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Consumer Footprint

Basket of Products indicators on household appliances

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Corrado S., Sala S.

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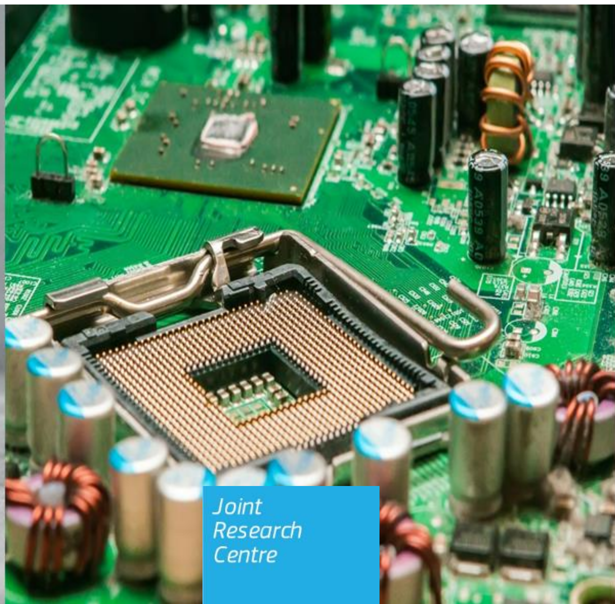

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The study underpinning the calculation of the Consumer Footprint started in 2016 and ran in parallel to the Environmental Footprint (EF) pilot phase. Hence, the modelling approach adopted and the life cycle inventory data used are not fully compliant with EF rules and are only intended to illustrate the use of Life Cycle Assessment (LCA) to define the baseline of impacts due to consumption in the EU and to test eco-innovation and policy options against that baseline.

Moreover, 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/sustainableConsumption.html

Please address comments or requests for further information or clarification on the contents of the report to JRC-ConsumptionFootprint@ec.europa.eu

Abstract

The Consumer Footprint is a set of life cycle assessment (LCA) indicators aimed to measure the environmental impact of an average European Union (EU) citizen. The Consumer Footprint encompasses 5 areas of consumption, namely food, mobility, housing, household goods, and appliances. For each of the areas of consumption, a basket of products (BoPs) has been defined. This report is about the assessment of the environmental impact generated by the BoP on household appliances ("BoP appliances"). The BoP appliances covers a number of representative products, selected in terms of economic value and diffusion in households such as television, washing machine, dishwasher, refrigerator, and laptop. The list of appliances has been selected with the Directorate-General for Environment of the European Commission (DG ENV) with the aim of strengthening the link with several product policies, allowing comparison of the baseline scenario and eco-innovations ones, including - where relevant - consumer behaviour scenarios.

The BoP appliances has been developed in order to support the evaluation of the improvement potential of the household appliances sector from a life cycle perspective, providing a baseline scenario for the year 2010. This is the basis for analysing the environmental savings potential related to intervention, i.e. policy measures taken via the use of Ecodesign, Energy labelling, etc. Overall, more than 15 scenarios have been elaborated, and results calculated using the impact assessment methods as in the International Reference Life Cycle Data System (ILCD v 1.08) and in Environmental Footprint (EF 3.0). A comparison of results between the Methodology for Ecodesign of Energy-related Products (MEErP), used in Ecodesign, and the Consumer Footprint has been conducted as well.

The hotspot analysis done with ILCD v 1.08 and EF 3.0 impact assessment methods confirmed the high relevance of the use phase of energy-related products, due to electricity use. Within the use phase, the energy efficiency of products and consumer behaviour (i.e. intensity of use) are the two factors that determine the impact. Large appliances, such as TV screens and washing machines, are the product groups that contribute the most to the overall impact of the BoP appliances. This is partially due to their specific impact per unit of products and partially to the high number of those appliances owned by EU households combined with the use patterns. As expected, the impact from the investigated appliances on resource depletion, and specifically on energy carriers, is the most relevant one among the impact categories considered in the two methods. Instead, the environmental profile of the photovoltaic (PV) system, included in the study, is dominated by the impacts coming from the production of the PV panel components.

The scenarios on improved energy efficiency of the representative products (i.e. in line with the requirements of the Ecodesign directive) showed that there is a good potential (around 10%-20% savings) for most of the impact categories considered. The greatest potential appears to be on the reduction of the ozone depletion from the use of refrigerants in air conditioning units. A scenario combining several measures has been run as well (Scenario 11). The result of all these interventions is a significant reduction of impact for most of the impact categories (up to -65% for ozone depletion and around -35% for climate change). However, there are some trade-off which should be minimized, namely the impacts on land use, freshwater ecotoxicity, and resource depletion (minerals and metals) which are larger than in the baseline.

The main conclusions drawn from the results could support several policies acting at the product level, such as the Ecodesign directive (2009/125/EC), and Waste Electrical and Electronic Equipment (WEEE) directive (2012/19/EU), but also for policies with a broader scope, such as those related to resource efficiency (COM/2011/0571), critical raw materials (EC, 2011a), energy efficiency (2012/27/EU) and certain aspects and action steps contained in the circular economy action plan (COM/2015/0614). Moreover, the structure of the BoP and the possibility to build scenarios acting on user behaviour can be useful in light of the currently increasing interest in behaviour-oriented policies.

1 The European (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 well as an important element of the European Green Deal (von der Leyen, 2019). As part of its commitment towards more sustainable production and consumption, the European Commission (EC) has developed an assessment framework to monitor the evolution of environmental impacts associated to the EU 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), SDG 9 (on industry, innovation and infrastructure), and SDG 8 (on sustainable economic growth), and assessing impact on a number of environmental impact categories related to other SDGs, mainly the ones addressing ecosystems quality and human health (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 eco-innovation. 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 allows 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 EU 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 appliances, 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 Recommendation "on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations (EC, 2013a)", which is linked to the Communication "Building the Single Market for Green Products" (EC, 2013b). 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 solutions tested, as well as to unveil possible trade-offs.

Complementary to the Consumer Footprint the JRC has also developed 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 Footprint and Consumption Footprint) is presented in Box 2. As mentioned above this report focuses on the Consumer Footprint indicator (Sala et al., 2019a, Sala et al., 2019b) and in particular to the Consumer Footprint Basket-of-product on household appliances (herein referred to as "BoP appliances").

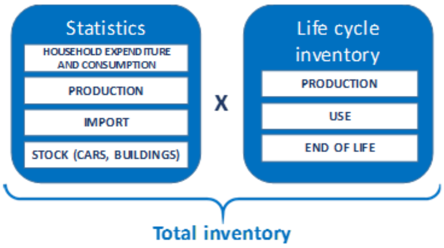
Box 2. Overview of the life cycle-based indicators for assessing the impacts of EU consumption

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

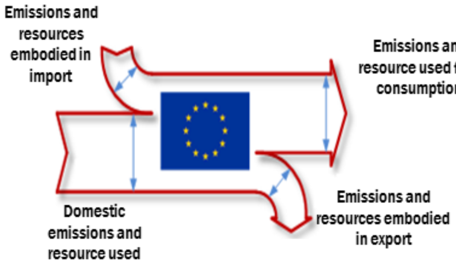
- Focusing on resources used and emissions due to production and consumption during the entire life cycle of a product in selected areas of consumption (food, mobility, housing, household goods, appliances)
- Combining life cycle data (environmental profiles of products) with consumption statistics



The Consumption Footprint (TOP DOWN)

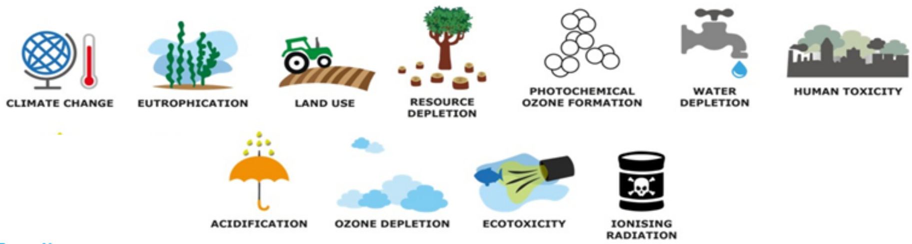
Economy-wide assessment of apparent consumption in the EU

- 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 through the use of the Environmentally Extended Input-Output Approach for assessing the trade



Life Cycle Impact Assessment

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



Results

Environmental impacts associated to households in the EU. 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 eco-innovations 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 the EU and for each Member State, including the distinction of impacts in three categories:

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

2 Environmental impact of household appliances

Household appliances are an important contributor to the overall impact generated by EU citizens' consumption of products, especially because of the intensive energy consumption during the use phase of their life cycle. In 2010 the energy-related products covered by the Ecodesign directive (EC, 2009a) represented approximately 38 700 PJ (925 Mtoe) of direct and indirect primary energy consumption. This corresponds to 53% of total EU-28 gross energy consumption in 2010 (1759 Mtoe) (VHK, 2016a). The major energy consumers are space heating (32% of total), industry components (20%), water heating (11%) and lighting (10%).

Energy-related products are also responsible for 4.6% of EU consumption of plastics, metals, glass, cardboard and rubber, corresponding to 14.6 Mt of materials. Apart from tyres (which contribute to 21% of this total), the most relevant products are household refrigerators (1204 kt, 8%) and washing machines (952 kt, 6.5%). Among the materials used in these products, ferrous metals (galvanized steel sheet, cast iron, steel tubes and profiles, stainless steel) represent 46% of the total weight, whereas plastics (bulk and technical) account for 14%, and nonferrous metals (e.g. aluminium, copper) for 8% (VHK, 2016b). Other materials, even if not relevant in terms of weight, may be relevant from the environmental point of view. This is the case, for instance, of critical raw materials (CRM) contained in electronics (e.g. laptops, smartphones, etc.) and in electronic components of big appliances (e.g. washing machines and dishwasher) and of chlorofluorocarbons *(*CFCs) used for refrigeration.

The residential sector plays a different role depending on the type of energy-related product considered: it is the major energy consumer for cleaning (92% of EU energy consumption for cleaning is in the residential sector), cooking (89%), water heating (65%), space heating (58%), electronics (66%), and food preservation (39%), but it is a minor contributor to the overall EU consumption of energy for lighting (22%) and space cooling (only 6%). According to VHK (2016a), there is a great potential for energy savings in the residential sector: the 2020 primary energy savings of 1918 TWh/y derive for 52% from the residential sector, 31% from tertiary sector, 14% from industry and 3% from other sectors.

Consumer behavior is particularly relevant for this type of products, especially in the use phase, but also at the end of life especially for what concerns the material efficiency. The Directive on Waste of Electronics and Electric Equipment (WEEE Directive, EU, 2012a) focuses on the collection of energy-related products at the end of life with the aim to increase the recycling rate of materials contained in those products. A proper collection and recycling can help to reduce the impact from material extraction, especially for CRM. However, recycling of material contained in the appliances is not always possible, at least with the current technology and related recovery prices, because of the difficulty to separate materials in product components (e.g. for plastics that contain flame retardants).

Another aspect that is investigated to reduce the environmental impact is product life extension, e.g. through repairing of appliances or simply avoiding to replace them before the end of their usable life. Product life extension is recognized as an effective way to reduce the environmental burden of non-energy-related products, because the impacts of all the life cycle phases are simply spread on a longer time period, and the production of a newer one is avoided for some time. However, this is not always the case for energy-related products, which usually have an environmental profile dominated by the use phase. In some cases, the substitution of a product with a newer and often more efficient one, can be more favourable than the extension of the product life (Bakker and Schuit, 2017).

Several studies compared the environmental impacts of the two options (i.e. keeping the product for longer time or substituting it with a newer and more efficient one), through LCA of several products, such as washing machines (Ardente and Mathieux, 2014a), domestic refrigerators and electric ovens (Iraldo et al., 2017), and computer displays (Socolof et al., 2005). Results show that the effects of the increased durability of products can vary according to the products object of the study and the impact category considered.

Therefore, an assessment case-by-case, considering the specific features of the product under study and of the conditions for lifetime extension or substitution, should be performed, to derive conclusions in support to decision-making.

Both for product durability and for the consumption intensities, consumer behavioural studies are more and more present in literature (Sabbaghi et al., 2017).

