and the one of the mounting structure. The assumptions for transport at the stage of packaging production are the same ones above mentioned for the production of these two components.

The manufacturing of the product, intended as manufacturing of the PV system, includes the assembly of the different components (panels, materials/components of the electric installation, and materials/components of the mounting structure) at the building site. This stage includes the energy for the erection of the plant, a 1% of PV panel substitution due to rejects, and transport to the building site, for which a distance of 100 km, by lorry, is considered, consistently with PV PEF screening Report (PEF screening Report, 2016).

The distribution and retail stage includes the transport of the PV system components to the regional storage. The PV panels are produced in Europe just for the 15%, whereas the 79% is imported from China and 6% from Asia and Pacific region. The production of electric installation and mounting structure is assumed to occur in Europe. For the share of production coming from outside EU, as done for all products in the BoP Appliances, an international transportation has been considered (source: www.sea-distances.org and Google maps) as showed in Table 148. The share of production occurring in Europe is assumed to undergo a local supply chain, according PEFCR rules, thus 1200 km by truck, EURO 4.

Table 148. Share of imported PV panel and related sea transport distance and the road transport distance.

Product	**Import (% of apparent consumption)**	**Sea transport (km per unit)**	**Road transport (km per unit)**
PV panel	85%	19680	950

In the use phase it is assumed that the PV system produces 975 kWh of electricity for each kWp. This is the annual yield adopted in the PV PEF screening report (PEF screening Report, 2016) and already takes into account the annual degradation rate (0.7%) occurring during the lifetime (30 years). As the average m^2 of panel in the BoP is composed by Mono-Si (147 Wp/m^2) and Multi-Si (151 Wp/m^2), the weighted average Wp has been calculated, based on the percentages of the two different technologies, namely 47% for the Mono-Si and 53% for the Multi-Si. The final Wp of 1 m^2 of PV panel in the BoP is 148.8 Wp, which means an annual production of 145 kWh.

It is assumed that in the maintenance phase, 2% of the PV panels is replaced.

The PV system is dismantled and disposed of at EoL. The same scenario adopted in the PV PEF screening Report is considered (PEF screening Report, 2016). In particular, as data on the recycling on Mono-Si and Multi-Si panels are scarce, the recycling is modelled according to the recycling of Cadmium-Telluride (CdTe) PV modules, which consists of a shredding process, followed by dissolving in a chemical bath. Materials gained are sorted and prepared for recycling. This process requires electricity and produce wastewater and waste materials which are disposed of in a wastewater treatment plant and in a municipal incineration plant or inert material landfill, respectively. The specific recycling efforts for 1 kg of unframed CdTe module has been adapted with a 1.5 factor. It is assumed that 90% of the glass is recovered and substitute primary glass (namely, packaging glass). In addition, as the junction box and the frame are manually dismantled, it is assumed that copper and aluminium are 100% recycled. Aluminium and steel in the mounting structure as well as the copper and steel in the electric installation are recycled and substitute primary resource. They are recycled with a 100% efficiency, being large construction part. Plastics are assumed to go to municipal incineration.

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