LCA has been widely used to assess the environmental profile of energy-related products (e.g. Ciantar and Hadfield, 2004, Lee et al 2012; Elduque et al., 2014, Cellura et al., 2014) and to quantify the potential impact reduction coming from energy efficiency measures (e.g. Ardente and Mathieux, 2014b, Louis et al., 2015, Amienyo et al., 2016, Tao et al., 2014). A life cycle approach allows for enlarging the scope of the study to all the life cycle stages (i.e. including material-related aspects) and to highlight potential burden shifting among life cycle stages and impacts (e.g. reducing the environmental pressure related to energy resources, while increasing the pressure on material resources or toxicity-related impacts). Studies are usually focused on one product group or one type of innovation. The Ecodesign Impact Accounting by VHK (2016a) gives a comprehensive overview of the environmental and economic aspects associated to the use of energy-related products in EU. However, the Methodology for Ecodesign of Energy related Products (MEErP) focuses mainly on specific aspects (e.g.energy use, greenhouse gas emissions, waste) that refer to the scope of the Ecodesign directive (EC, 2009a).

The present study has the aim to complement and to enlarge this approach, by applying a full set of LCA indicators (using the ILCD and EF 3.0 impact assessment methods) to to the BoP appliances. The use of representative products allows for building a bottom-up inventory, based on the characteristic of average products and of average behaviours of the users. This structure is flexible and allows for changes of parameters related to product composition, use of end of life treatments, to compare several options and scenarios of eco-innovation.

The BoP appliances represents a model of the stock of appliances in the EU in the reference year (2010) and it is taken as the baseline scenario upon which to compare scenarios of technological improvement or behavioral changes. The possibility to model the entire stock of appliances becomes relevant in light of the trends of evolution of the stock along time. The current tendency highlights that, along with an improvement in energy efficiency, most household appliances (e.g. fridges, freezers, laundry appliances, etc.) showed an increase in capacity during the last decades (larger refrigerated volume, larger drum of washing machine, etc.), often considerably beyond population growth. This is especially evident for TV (the average viewable surface area grew from 10 dm^2 - 19″ diagonal - in 1990 to 28 dm^2 - 32″ - in 2010 and is projected to rise to an average 71 dm^2 - 51″ - in 2030) and for lighting (the number of light sources per household has steadily increased over time). Nevertheless, the improvements in the efficiency of one unit of appliance have been (and are predicted to be in the future) able to offset the effect of the increase in stock and load and, therefore, to grant a reduction of energy consumption (and of related environmental impacts) over time (VHK, 2016a).

Overall objectives of the project are: i) the calculation of the environmental impacts associated to the consumption and use of appliances in the EU; ii) the identification of the hotspots in terms of products, processes, and elementary flows contributing the most to the impacts; iii) the testing of eco-innovation scenarios in the areas of appliances and the potential environmental benefits and burdens associated to their adoption, iv) the comparison of the obtained LCA results with MEErP (used in Ecodesign).

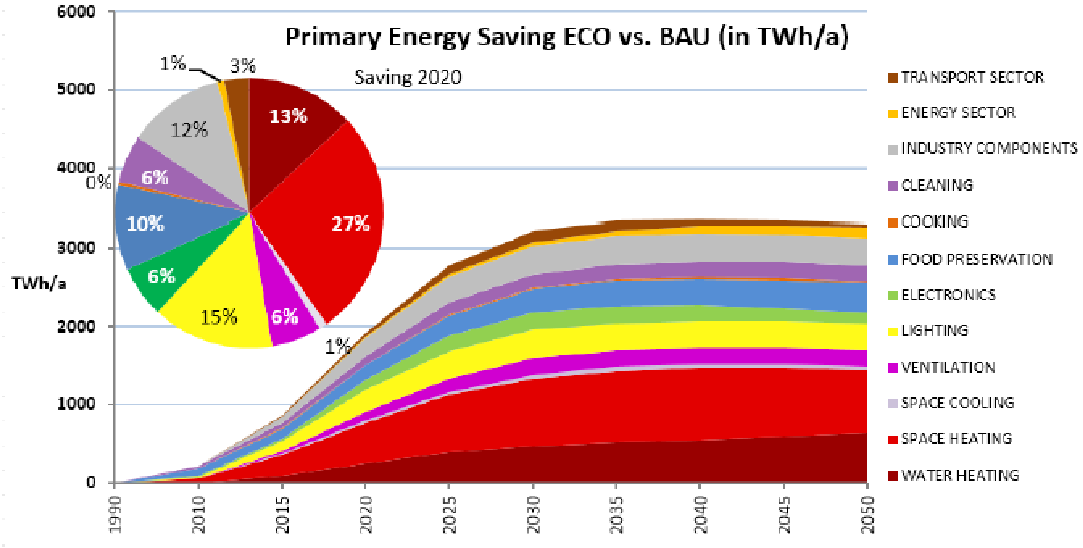
2.1 Household appliances in the framework of the Ecodesign directive

Household appliances are part of the group of energy-related products as defined by the Ecodesign Directive (EC, 2009a), i.e. products that are using energy during the use phase or have a significant impact on the energy consumption of products that are using energy.

The Ecodesign Directive establishes a framework for the setting of ecodesign requirements for energy-related products with the aim of reducing their environmental impact. The European Commission periodically monitors the effects of ecodesign measures and of energy labelling of products, using MEErP methodology (Kemna, 2011), adopting a life cycle approach. Results are summarized in the Ecodesign Impact Accounting (EIA) report produced in 2016 by VHK (VHK, 2016a). The accounting covers projections for the period 2010-2050, with inputs going as far back as 1990 and earlier. Projections use two scenarios: a 'business-as-usual' (BAU) scenario, which represents what was perceived to be the baseline without measures at the moment of the decision making, and an 'ECO scenario' derived from the policy scenario in the studies which come closest to the measure taken.

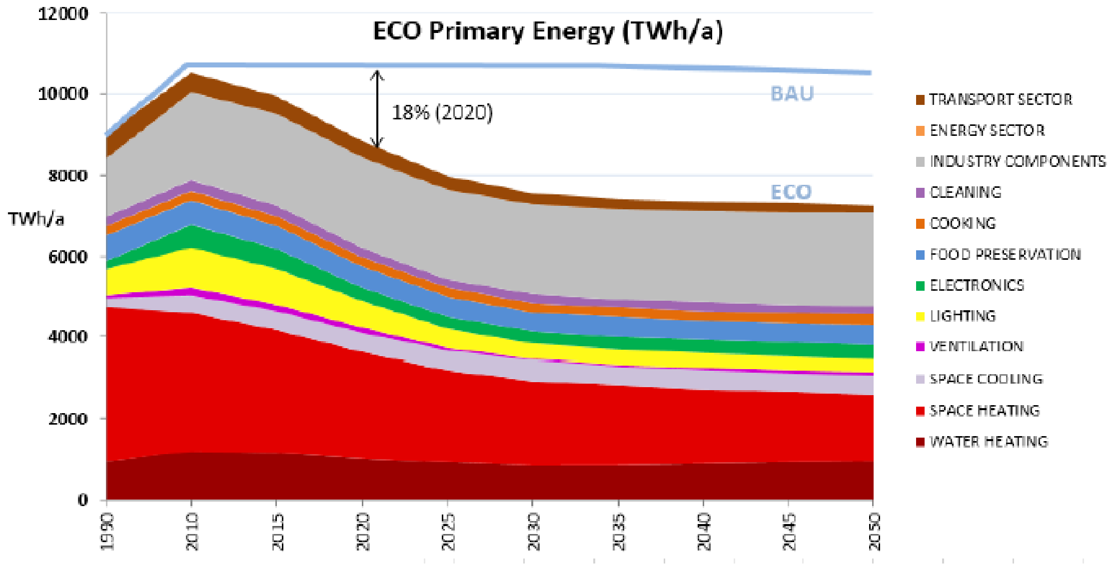
According to VHK (2016a), part of the improvement potential for energy efficiency has already been exploited in the past years (1990-2010). However, there is still room for improvement, especially because the stock of appliances in the EU (including the number of appliances per household) and the use of these appliances (called "load" in the report), is projected to rise in the coming years. The results of the accounting highlight that on average the primary energy saving in 2020, thanks to improved energy efficiency of products (ECO versus BAU scenario), would be 18% (compared to 2010) for the products included in the accounting. For 2030, when there would be a full change of the stock of most regulated products, the energy saving could increase by more than 60%, to 11 543 PJ (276 Mtoe, 3206 TWh) with an average saving of the included products near 30%. Compared to the 2010, this would be a saving of 16%. The main product groups that could contribute to the savings are space and water-heating products (not included in the scope of the BoP appliances, but covered in the BoP housing), followed by lighting (Figure 1). This is not surprising, as they are the major contributors to energy consumption in the EU (Figure 2).

Figure 1. Primary energy savings of ECO versus BAU scenarios of products in ecodesign impact accounting



Source: VHK, 2016a

Figure 2. Primary energy consumption of products included in ecodesign impact accounting



Source: VHK, 2016a

The reduction of energy consumption obtained through the implementation of ecodesign measures and energy labelling is accompanied by a reduction in greenhouse gas and pollutants emissions, partly fuel-related (also with the contribution of other policies and market trends) and partly due to improvements in the design of products (e.g. reduction of refrigerants leakages or use of less impacting materials).

The reduction of greenhouse gas emissions, due to fuel-related carbon dioxide (CO_2) emissions and to losses of refrigerants, is expected to be 319 Mt CO_2 equivalent in the EU in 2020 (ECO versus BAU). This would be 17% of the total emissions of the products included in EIA and 6.8% of the EU total (4721 Mt CO_2). A further reduction (10% compared to 2010) is expected for 2030. Regarding PM emissions, a reduction of 20% of the emissions generated by the energy-related products included in the study is expected in 2020 (compared to 2010).

Other emissions that could be affected by the implementation of the measures (ECO scenario) are: nitrogen oxides (-229 ktSO_2 eq in 2020; 2% of EU-total), carbon monoxide (-507 kt; 1.8% of EU total), and organic gaseous carbon (-22 kt; 0.2% of EU-total).

3 Basket model for household appliances

This report describes the scope and the structure of the BoP appliances, including a description of the key components of the Life Cycle Inventory (LCI). Aim of this section is to enable the reader to understand how the BoP appliances is modelled, to better interpret the results and, ultimately, to replicate the exercise.

Starting from 2012, the European Commission's Joint Research Centre has developed a lifecycle-based methodology that focuses on the environmental impacts of specific representative products (BoP) that are up-scaled to cover the consumption of an average EU citizen. The overall results of this assessment are named 'Consumer Footprint' (EC-JRC, 2012). The project (called LC-IND) focused on indicators that measure the environmental impact of the consumption of products by the average EU citizen, focusing on housing, food, and transport, via the identification and the assessment of the environmental impacts of the most representative products of each category (BoP). The initial BoPs developed in the LC-IND projects were revised extensively in the context of 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.

This report, specifically, covers the BoP appliances, added during the LC-IND2 project, together with BoP on household goods. Household appliances have been considered a specific area of consumption to be treated separately in the modelling. The policy relevance is very broad, interesting the ecodesign (EC, 2009a), the critical raw materials (EC, 2011a), the resource efficiency (EC, 2011b), the energy efficiency (EU, 2012b), and the circular economy (EC, 2015).

3.1 Description of the BoP for household appliances

The BoP appliances consists of a process-based set of LCI models for products that represent the most relevant household appliances product groups in terms of energy consumption and market share. The BoP appliances is built to assess the impact associated to household appliances consumption in EU. The Functional Unit (F.U.) is the average EU citizen consumption in the reference year 2010. The reference flow is the amount of household appliances consumed by the average EU citizen and their use in the reference year 2010.

The selection of the products to be included in the BoP appliances covers three main areas in the household appliances consumption and use: i) white goods; ii) appliances for basic functions related to the housing (e.g. space cooling); iii) entertainment and leisure. An additional criterion for the selection of the products has been its inclusion among the products covered by Ecodesign directive (EC, 2009a). This can be considered a proof of the product's relevance in terms of environmental impacts and potential improvements (especially in terms of energy performance and emissions of carbon dioxide). In addition to those products, a PV system has been analysed, as a potential source of electricity, to reduce the consumption of electricity from the grid during the use phase of other appliances.

Table 1 provides an overview of the products covered by the Ecodesign directive (EC, 2009a) and of those selected for the BoP appliances. In the area "entertainment and leisure", the sound and imaging equipment is not included in the BoP, because it is considered not very relevant in the context of "household", if compared to computers and televisions. Moreover, in the area of "basic functions of housing", products related to heating and domestic hot water are left out because they are already included in the BoP on housing, from the point of view of both energy consumption in use and equipment production.

Table 1. Overview of product covered by the Ecodesign directive (EC, 2009a) and those included in the BoP appliances

Selected in the BoP	Covered by Ecodesign directive (related status at the time of the analysis)
Product for the "Entertainment and leisure" area	
yes	Televisions (adopted in 2009 and 2010, currently under revision)
yes	Computers (desktop and laptop) and servers (adopted in 2013)
no	Sound and Imaging Equipment (voluntary agreement recognized in 2014 and 2015)
no	Simple and complex set-top box (simple - adopted in 2009, complex - voluntary agreement discussed in 2014)
Product for the "White goods" area	
yes	Household Dishwashers (adopted in 2010, under revision)
yes	Household tumble driers (adopted in 2012)
yes	Household washing machines (adopted 2010, under revision)
yes	Domestic refrigerators and freezers (adopted in 2009)
Product related to "basic housing functions" area	
yes	Domestic lighting, general lighting equipment (adopted in 2009 and 2012, under revision)
	Linear and compact fluorescent lamps, high intensity discharge lamps and ballast (adopted in 2009, under revision)
	Directional lighting (2012, under revision)
yes	Domestic cooking appliances (excluding microwave) (adopted in 2014)
yes	Air conditioners and comfort fans (adopted in 2012)
Product already covered by BoP Housing	Local room heating products (adopted in 2015)
	Space and combination heaters (adopted in 2013)
	Water heaters and hot water storage tanks (2013, in force)
	Solid fuel boiler (adopted in 2015)
Other product not related to the three main areas above mentioned	
no	Taps and showers (study on going)
no	Water pumps (electric pump) (adopted in 2011, under revision)
no	Circulators (adopted in 2009)
no	Standby and off mode electric power consumption of household and office equipment and network standby (adopted in 2009)
no	Distribution and power transformers (adopted in 2014, under revision)
no	Networked stand-by losses (adopted in 2013)
no	Non-tertiary coffee machine (adopted in 2013)
no	Vacuum cleaners (adopted in 2013)
no	Ventilation fans (adopted in 2011, under revision)

The selected product groups (and related representative products) that form the BoP appliances are listed in Table 2.

Table 2. Selected products in the BoP appliances

Product group	Representative products
Lighting	• Compact fluorescent lamp with integrated ballast (CFLi) • Halogen lamp, low voltage (model with reflector – R) (HLLVR) • Halogen lamp, mains voltage (model HLLME) • Incandescent lamp (GLS) • Light Emitting Diodes (LED)
Dishwashing	• Dishwasher 10ps • Dishwasher 13ps
Washing and drying machine	• Washing machine (7 kg capacity) • Electric condenser tumble dryer (3.4 kg capacity)
Air conditioning	• Air conditioner (reversible single split unit with cooling capacity of 3.5 kW)
Refrigeration	• Combined refrigerators-freezer
TV screen	• LCD TV screen 32”
Computer	• Notebook
Domestic cooking appliances	• Electric oven (built-in)
Photovoltaic	• Multi-cristalline silicon (Multi-Si) and Monocristalline silicon (Mono-Si) phtovoltaic panels (PV)[1]

For each product group in the BoP, one or more inventory models based on representative products have been developed. Data about representative products have been taken mainly from preparatory studies compiled for the definition of Ecodesign requirements. The characterised impact of each representative product is then multiplied by the mass of products that is consumed/used in one year by an average EU citizen.

3.1.1 Details on products groups in the BoP and estimation of related quantities

A quantitative and qualitative analysis of the structure of EU household consumption of the above-mentioned product groups was performed, including an analysis of international trade. Data on apparent consumption (defined as Production - Exports + Imports) of the representative products were taken from the Eurostat database (Eurostat, 2017a).

However, two aspects deserve consideration in relation to the definition of the quantities to be included in the BoP for the intended purpose. The first one is that all the selected appliances have a service life longer than one year and this affects the annual apparent consumption. Secondly, all appliances consume energy during their service life. Consequently, including in the BoP the mere apparent consumption would not capture the effective environmental impacts due to the annual consumption and use of appliances. Hence, it has been considered more meaningful for the project aim to consider, for each product, the whole stock in the reference year, to divide the impact from the stock by the number of service life years of the representative product chosen, and to allocate this impact to the reference year and then to the number of users (i.e. EU citizens in the reference year). Table 3 reports the quantities included in the BoP for each product.

The reference year for the baseline scenario is 2010. This year was chosen firstly to ensure consistency with the baseline scenarios of the other BoPs developed in the context of the Consumer Footprint and, secondly, because it was the closest year for which the Ecodesign preparatory studies have complete data for the modelling of the reference products.

[1] The PV panel is analysed separately from the BoP appliances. Being used at the building level, it is tested as an additional system to the inventory of the BoP housing, which models the EU building stock.

Table 3. Quantities of products in the BoP appliances

Representative Product	Total stock of the product group – 2010 (unit)	Share of the EU stock covered by the representative product (%)	Product lifetime (y)	Amount consumed by an EU citizen in 2010 (unit/pers*y^{-1})
Dishwasher 10 ps	12,419,850	15%	12.5	0.002
Dishwasher 13 ps	70,379,150	85%	12.5	0.011
Washing Machine	185,828,000	100%	12.5	0.030
Electric condenser tumble dryer	63,037,000	60%	13	0.006
Combined refrigerators-freezers	299,289,000	56%	15	0.022
Air conditioner	28,077,000	100%	15	0.004
Electric oven (built-in)	97,878,595	46%	19	0.010
Compact fluorescent lamp	148,593,6824	100%	12	0.246
Halogen lamp, low voltage	902,902,229	100%	4.4	0.408
Halogen lamp, mains voltage	1,058,346,935	100%	3.3	0.638
Incandescent lamp	716,225,361	100%	2.2	0.648
LED[2]	0	0	5	-
Notebook	71,452,000	40%	6	0.028
LCD TV screen	332,254,364	53%	12.5	0.058

Stock data (for the reference year 2010) were, as a general rule, retrieved from Ecodesign preparatory studies[3]. Additional assumptions and/or different sources were considered when needed, as described below.

— Dishwasher. The preparatory study (Boyano et al., 2017a) reports the market shares for each Dishwasher size. As the higher shares are those of the Dishwashers for 9-10 and 12-13 place setting (ps), we used the 13ps model to represent Dishwashers of size ≥ 12 ps and the 10ps model to represent Dishwashers of size ≤ 11ps. Overall in the BoP, it is assumed that 85% of the stock is covered by the Dishwasher 13ps and the remaining 15% by the Dishwasher 10ps.

— Tumble dryer. Quantitative data about the specific features of the products in the stock are not reported in the preparatory study (Ecobilan – PricewaterhouseCoopers, 2009). However, it reports sales data for the year 2005 showing that (electric) condensed tumble dryers covered respectively 55% of total sales in Western EU and 75.1% of those in Eastern EU. VHK (2016b) reports the stock at 2010. It also confirms that electric condensed tumble dryers had the highest share on the market in 2010, namely the 60% of total sales at EU level. The composition of the stock always experiences a delay in comparison to the composition of the sales, however market share at 2010 for (electric) condensed tumble dryers is within the market share range reported for European countries (Eastern and Western) at 2005. In light of this, the market share (sales) at 2010 (from VHK, 2016b) was considered as an acceptable proxy of stock

[2] Added in the modelling of products for assessing scenarios of change of product group composition overtime but not having a share of the market in 2010

[3] http://susproc.jrc.ec.europa.eu/product_bureau/projects.html (for the current ones and for those under development, for which working documents and draft technical report are available)

composition. Thus, it was considered that 60% of the stock is composed of condensed tumble dryers.

- Refrigerator. Detailed data on stock composition at 2010 are not available. The preparatory study (VHK, 2015) reports that, in 2014, the selected representative product (combined refrigerator-freezer) covered the 56% of the stock. Hence, it has been assumed the same share for the 2010 stock.
- Air conditioner. The Ecodesign preparatory study (ARMINES, 2008) focuses on the residential market, addressing room air conditioning appliances below 12kW. According to the reported data, the residential market is dominated by single split units, namely 85% of residential power for air conditioning is associated to single split units, followed by 11% of moveable units. However, the reference year of this market shares is not well specified. In the BoP it is assumed that the selected representative product covers 100% of the stock. The stock of residential room air conditioners is calculated by multiplying the dwelling stock reported in BoP Housing for the penetration rate of air conditioning system in residential (reworking of data from Intelligence Energy Europe-IEE Project ODYSSEE database, for the reference year 2010) and assuming one unit installed for each dwelling with an air conditioning system. The final EU average penetration rate of air conditioning systems is 14% (in line with the 12-15% reported by VHK, 2016b).
- Lighting. The stock for each selected representative product was derived starting from the overall electricity consumption for lighting in residential at 2010 (reworking of data from IEE Project ODYSSEE database, for the reference year 2010), as follows. The overall electricity consumption for lighting was distributed among the lamp technologies used in residential proportionally to the average residential installed power for each of them in a dwelling (% of installed power of Linear fluorescent lamps - LFL, Compact fluorescent lamps - CFL, Halogen lamps - HL, Incandescent lamps - GLS, High intensity discharge lamps - HID, Light emitting diodes - LED on the total installed power for lighting in a dwelling). Residential installed power for each lamp technology was reported in the Ecodesign preparatory study (VITO, 2015a) with reference to 2010. The annual electricity consumption associated to each lamp technology was then divided by the related average annual operating hours, as reported in the preparatory study, to obtain the overall kWh per light source. This value was finally divided by the average power of each light source so as to find out the total stock in households (Table 4).

Table 4. Summary of the parameters considered for the definition of the stock and the average annual consumption by each lamp technology

<table>
<tr><th>Parameters</th><th>CFLi</th><th>GLS</th><th>HL (low voltage - LV)</th><th>HL (mains voltage - MV)</th><th>LED</th></tr>
<tr><td>Electricity consumption (kWh/year)</td><td>8,358,394,634</td><td>38,289,407,799</td><td colspan="2">32,080,314,642</td><td>0</td></tr>
<tr><td>Operating hours per year</td><td>500</td><td>450</td><td>450</td><td>450</td><td>585</td></tr>
<tr><td>Average power of a single lamp (W)</td><td>11.25</td><td>54</td><td colspan="2">36.35*</td><td>12.5</td></tr>
<tr><td rowspan="2">Stock (units)</td><td rowspan="2">1,485,936,824</td><td rowspan="2">1,575,695,794</td><td colspan="2">1,961,249,164** of which</td><td rowspan="2">0</td></tr>
<tr><td>902,902,229.2</td><td>1,058,346,935</td></tr>
<tr><td>Average consumption of a lamp (kWh/year)</td><td>5.625</td><td>24.3</td><td>16.35</td><td>16.35</td><td>0</td></tr>
</table>

*It is a weighted average considering that the average power of HLLV is 35 W, the average power of HLMV is 37 W and the share of HLLVR (selected representative product for HLLV) and HLMLE (selected representative product for HLMV) on the total of HLLVR + HLMVE, in residential in 2013, is respectively 46% and 56%.

** Based on the above mentioned % of residential stock for HLLVE and HLMVE in 2013 (respectively 46% and 56%).

4 Life Cycle Inventory of the BoP

The studied system covers the whole life cycle of the products included in the BoP, from the production of the materials/components used in the products until the end of life, as reported in Table 5.

Table 5. System boundaries, life cycle stages, and activities included in the assessment of BoP appliances

Life Cycle Stage	Activities/processes included
Manufacturing of components	• Production of raw materials • Processing of raw materials • Transport of the components to the factory where the manufacturing takes place
Manufacturing of the product	• Assembly of components
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
Use phase	• Transport of the product from Retail/Distribution Centre to the final consumer • Consumption of energy and water from the use of the product • Use of detergents and salt, if any (detergents, salt and additives (rinse off) for Dishwashers and detergents and additives – e.g. softeners, bleaching agents, etc. - for Washing machines) • Waste management, if any (e.g. treatment of wastewater from product use).
Maintenance and repair	• Manufacturing of components to be substituted (production of raw materials, processing of raw materials, transport of the materials to the factory) • Waste management of substituted components
EoL of the product	• Sorting of materials/components • Recycling • Incineration and energy recovery • Landfill

To model the process-based LCI inventories of the selected representative products, the following approach was followed:

- priority was given to the inventories already defined in Ecodesign preparatory studies;
- when the LCI reported in the preparatory studies was not detailed enough, it was complemented with additional information taken from literature;
- when the LCI reported in the preparatory studies was not recent enough other sources from literature were considered.

Table 6 reports, for each selected representative product, the data source and the source type.

Table 6. Overview of LCI data used to model the representative products

Representative Product	Data source	Type
Dishwasher 10 ps Dishwasher 13 ps	Tecchio et al., 2016	Technical report
	Working document EU Ecodesign for dishwasher, 2015a Working document EU Ecodesign for dishwasher, 2015b Boyano et al., 2017a	Preparatory study for Ecodesign requirements
	Screening report of the PEF pilot on Household Heavy Duty Liquid	Screening report
	Ardente and Talens Peirò 2015	Technical report
	ISIS, 2007a	Preparatory study for Ecodesign requirements
Washing Machine	Tecchio et al., 2016	Technical report
	Working document EU Ecodesign for washing machines and washer dryers, 2015a Working document EU Ecodesign for washing machines and washer dryers, 2015b Boyano et al., 2017b	Preparatory study for Ecodesign requirements
	Ardente and Talens Peirò, 2015	Technical report
	Ardente and Mathieux 2012	Technical report
	Screening report of the PEF pilot on Household Heavy Duty Liquid	Screening report
	Hischier et al., 2015	Scientific paper
	ISIS, 2007a	Preparatory study for Ecodesign requirements
Electric condenser tumble dryer	Ecobilan – PricewaterhouseCoopers, 2009	Preparatory study for Ecodesign requirements
	VHK, 2016b	Annual overview report
Combined refrigerators-freezers	VHK, 2016b	Annual overview report
	VHK, 2015	Preparatory study for Ecodesign requirements
	ISIS, 2007b	Preparatory study for Ecodesign requirements
Air conditioner, single split	Almutairi et al., 2015	Scientific paper
	Grignon-Masse' et al., 2011	Scientific paper
	ARMINES, 2008	Preparatory study for Ecodesign requirements
	IEE Project ODYSSEE database	EU Project
Electric oven (built-in)	BIO Intelligence Service, 2011	Preparatory study for Ecodesign requirements
Compact fluorescent lamp Halogen lamp, low voltage Halogen lamp, mains voltage Incandescent lamp	Chen et al., 2017	Scientific paper
	Biganzoli et al., 2015	Scientific paper
	VITO, 2015b	Preparatory study for Ecodesign requirements
	Eurostat, 2017b	Statistical data for Waste Electrical and Electronic Equipment (WEEE)

Representative Product	Data source	Type
LED	IEE Project ODYSSEE database	EU Project
Notebook	Tecchio et al., 2017	Technical Report
	Subramamian and Yung, 2017	Scientific paper
	VITO, 2017	Preparatory study for Ecodesign requirements
	IVF, 2007	Preparatory study for Ecodesign requirements
LCD TV screen	Tecchio et al., 2017	Technical Report
	Talens Peirò et al., 2016	Technical Report
	Fraunhofer IZM, 2007	Preparatory study for Ecodesign requirements
	Bertoldi and Atanasiu, 2009	Status report

4.1 LCI of the production of materials and components

The LCI for each household appliance is mainly based on information taken from Ecodesign preparatory studies, complemented with additional information and further details from scientific technical literature. The background system, e.g. electricity and materials production, is modelled according to the information reported in LCA databases, such as ecoinvent[4]. Annexes 1 to 9 describe the assumptions made for the modelling of the representative products. Below, modelling assumptions common to all products in the BoP are listed.

- For all plastics, an average injection moulding operation was assumed to represent the processing, namely the dataset "Injection moulding {GLO[5]}| market for | Alloc Def, U" was used.
- For ferrous metal (steel), when used as a sheet, an average sheet rolling was assumed to represent the processing, namely the dataset "Sheet rolling, steel {GLO}| market for | Alloc Def, U" was used.
- For non-ferrous metal (aluminium), when used as a sheet, an average sheet rolling was assumed to represent the processing, namely the dataset "Sheet rolling, aluminium {GLO}| market for | Alloc Def, U" was used.
- For non-ferrous metal (aluminium), when classified as "Al diecast", a lost wax casting was assumed to represent the processing, namely the dataset "Casting, aluminium, lost-wax {GLO}| market for | Alloc Def, U" was used.
- For non-ferrous metal (brass), when classified as cast, a brass casting was assumed to represent the processing, namely the dataset "Casting, brass {GLO}| market for | Alloc Def, U" was used.
- For Dishwasher, drying machine, room air conditioner, and refrigerator, the electronic part is assumed as composed by cables, Printed Circuit Boards (PCBs), steel (for the housing) and plastic; these input components are indicated in the ecoinvent process "electronic for control unit", however the percentages of input components was revised, based on Tecchio et al. (2016). Thus, cables are the 38% of the electronic mass, PCB is the 37%, 24% is assumed as steel (in Tecchio et al., (2016) this % is composed by 8.6% of motor, 2% of display and 13.4% of other electronics), whereas the remaining 1% is plastic and it is assumed to be PVC. Major details about the share of this component on the total weight of electronic is provided for each product in annexes 1-9.
- For the oven, washing machine, dishwasher, drying machine, room air conditioner, refrigerator, LED lighting, and compact fluorescent lamp, the ecoinvent process

[4] www.ecoinvent.org

[5] The code {GLO} in ecoinvent datasets indicates that the dataset refers to the global market, i.e. represents the average conditions and features of that process or product at global scale

"Printed wiring board, surface mounted, unspecified, Pb free {GLO}|market for| Alloc Def, U" was used to represent the PCBs.
- For the laptop, and LCD TV screen, the ecoinvent process "Printed wiring board, mounted mainboard, laptop computer, Pb free {GLO}|market for" was used to represent the PCBs.
- A zinc flow was used to represent the steel sheet galvanization. The % of zinc on the total weight of the sheet is derived by the European Reference Life Cycle Database (ELCD) dataset "Steel hot dip galvanized, including recycling, blast furnace route, production mix, at plant, 1 kg, typical thickness between 0.3 - 3 mm, typical width between 600 - 2100 mm. GLO S".
- Transports are modelled according to Product Environmental Footprint Category rules (PEFCRs) concerning the transport from supplier to factory, in case no data are available about the location of supplier.

4.2 LCI of the packaging

In the production of packaging materials, transport is modelled according to PEFCR rules concerning the transport from supplier to factory, for the specific case in which information on supplier location are not available. Modelling of packaging (and end of life of packaging) was made consistently with what was done for the other BoPs, i.e. using the same datasets for the materials and using the same scenario for the end of life (treatments and ratios). Details are provided in Annex 10.

4.3 LCI of the manufacturing of the product

The LCI of product's manufacturing includes, generally, energy and water use. The definition of the energy mixes used to model this stage was based on the results of a specific analysis done about the international trade of imported products.

In the present study, trade from outside of the EU is called international trade and it was considered for all products in the BoP. The countries of origin and amount of imports were considered in relation to apparent consumption in the EU. Country-specific import data for the BoP appliances were taken from the Eurostat international trade database for the year 2010 (Eurostat, 2015). Transport from those countries that represents the source of at least 90% of total EU imports of a specific product was considered in the study. Distances and modes of transport used in import countries were also accounted for.

For each product, the EU electricity mix was used for the share of production that is known to happen in the EU. The dataset for the European electricity mix "Electricity, low voltage {Europe without Switzerland}| market group" (from ecoinvent 3.2 library) was used to represent the EU electricity profile. For the share of production known to happen outside the EU, a specific electricity mix was created, to represent the real conditions of the production sites (according to the share of imports from extra-EU countries). Table 7 reports, for each product, the % of imports (on the apparent consumption) from outside EU and main importing countries. The same data were used to build the electricity mixes for the production stage of imported products. These mixes were included in the inventory of the production stage of representative products, for the percentage of final products that are imported from outside EU.

Table 7. Summary of the electricity mixes used to model the share of production that happens outside Europe (based on the total share of finished products that are imported and on the specific share from the different importing countries)

Dishwasher

Import countries	% of mix
CHINA	51.0%
TURKEY	46.6%
KOREA	2.0%
MEXICO	0.2%
UNITED STATES	0.1%

Washing machine and drying machine

Import countries	% of mix
TURKEY	47.1%
CHINA	40.1%
KOREA	9.7%
RUSSIAN FEDERATION	1.2%
THAILAND	0.5%
BELARUS	0.4%
UNITED STATES	0.3%

Room Air Conditioner

Import countries	% of mix
CHINA	66.7%
THAILAND	13.2%
KOREA	6.1%
JAPAN	5.8%
TURKEY	3.9%
MALAYSIA	3.1%
ISRAEL	0.6%

Refrigerator

Import countries	% of mix
CHINA	48.4%
KOREA	21.3%
TURKEY	20.9%
THAILAND	2.1%
INDONESIA	1.4%
SERBIA	1.4%
BRAZIL	1.2%
BOSNIA	0.9%
MEXICO	0.4%
UNITED STATES	0.4%

Laptop

Import countries	% of mix
CHINA	44.2%
SINGAPORE	23.8%
MALAYSIA	14.9%
UNITED STATES	7.2%
THAILAND	4.0%
SWITZERLAND	1.1%
HONG KONG	1.2%
CANADA	0.4%
ISRAEL	0.3%
MEXICO	0.2%

TV screen

Import countries	% of mix
CHINA	85.9%
TAIWAN	3.4%
MALAYSIA	3.1%
KOREA	2.1%
JAPAN	1.5%
TURKEY	1.5%
HONG KONG	1.1%
UNITED STATES	0.6%

Fluorescent lamp, hot cathode (CFLi)

Import countries	% of mix
CHINA	89.4%
UNITD ARAB EMIRATES	1.9%
INDONESIA	0.7%
UNITED STATES	0.5%
JAPAN	0.9%
HONG KONG	0.7%
INDIA	1.4%
MALAYSIA	0.2%

Incandescent lamp (GLS_X)

Import countries	% of mix
CHINA	89.1%
UCRAINA	4.8%
TUNISIA	1.1%
INDIA	1.1%
HONG KONG	1.0%
INDONESIA	0.8%

Halogen lamp, low voltage (HLLVR)

Import countries	% of mix
CHINA	89.8%
INDIA	2.6%
KOREA	1.8%
HONG KONG	1.7%
UNITED STATES	1.2%
JAPAN	0.6%

Halogen lamp, mains voltage (HLMVE)

Import countries	% of mix
CHINA	89.8%
INDIA	2.6%
KOREA	1.8%
HONG KONG	1.7%
UNITED STATES	1.2%
JAPAN	0.6%

Electric oven

Import countries	% of mix
CHINA	56.3%
TURKEY	37.4%
THAILAND	3.6%
HONG KONG	0.6%
UNITED STATES	0.4%
KOREA	0.3%
MALAYSIA	0.3%

4.4 LCI of the distribution and retail phase

The modelling of distribution and retail phase concerns the transport from factory to Distribution Centre (DC) and retail. For the share of products consumed in the EU but imported from outside EU (source: Eurostat, 2017a), it has been considered an international transportation, based on the different exporting countries, means of transport and distances.

The transport of finished products is assumed to occur from the capital of the exporting country to the city of Frankfurt, which is considered a central destination for the arrival of imported goods in the EU. For exporting countries directly connected to EU by land, such as Switzerland or Belarus, only a transport by lorry is considered from the capital of the exporting country to the city of Frankfurt. For the others, the transport is considered to be composed by: a transport by lorry between the capital of the exporting country and the country's main port; a transport by ship from the port of the exporting country to the main EU ports and, finally, a transport by lorry between the port of destination and the city of Frankfurt. Rotterdam and Marseilles are considered as the EU ports of arrival of the goods. The distances are calculated by using www.sea-distances.org and Google maps. The results are reported in Table 8. This transport is allocated to a percentage of the final product in the LCI model, corresponding to the share of imported goods out of the total apparent consumption of that kind of product.

For the sea transport, it has been used a transoceanic container whereas for the road transport a truck >32 t - EURO 4. The share of products produced in Europe is assumed to undergo a local supply chain, according PEFCR rules, thus 1200 km by truck, EURO 4.

Table 8. Summary of the share of imported appliances, sea transport distance and the road transport distance for each representative product

Representative product	Import (% of apparent consumption) (Eurostat, 2017a)	Sea transport (km per unit)	Road transport (km per unit)
Dishwasher10ps	26%	9143	1405
Dishwasher13ps	26%	9143	1405
Washing Machine	21%	8687	1407
Electric condenser tumble dryer	21%	8687	1407
Combined refrigerators-freezers	48%	12731	1250
Air conditioner, single split unit	57%	15663	1144
Electric oven (built-in)	15%	10478	1350
Compact fluorescent lamp	91%	16750	1153
Halogen lamp, low voltage	36%	16743	1165
Halogen lamp, mains voltage	59%	16743	1165
Incandescent lamp	43%	15986	1153
LED	100%	17210	1142
Notebook	92%	13846	1073
LCD TV screen	80%	16484	1134

4.5 LCI of the use phase

The use phase includes the transport to final consumer and the energy and water consumption (if any) during the operation stage. As a general rule, the annual consumption of energy and water (if any) is taken from the Ecodesign preparatory studies related to each selected product, with few exceptions specified in Annexes 1-9. The transport from DC/retail to final consumer is modelled according PEFCR rules; as the share of products to the final consumer from the DC from retail is unknown, all the products are assumed to be transported from DC to final consumer (250 km round trip, by van EURO 3). An alternative option to be tested could be an equal distribution between the transport from DC to final consumer and that one from retail to final consumer. For the Dishwasher and washing machine, the detergents are included in the model. The models of detergents are the ones included in the BoP on household goods (Castellani et al., 2019). The dishwasher detergent is modelled as the reference product of the Ecolabel background study (Arendorf et al., 2014a). The laundry detergent used in washing machines is assumed to be 50% liquid and 50% powder. The model for the powder detergent is based on the reference product of the Ecolabel background study (Arendorf et al., 2014b). The liquid detergent model is based on the reference product defined in the screening report of the PEF pilot on Household Heavy Duty Liquid.

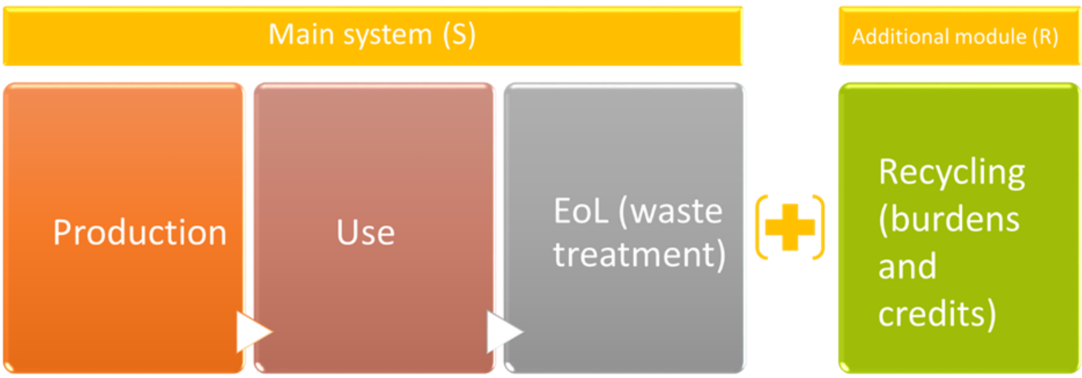
4.6 LCI of the maintenance and repair phase

In the maintenance and repair, the efforts for maintaining the functionality of the appliances during the life time are considered. The approach commonly used in the Ecodesing preparatory studies requires for the accounting of 1% of the bill of materials to be substituted during the whole life time. This approach is clearly mentioned in the Ecodesign preparatory studies for Dishwasher (Working document EU Ecodesign for Dishwashers, 2015a; Working document EU Ecodesign for Dishwashers; 2015b, Boyano et al., 2017a) and washing machine (Working document EU Ecodesign for washing machine, 2015a; Working document EU Ecodesign for washing machine, 2015b; Boyano et al., 2017b), refrigerators (VHK, 2015), air conditioners (ARMINES, 2008), computer (IVF, 2007) and television (Fraunhofer IZM, 2007). In this study, the same approach is applied, with the exception of lighting, for which the maintenance and repair is not an issue, and notebook, for which just the substitution of battery has been accounted for, in consistency with replacement battery data reported in Tecchio et al. (2017).

4.7 LCI of the EoL phase

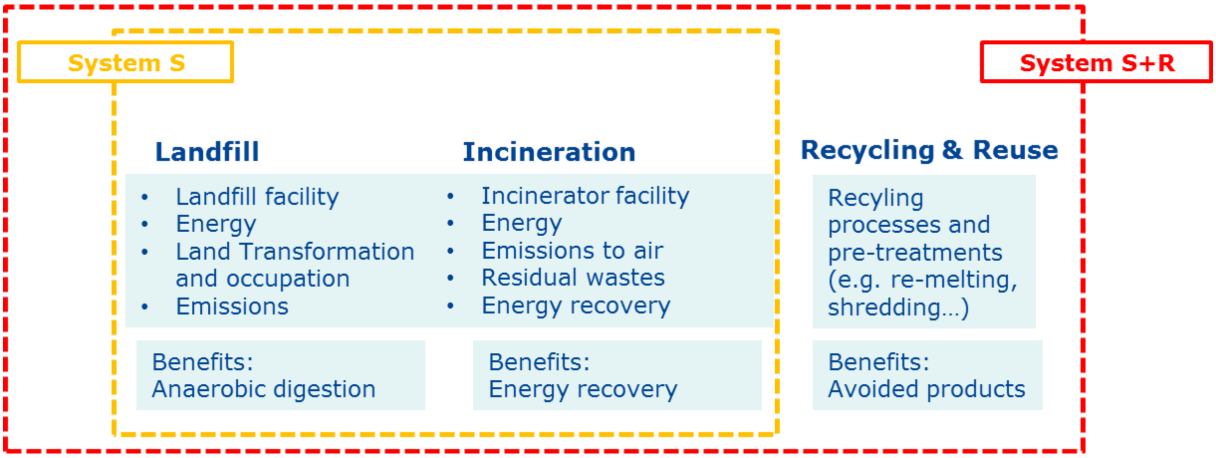
The end of life stage in the BoP is modelled in a way that allows separating the burdens and benefits of recycling from the rest of the system, in order to provide a clearer picture of their contributions to the total impact. Two systems are identified: "S", referring to the system excluding recycling activities, and "R", including burdens and credits from recycling activities. Figure 3 illustrates the approach followed in modelling the end of life in the BoP appliances.

Figure 3. Illustration of the approach adopted to model EoL as waste treatment and recycling, as systems "S" and "R"



The sum of the two, named System "S+R", is the one which allows to evaluate in a more comprehensive way those 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. Details on activities included in each system are provided in Figure 4.

Figure 4. EoL activities included in System S, R and S+R



The end of life of packaging materials was modelled following the distinction of the systems S and R, then, summed in the system S+R. EoL of packaging is included in the packaging stage.

4.7.1 Collection rate of WEEE and recycling, energy recovery and landfill rates for materials

In order to model the end of life of products included in the BoP and to estimate the environmental benefits from recycling at end of life, the WEEE collection rates and the recycling rates needed to be defined.

Collection rate

Although collection rates and recovery rates of WEEE are regularly reported by Member States to Eurostat as per the WEEE Directive (EU, 2012a), recent studies, as for example also CWIT (2015), show that the WEEE flows are far to be addressed to proper treatment. In 2012, just the 35% of the WEEE flow ended up in the officially reported amounts of collection and recycling systems (CWIT, 2015). The remaining 65% was illegally exported, recycled under non-compliant conditions, scavenged for valuable parts or simply thrown in waste bins.

In order to account for the impacts of WEEE consumption in the EU and by an average EU citizen, impacts arising from each WEEE route at EoL should in principle be considered. However, for the scavenged and exported flow, it is hard to define a scenario. Materials extracted in scavenged WEEE are most probably base-metal parts (e.g. iron, aluminium, copper parts). WEEE can be exported, although it is known that some exports hide illegal activities (e.g. EEE exported for reuse, while instead illegally discarded). Improper/illegal activities (e.g. recycling, reuse, energy recovery and landfill from both scavenged and illegally exported flows) are difficult to be drawn. Therefore in the present study these flows have been considered as resulting in a landfill process without any benefit.

Collection rates have been firstly defined on the base of statistical data in Eurostat database (Eurostat, 2017b). Statistical data report the amount of products (in t) put on the market and the amount of collected WEEE per year (as well as collected WEEE from households) per each Member State.

The amount reported under "waste collected" in the Eurostat database corresponds to the amount of WEEE collected for proper treatment, which also includes the legal export. Table 9 and Table 10 report results from the reworking of statistical data for the reference year 2010. The collection rate has been calculated for the EU for the reference year, both considering the EEE put on the market in the specific reference year and the average EEE put on the market in the three preceding years, according to the Directive (EU, 2012a) for the year from 2019 on. It is important to underline that target established by the WEEE Directive refer to the overall WEEE and not to the single WEEE categories.

Table 9. European EEE put on the market and WEEE collection rate, total and by WEEE flow, in 2010. Collection rate is calculated as the ratio between the amount put on the market and the amount collected in the same year.

Flow	EEE put on the market 2010 (t)	Collected WEEE 2010 (t)	Collection rate - collected WEEE / put on the market 2010 (%)
Total WEEE*	9,345,750	3,379,077	36%
Large Household Appliances*	4,624,701	1,448,970	31%
IT and Telecommunication equipment **	1,362,782	660,087	48%
Consumer equipment and photovoltaic panels***	706,153	418,757	59%
Lighting equipment****	305,753	15,489	5%
Gas discharge lamps*****	111,886	30,847	28%

*Netherland excluded; **Italy, Denmark, Finland, Sweden, UK, Estonia and Netherland excluded; ***Italy and Netherland excluded; **** Italy, Portugal, Ireland and Netherland excluded; *****Italy excluded

Table 10. European EEE put on the market and WEEE collection rate, total and by WEEE flow, at 2010. Collection rate is calculated as the ratio between the collected WEEE at 2010 and the annual average amount of products put on the market in the period 2007-2009.

Flow	EEE put on the market – average 2007-2009 (t)	Collected WEEE – 2010 (t)	Collection rate - collected WEEE / put on the market 2010 (%)	Collection rate - collected WEEE/put on the market average 2007-2009 (%)
Total WEEE*	9,518,165	3,379,077	36%	36%
Large Household Appliances*	4,497,312	1,448,970	31%	32%
IT and Telecommunication equipment's *****	1,394,050	660,087	48%	47%
Consumer equipment and photovoltaic panels**	799,362	418,757	59%	52%
Lighting equipment***	308,065	15,489	5%	5%
Gas discharge lamps****	94,044	30,847	28%	33%

*Netherland excluded; **Italy, Denmark, Finland, Sweden, UK, Estonia and Netherland excluded; ***Italy and Netherland excluded;**** Italy, Portugal, Ireland and Netherland excluded; *****Italy excluded

Values from statistics have been deeply discussed with experts in the field of WEEE's EoL. In relation to the large household appliances it was pointed out that, due to their size, these products go more and more in the official collection systems once the owner decide to throw it away, although some differences still exist between the different Member States and between Western and Eastern EU. The collection rates for refrigerators and air conditioners were considered to be slightly lower compared to the other large household appliances, due to the higher cost for their treatments.

Regarding the lighting equipment, the collection rate for compact fluorescent lamp was considered quite in line with value from statistics and with collection rate values reported in the Ecodesign preparatory study (VITO, 2015a), although the share of properly collected items is increasing. Collection rate for LED were considered similar to the compact fluorescent lamps. However, information on LED is still scarce, due to the limited use compared with other lamp types, especially in residential sector. For the other lamp types the collection rate is very limited, this clearly arises from statistics as well as from the Ecodesign preparatory study (VITO, 2015a). TV screen collection rate was judged by the experts as quite close to that one for large household appliances, especially for large size TV screen. Compared to TV screen, the collection rate for laptop was judged a little bit lower.

Considering values from statistics in light of the expert judgement above described, in the present study the collection rates reported in Table 11 are assumed. In particular the baseline is set on the minimum value of the reported range.

Table 11. Collection rate at end of life of products included in the BoP

Product	**Collection rate (%)**
Dishwasher	70 – 90
Washing machine	
Tumble dryer	
Electric oven	
Refrigerator	60 -80
Air conditioner	
Compact fluorescent lamp	30 - 40
Halogen lamp, low voltage	0 - 5
Halogen lamp, main voltage	0 - 5
Incandescent lamp	0 - 5
LED	20 -30
Notebook	45 - 60
TV screen	55 - 70

Recycling rate

Similarly to the collection rates, recycling, energy recovery, and landfill rates for materials included in the collected WEEE, were defined by reviewing literature sources with the support of expert judgement. The starting point has been the set of default values defined in the context of the Ecoreport tool (COWI, 2011) and indicated in Table 12.

Table 12. End of life mass fractions (default values) in the Ecoreport tool

Material/component	Reuse (%)	Recycling (%)	Energy recovery (%)	Incineration (%)	Landfill (%)
Bulk Plastic	1	29	15	22	33
Tec Plastic	1	29	15	22	33
Ferrous Metal	1	94	0	0	5
Non Ferrous Metal	1	94	0	0	5
Coating	1	94	0	0	5
Electronic	1	50	0	30	19
Miscellaneous, excluding elec.	1	64	1	5	29
Refrigerant	1	30	0	5	64
Extra	1	60	0	10	29
Auxiliaries	5	30	10	10	45

Default values are provided for reuse, recycling, energy recovery, incineration, and landfill. However, a two-fold problem is associated to the set of default values, which hampers the application in the context of the BoP. In fact, i) it seems that default values already take into account that not all WEEE are properly treated and, as a consequence, they are representative of EoL mass fraction from the collected WEEE flow plus that one from the remaining WEEE, ii) it is not clear how reuse is treated and if some credits are assigned. In addition, the collection rate of EEE at end of life (with the exception of lighting equipment) is not clearly mentioned in the Ecodesign preparatory studies related to the different products.

On the contrary, the standard IEC 62635 (IEC, 2012) provides recycling rates for materials in the product for the case of both manual dismantling and shredding of the product. According the IEC 62635, in case of manual dismantling, ferrous and non-ferrous metals from WEEE have a recycling rate of 95%. In case of shredding, ferrous metals have a recycling rate of 94% whereas for non-ferrous metals, the recycling rates runs from 91% for the aluminium to 70% for the brass. Plastics also have high recycling rates when manual dismantled is done, whereas in case they undergo to shredding values are 74% for acrylonitrile butadiene styrene (ABS), 83% for polypropylene (PP), and 89% for polystyrene (PS). Other plastics can be recovered at very low rate.

According to expert judgement, metals are easily recovered at rates in line with the standard IEC 62635. Plastics are recycled at 20% rate on average, whereas the recycling rate is zero if plastics contain flame retardants (FR). As far as the electronic components are concerned, the extraction rate of PCB stays in the range 51 – 100%, depending on the specific product, although 100% is hard to be reached.

Considering values reported in the Ecoreport tool (COWI, 2011) and IEC 62635 and, in the light of the expert judgement described above, the recycling rates in Table 13 were considered for the BoP appliances. For metals, the not recycled fraction is assumed to go to landfill. It is assumed that recycled plastics are just ABS, PP and PS whereas the other ones, including those containing FRs are assumed to go 50% to landfill and 50% to energy recovery. An extraction rate of 51% is assumed for PCBs from all WEEE, with the exception of notebook and LCD TV screen for which it reaches 80%. Glass and concrete are basically recycled at the rate indicated by the Ecoreport tool (COWI, 2011), although the remaining part is equally spread among energy recovery and landfill. For other materials (paper, paperboard, bitumen), it is assumed that 50% goes to landfill and 50% goes to energy recovery. In the context of BoP appliances, the reuse is modelled as recycling.

Table 13. Recycling, energy recovery and landfill rates adopted in the BoP

Material/component	**Recycling (%)**	**Energy recovery (%)**	**Landfill (%)**
ABS/PP/PS	80	10	10
Plastic (with flame retardant) and other plastic	0	50	50
Ferrous Metals	95	0	5
Non Ferrous Metals	85	0	15
PCB (extraction rate)	51* for all products 80* (for laptop and TV screen)	24.5** for all products 10 **(for laptop and TV screen)	24.5** 10** (for laptop and TV screen)
Miscellaneous (glass and concrete)	65	6	29
Miscellaneous (bitumen, paper, paperboard, mix)	0	50	50

*amount addressed to treatment for recovery of precious metal (the treatment also generates a flow, mainly plastics, to energy recovery); **Amount not addressed to treatment for recovery of precious metals; *** e.g. glass, concrete, etc.

Other modelling assumptions regarding the end of life are listed below.

— For the dishwashers, in order to model the end of life and to account for the quantity of elements extracted from PCBs, it has been considered an average composition of PCBs according to Ardente and Talens Peirò (2015). The same composition is also considered for the washing machines, refrigerators, tumble dryers, room air conditioners, and electric ovens.

— For the notebook and LCD TV screen, in order to model the end of life and to account for the quantity of elements extracted at end of life from PCBs, it has been considered an average composition of PCBs according to Mathieux and Talens Peirò (2016).

— The average electricity consumption for the first treatment (usually including shredding and separation) is retrieved in Biganzoli et al (2015).

— A consumption of 0.6 kWh/kg is considered for the average recycling of plastics.

— The PCBs fraction sent to reuse/recycling is assumed to be further processed to extract precious and special metals (in particular, copper, nickel, gold, silver and palladium) and other valuable materials. The maximum % of each metal/material recoverable as well as the % that, after the process, is send to landfill, energy recovery and other material recovery is taken from Mathieux et al. (2016). In the study, the shares of metals extracted from the PCBs fraction sent to recycling are included in the "System R", together with the benefits from the related avoided process, whereas the other fractions are included in the "System S" (landfill and energy recovery) or are out of the system (those addressed to other materials recovery). In particular, a metal fraction including several metals (main elements are iron, copper, aluminum, zinc) and a glass reinforced plastic fraction are considered out of the system.

— PCB fraction sent to landfill and energy recovery is made up a mixture of plastics.

4.8 LCI of PV system

This chapter describes the PV system model developed in the context of BoP appliances. As already mentioned in the description of BoP appliances (section 3), the application of the PV system is intended on the building stock and as such a scenario is developed and applied to the inventory of the BoP Housing (Baldassarri et al. 2017).

The PV system model in the BoP appliances is represented by 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 14. Activities that differ from the general structure of the LCI of other appliances (as presented in Table 5) are reported in *italic*.

Table 14. 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 modules and of the mounting structure*
Manufacturing of the product	• Assembly of components *(at 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 use in the BoP housing)*
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 includes Multicrystalline-Silicon (Multi-Si) and Monocrystalline-Silicon (Mono-Si) technologies, which are the most used ones in the residential sector and cover the vast majority of the market: 45.2% and 40.4% of the market respectively (FHI-ISE, 2013). In order to model the panel, the abovementioned market coverage percentages have been upscaled to cover the whole market. Thus, the PV panel in the BoP is composed by Multi-Si for 53% and Mono-Si for 47%.

The model of each PV technology is based on the information reported in the PEF screening report of electricity from photovoltaic panels, version 24th April 2016, hereinafter PV PEF screening report (PEF screening Report, 2016). Table 15 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 modules 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, non-methane volatile organic compounds (NMVOC), and carbon dioxide.

Table 15. Bill of Materials for the two different PV technologies constituting the PV module 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-01		
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 16 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 16. BoM for the electric installation of a 3 kWp PV system.

Materials/components	**Electric installation for a 3 kWp system (kg)**
Brass	2.00E-02
Copper	1.47E+01
Epoxy resin	2.00E-03
Nylon	2.30E-01
Polycarbonate	2.00E-01
Polyethylene (HDPE)	1.44E+01
Polyvinyl chloride	2.13E+00
Steel	8.60E-01
Zinc	4.00E-02

On the contrary, the PV framed and unframed require different input material in the mounting structure (Table 17).

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 modules, 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 module and the one of the mounting structure. The assumptions for transport at the stage of packaging production are the same ones abovementioned for the production of these two components.

Table 17. BoM 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)
Aluminum 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

The manufacturing of the product, intended as manufacturing of the PV system, includes the assembly of the different components (modules, 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 module 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. Only the 15% of the PV modules for both technologies, Mono-Si and Multi-Si are produced in the EU whereas the 79% is imported from China and 6% from Asia and Pacific region (PEF screening report, 2016). The production of electric installation and mounting structure is assumed to occur in EU. 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 18. The share of production occurring in EU is assumed to undergo a local supply chain, according PEFCR rules, thus 1200 km by truck, EURO 4.

Table 18. Share of imported PV module and related sea and road transport distance.

Product	Import (% of apparent consumption)	Sea transport (km per unit)	Road transport (km per unit)
PV module	85%	19680	950

In the use phase it is assumed that the PV system produces 975 kWh of electricity per 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 module 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 peak power corresponding to 1 m^2 of PV module in the BoP is 148.8 Wp, which means an annual production of 145 kWh. It is assumed that 2% of the PV modules are replaced in the maintenance phase.

The PV system is dismantled and disposed of at end of life. The same scenario adopted in the PV PEF screening Report is here considered (PEF screening Report, 2016). In particular, as data on the recycling on Mono-Si and Multi-Si modules 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 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 have been adapted with a 1.5 factor. It is assumed that 90% of the glass is recovered and substitutes 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 parts. Plastics are assumed to go to municipal incineration.

5 Results of baseline's hotspot analysis

The inventory of the BoP appliances (reference flow: consumption and use of household appliances by an average EU citizen in the reference year 2010) has been characterized using ILCD v. 1.08 (EC-JRC, 2011). Table 19 and Table 20 report the results for the whole BoP and for one citizen respectively. Characterised results have been normalized using ILCD EU-27 normalisation factors (NFs) (Benini et al., 2014) (Table 21) and ILCD Global normalization factors (Crenna et al., 2019) (Table 22). Impacts of long-term emissions have been excluded from the calculation. Results in Table 19 and Table 20 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 19. Characterized results for the whole BoP appliances baseline (impacts of household appliances in EU in 2010).

Impact category	Unit	System S+R	System S	System R
Climate change	kg CO_2 eq	1.69E+11	1.71E+11	-1.88E+09
Ozone depletion	kg CFC-11 eq	5.39E+04	5.27E+04	1.20E+03
Human toxicity, non-cancer effects	CTUh	2.57E+04	2.74E+04	-1.69E+03
Human toxicity, cancer effects	CTUh	3.54E+03	3.51E+03	3.04E+01
Particulate matter	kg $PM_{2.5}$ eq	9.36E+07	9.74E+07	-3.81E+06
Ionizing radiation, effects on human health (HH)	kBq U^{235} eq	2.11E+10	2.09E+10	1.60E+08
Photochemical ozone formation	kg NMVOC eq	4.43E+08	4.52E+08	-9.40E+06
Acidification	molc H^+ eq	1.05E+09	1.09E+09	-3.24E+07
Terrestrial eutrophication	molc N eq	1.51E+09	1.54E+09	-2.47E+07
Freshwater eutrophication	kg P eq	3.99E+07	4.19E+07	-1.99E+06
Marine eutrophication	kg N eq	1.90E+08	1.91E+08	-1.29E+06
Freshwater ecotoxicity	CTUe	1.22E+11	1.24E+11	-1.31E+09
Land use	kg C deficit	2.03E+11	1.97E+11	5.97E+09
Water resource depletion	m^3 water eq	1.83E+10	1.83E+10	-1.97E+07
Resource depletion	kg Sb eq	2.19E+07	2.22E+07	-3.24E+05

Table 20. Characterized results for the FU of the BoP appliances baseline (impacts of household appliances used by an average EU citizen in 2010).

Impact category	Unit	System S+R	System S	System R
Climate change	kg CO_2 eq	3.33E+02	3.40E+02	-3.74E+00
Ozone depletion	kg CFC-11 eq	1.07E-04	1.05E-04	2.39E-06
Human toxicity, non-cancer effects	CTUh	5.12E-05	5.46E-05	-3.36E-06
Human toxicity, cancer effects	CTUh	7.04E-06	6.98E-06	6.06E-08
Particulate matter	kg $PM_{2.5}$ eq	1.86E-01	1.94E-01	-7.59E-03
Ionizing radiation, effects on human health (HH)	kBq U^{235} eq	4.20E+01	4.16E+01	3.18E-01
Photochemical ozone formation	kg NMVOC eq	8.81E-01	9.00E-01	-1.87E-02
Acidification	molc H+ eq	2.10E+00	2.16E+00	-6.45E-02
Terrestrial eutrophication	molc N eq	3.01E+00	3.06E+00	-4.92E-02
Freshwater eutrophication	kg P eq	7.94E-02	8.33E-02	-3.96E-03
Marine eutrophication	kg N eq	3.78E-01	3.80E-01	-2.57E-03
Freshwater ecotoxicity	CTUe	2.43E+02	2.46E+02	-2.61E+00
Land use	kg C deficit	4.03E+02	3.91E+02	1.19E+01
Water resource depletion	m^3 water eq	3.64E+01	3.64E+01	-3.93E-02
Resource depletion	kg Sb eq	4.35E-02	4.41E-02	-6.46E-04

Table 21. Normalised results, ILCD EU-27 and ILCD EU-27 NFs water regionalized, BoP appliances baseline

Impact category	System S+R (ILCD EU-27)			System S+R (ILCD EU-27 NFs water regionalised)		
	Value (tot. BoP)	Value (per person)	%	Value (tot. BoP)	Value (per person)	%
Climate change	1.84E+07	3.66E-02	2%	3.63E-02	7.24E-11	3%
Ozone depletion	2.50E+06	4.97E-03	0%	5.00E-03	9.94E-12	0%
Human toxicity, non-cancer effects	4.83E+07	9.61E-02	6%	9.56E-02	1.91E-10	9%
Human toxicity, cancer effects	9.58E+07	1.91E-01	13%	1.88E-01	3.74E-10	17%
Particulate matter	2.46E+07	4.90E-02	3%	4.93E-02	9.81E-11	5%
Ionizing radiation HH	1.87E+07	3.71E-02	2%	3.74E-02	7.44E-11	3%
Photochemical ozone formation	1.39E+07	2.78E-02	2%	2.80E-02	5.58E-11	3%
Acidification	2.22E+07	4.42E-02	3%	4.46E-02	8.89E-11	4%
Terrestrial eutrophication	8.58E+06	1.71E-02	1%	1.73E-02	3.43E-11	2%
Freshwater eutrophication	2.70E+07	5.37E-02	4%	5.38E-02	1.07E-10	5%
Marine eutrophication	1.12E+07	2.24E-02	2%	2.25E-02	4.48E-11	2%
Freshwater ecotoxicity	1.39E+07	2.78E-02	2%	2.74E-02	5.46E-11	3%
Land use	2.71E+06	5.40E-03	0%	5.36E-03	1.07E-11	0%
Water resource depletion	2.25E+08	4.47E-01	30%	4.62E-02	9.20E-11	4%
Resource depletion	2.16E+08	4.31E-01	29%	4.34E-01	8.66E-10	40%
TOTAL	*7.49E+08*	*1.49E+00*	*100%*	*1.09E+00*	*2.17E-09*	*100%*

Table 22. Normalized results, ILCD Global, BoP appliances baseline

Impact category	System S+R		
	Value (total BoP)	Value (per person)	%
Climate change	3.41E-03	4.71E-02	6%
Ozone depletion	1.62E-04	2.23E-03	0%
Human toxicity, non-cancer effects	4.35E-03	6.02E-02	7%
Human toxicity, cancer effects	1.05E-02	1.45E-01	17%
Particulate matter	1.01E-03	1.40E-02	2%
Ionizing radiation HH	2.21E-02	3.06E-01	37%
Photochemical ozone formation	1.58E-03	2.18E-02	3%
Acidification	2.75E-03	3.80E-02	5%
Terrestrial eutrophication	1.24E-03	1.71E-02	2%
Freshwater eutrophication	3.58E-03	4.96E-02	6%
Marine eutrophication	1.41E-03	1.95E-02	2%
Freshwater ecotoxicity	2.12E-03	2.93E-02	3%
Land use	2.29E-04	3.17E-03	0%
Water resource depletion	2.38E-04	3.29E-03	0%
Resource depletion	5.84E-03	8.08E-02	10%
TOTAL	*6.05E-02*	*8.37E-01*	*100%*

The relative contribution of some impact categories (when applying equal weighting) varies quite significantly depending on the set of normalisation references used. When using the ILCD EU-27 normalization factors, the most relevant category is water depletion (30%) followed by the resource depletion and human toxicity, cancer effects (respectively 29% and 13%). When applying the ILCD GLO normalization factors the ionising radiation pops up as the most relevant (37%) followed by human toxicity, cancer (21%) and resource depletion (15%).

The highest variations in impacts arising from the two set of normalisation factors are in water resources depletion (from 30% with ILCD EU-27 to 0.4% with ILCD GLO), in ionising radiation (from 2% with ILCD EU-27 to 37% with ILCD GLO), in human toxicity, cancer (from 13% with ILCD EU-27 to 17% with ILCD GLO) and resources depletion (from 29% with ILCD EU-27 to 10% with ILCD GLO). It has to be underlined that the ILCD EU-27 normalisation factors for water resource depletion is based on average EU value, whereas the characterization factors used for the impact assessment are country-specific. When applying the country-specific normalisation factors (ILCD EU-27 NFs water regionalised) (Table 21), the relevance of water depletion impact category changes from 30% to 4%.

As a sensitivity analysis, the BoP appliances has been analysed with the impact assessment method of the Environmental Footprint (EC-JRC, 2018) (called here "EF 3.0"), where some impact categories (Table 23) considered in ILCD were updated with a selection of recent impact assessment models and factors. The updated list of impact assessment models used in the EF 3.0 method is presented in Table 23. Differences with ILCD are highlighted in green. Results of characterization and normalization with the EF 3.0 method are presented in Table 24 for the whole BoP appliances baseline and in Table 25 for the F.U. of the BoP appliances baseline (impact of an average citizen in one year). Global normalisation factors for the EF 3.0 method have been used (updated from Crenna et al., 2019, Annex 11).

Table 23. Impact categories, models and units of EF 3.0 impact assessment method. Differences with ILCD (EC-JRC, 2011) are highlighted in green

Impact category	**Reference model**	**Unit**
Climate change	IPCC, 2013	kg CO_2 eq
Ozone depletion	WMO, 2014	kg CFC-11 eq
Human toxicity, non-cancer	based on USEtox2.1 model (Fantke et al., 2017), adapted as in Saouter et al. (2018)	CTUh
Human toxicity, cancer	based on USEtox2.1 model (Fantke et al., 2017), adapted as in Saouter et al. (2018)	CTUh
Particulate matter	Fantke et al., 2016	Disease incidence
Ionising radiation	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[6]	kg P eq
Eutrophication, marine	Struijs et al., 2009	kg N eq
Ecotoxicity, freshwater	based on USEtox2.1 model (Fantke et al., 2017), adapted as in Saouter et al. (2018)	CTUe
Land use	Soil quality index based on an updated LANCA model (De Laurentiis et al. 2019) and on the LANCA CF version 2.5 (Horn and Meier, 2018)	Pt
Water use	AWARE 100 (based on UNEP, 2016)	m^3 water eq
Resource use, fossils	Abiotic Depletion Potential (ADP) fossils (van Oers et al., 2002)	MJ
Resource use, minerals and metals	ADP ultimate reserve (van Oers et al., 2002)	kg Sb eq

[6] CF for emissions of P to soil changed from 1 to 0.05 kg P_{eq}/kg

Table 24. Characterized and normalised (with global normalisation factors) results for the whole BoP appliances baseline, calculated with EF 3.0 method, applied to the system S+R

Impact category	Unit	Characterisation	Normalisation (values)	Normalisation (%)
Climate change	kg CO_2 eq	1.75E+11	3.13E-03	5.8%
Ozone depletion	kg CFC-11 eq	4.43E+04	1.20E-04	0.2%
Human toxicity, non-cancer effects	CTUh	3.28E+03	2.07E-03	3.8%
Human toxicity, cancer effects	CTUh	1.09E+02	9.36E-04	1.7%
Particulate matter	Disease incidence	5.03E+03	1.22E-03	2.3%
Ionizing radiation	kBq U235 eq	2.11E+10	7.24E-04	1.3%
Photochemical ozone formation	kg NMVOC eq	4.50E+08	1.61E-03	3.0%
Acidification	molc H+ eq	1.05E+09	2.75E-03	5.1%
Terrestrial eutrophication	molc N eq	1.51E+09	1.24E-03	2.3%
Freshwater eutrophication	kg P eq	3.97E+07	3.58E-03	6.6%
Marine eutrophication	kg N eq	1.90E+08	1.41E-03	2.6%
Freshwater ecotoxicity	CTUe	3.55E+12	1.20E-02	22.1%
Land use	Pt	9.82E+11	1.37E-04	0.3%
Water use	m^3 water eq	7.81E+10	9.90E-04	1.8%
Resource use, fossil	MJ	3.52E+12	7.86E-03	14.4%
Resource use, minerals and metals	kg Sb eq	6.40E+06	1.46E-02	26.8%

Table 25. Characterized and normalized (with global normalization factors) results for the F.U. of the BoP appliances baseline, calculated with EF 3.0 method, applied to the system S+R

Impact category	Unit	Characterisation	Normalisation (values)	Normalisation (%)
Climate change	kg CO_2 eq	3.48E+02	4.29E-02	5.8%
Ozone depletion	kg CFC-11 eq	8.82E-05	1.64E-03	0.2%
Human toxicity, non-cancer effects	CTUh	6.53E-06	2.84E-02	3.8%
Human toxicity, cancer effects	CTUh	2.17E-07	1.28E-02	1.7%
Particulate matter	Disease incidence	1.00E-05	1.68E-02	2.3%
Ionizing radiation	kBq U235 eq	4.20E+01	9.94E-03	1.3%
Photochemical ozone formation	kg NMVOC eq	8.95E-01	2.20E-02	3.0%
Acidification	molc H^+ eq	2.10E+00	3.77E-02	5.1%
Terrestrial eutrophication	molc N eq	3.01E+00	1.70E-02	2.3%
Freshwater eutrophication	kg P eq	7.89E-02	4.91E-02	6.6%
Marine eutrophication	kg N eq	3.78E-01	1.93E-02	2.6%
Freshwater ecotoxicity	CTUe	7.06E+03	1.65E-01	22.1%
Land use	Pt	1.95E+03	1.87E-03	0.3%
Water use	m^3 water eq	1.55E+02	1.36E-02	1.8%
Resource use, fossil	MJ	7.01E+03	1.08E-01	14.4%
Resource use, minerals and metals	kg Sb eq	1.27E-02	2.00E-01	26.8%

5.1 Contribution by life cycle stages

Details on the contribution of life cycle stages to each impact category are provided in Table 26 (system S+R), Figure 5 (system S+R) and Figure 6 (only System S).

Table 26. Contribution of different life cycle stages to the impact categories (based on the characterized inventory results of System S+R before normalisation and weighting).

Climate change		**Human tox, non-cancer effects**		**Particulate matter**	
Life cycle stage	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*
Use phase	79%	Use phase	53%	Use phase	58%
Production of materials/components	19%	Production of materials/components	46%	Production of materials/components	39%
Manufacturing of the product	1%	Manufacturing of the product	0%	Manufacturing of the product	2%
Distribution and retail	0%	Maintenance and repair	0%	Distribution and retail	0%
Maintenance and repair	0%	Distribution and retail	0%	Maintenance and repair	0%
Packaging	0%	Packaging	-1%	Packaging	-1%
End of life	0%	End of life	-4%	End of life	-3%
Ozone depletion		**Human toxicity, cancer effects**		**Ionizing radiation HH**	
Life cycle stage	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*
Production of materials/components	48%	Production of materials/components	49%	Use phase	94%
Use phase	29%	Use phase	48%	Production of materials/components	4%
Maintenance and repair	18%	End of life	2%	End of life	1%
End of life	4%	Packaging	1%	Manufacturing of the product	0%
Packaging	1%	Maintenance and repair	1%	Packaging	0%
Distribution and retail	0%	Manufacturing of the product	0%	Distribution and retail	0%
Manufacturing of the product	0%	Distribution and retail	0%	Maintenance and repair	0%
Photochemical ozone formation		**Acidification**		**Terrestrial eutrophication**	
Life cycle stage	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*
Use phase	72%	Use phase	76%	Use phase	77%
Production of materials/components	25%	Production of materials/components	22%	Production of materials/components	20%
Manufacturing of the product	1%	Manufacturing of the product	1%	Manufacturing of the product	1%
Distribution and retail	1%	Distribution and retail	1%	Distribution and retail	1%
Maintenance and repair	0%	Maintenance and repair	0%	Maintenance and repair	0%
Packaging	0%	Packaging	0%	Packaging	0%
End of life	-1%	End of life	-1%	End of life	-1%
Freshwater eutrophication		**Marine eutrophication**		**Freshwater ecotoxicity**	
Life cycle stage	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*
Use phase	60%	Use phase	85%	Use phase	55%
Production of materials/components	39%	Production of materials/components	13%	Production of materials/components	40%
Manufacturing of the product	0%	Manufacturing of the product	1%	End of life	3%
Maintenance and repair	0%	Distribution and retail	1%	Packaging	1%
Distribution and retail	0%	Maintenance and repair	0%	Distribution and retail	1%
Packaging	-1%	Packaging	0%	Maintenance and repair	0%
End of life	-3%	End of life	-2%	Manufacturing of the product	0%
Land use		**Water resource depletion**		**Resource depletion**	
Life cycle stage	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*	*Life cycle stage*	*Contrib. (%)*
Use phase	78%	Use phase	92%	Use phase	54%
Production of materials/components	13%	Production of materials/components	7%	Production of materials/components	46%
End of life	5%	Manufacturing of the product	1%	Maintenance and repair	0%
Packaging	2%	Maintenance and repair	0%	Packaging	0%
Distribution and retail	1%	Distribution and retail	0%	Manufacturing of the product	0%
Manufacturing of the product	1%	Packaging	0%	Distribution and retail	0%
Maintenance and repair	0%	End of life	0%	End of life	-1%

The use phase is the most impacting stage in all impact categories with the exception of ozone depletion, and human toxicity, cancer effects. The use phase is dominated by the electricity use, which is thus the first responsible for the impacts in this phase. In the categories ozone depletion and human toxicity, cancer effects, the production of raw materials/components is the most relevant activity. This phase is dominated by the production of resources (metals), whose processing requires high energy inputs. In the category ozone depletion the maintenance and repair phase pop up, due to the leakage of refrigerant from the room air conditioners. Finally, benefits from recycling at end of life appear to contribute with low share (from -1% to – 3.9%) for the human toxicity, non-cancer effects, particulate matter, photochemical ozone formation, acidification, terrestrial eutrophication, freshwater eutrophication, marine eutrophication, resource depletion. End of life contribution to freshwater ecotoxicity and human toxicity, cancer effects is positive. This means that the impacts coming from the end of life treatments (including recycling) offset the benefits coming from the recycling of materials, i.e. the avoided production of virgin materials. According to a previous study on electric and electronic waste by Rigamonti et al. (2017), this could be due to the choice of excluding long-term emissions. Most of the avoided emissions thanks to recycling are, in fact, long-term emission. Thus, excluding them could lead to smaller results in terms of benefits, i.e. larger share of impacts at the end of life stage.

Figure 5. Contribution of different life cycle stages to the impact categories (based on the characterized inventory results before normalisation and weighting) (System S+R).

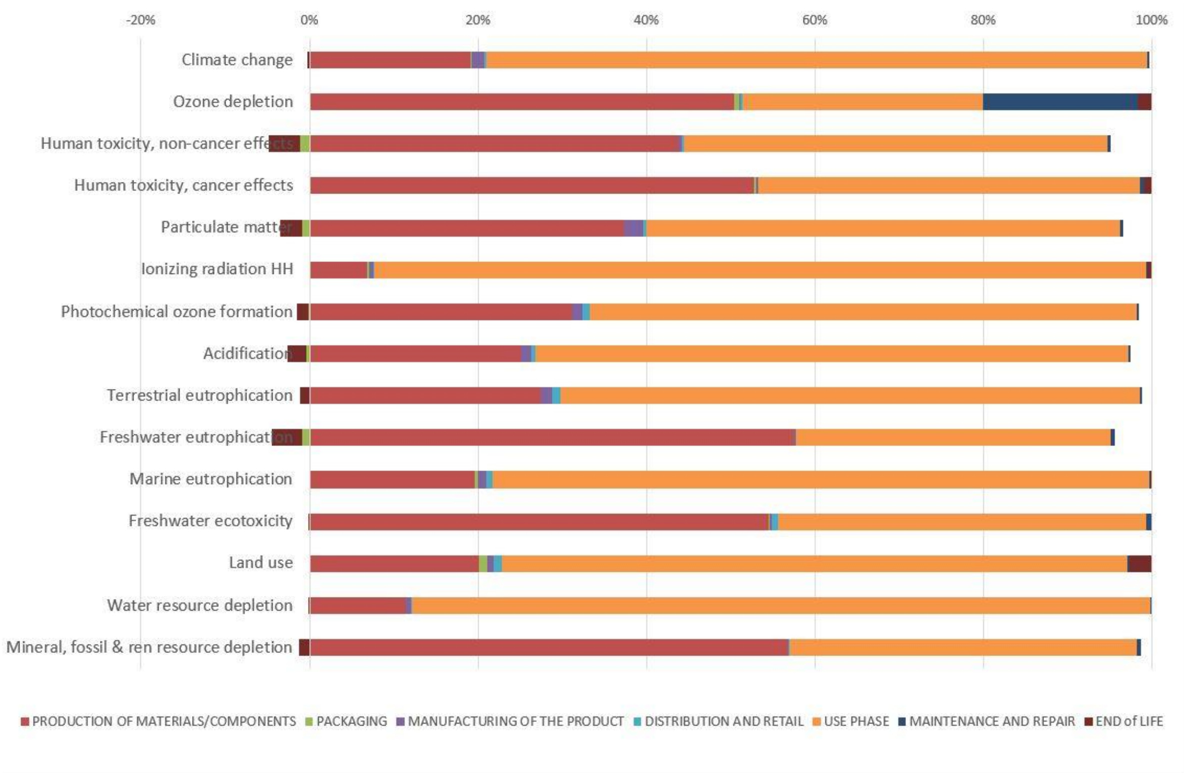
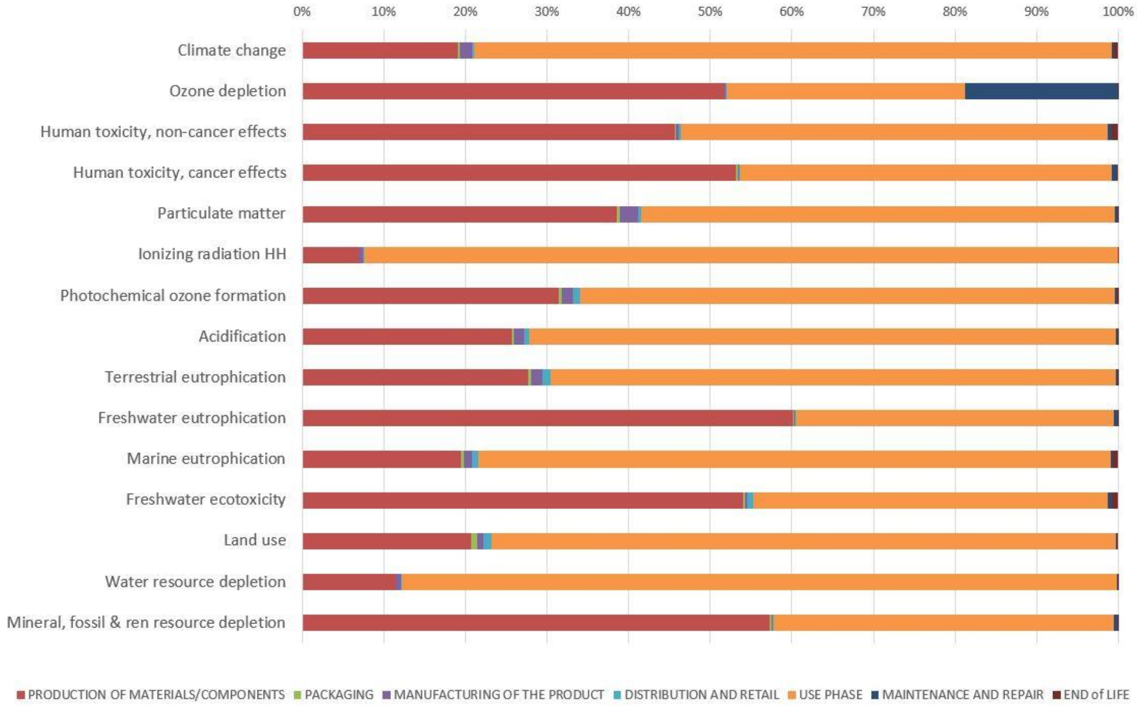


Figure 6. Contribution of different life cycle stages to the impact categories (based on the characterized inventory results before normalisation and weighting) (System S).



5.2 Most relevant elementary flows

Table 27 reports the most relevant elementary flows for each impact category. Within each impact category, for the flow that contributes the most, the main process from which it originates is specified (marked with *).

The electricity production and use play a relevant role for many impact categories. As regards the contribution of water cooling in the electricity production, 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), accounting for water withdrawal, and the model recommended in the EF 3.0 method (AWARE 100, Boulay et al., 2018, based on UNEP, 2016), accounting for water net consumption. 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, RoW".

Table 27. Contribution of elementary flows to each impact category considered in ILCD method

Climate change		**Human tox, non-cancer effects**		**Particulate matter**	
Elementary flow	*Contr. (%)*	*Elementary flow*	*Contr. (%)*	*Elementary flow*	*Contr. (%)*
Carbon dioxide, fossil*	89.70%	Mercury*, to air	33.77%	Particulates, < 2.5*	57.13%
Methane, fossil	6.50%	Zinc, to soil	17.93%	Sulfur dioxide	39.61%
		Zinc, to air	16.85%		
		Lead, to air	8.53%		
		Arsenic, to water	5.60%		
		Arsenic, to air	5.12%		
		Cadmium, to air	4.43%		
		Zinc, to water	4.00%		
*Electricity mix (DE)		*Production of gold used in PCB		*Electricity mix (IN)	
Ozone depletion		**Human toxicity, cancer effects**		**Ionizing radiation HH**	
Elementary flow	*Contr. (%)*	*Elementary flow*	*Contr. (%)*	*Elementary flow*	*Contr. (%)*

Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113*	62.63%	Chromium VI*, to water	40.41%	Carbon-14*	93.29%
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	14.93%	Chromium, to air	29.49%	Radon-222	5.63%
Methane, bromochlorodifluoro-, Halon 1211	6.43%	Chromium VI, to soil	18.48%		
Methane, bromotrifluoro-, Halon 1301	6.31%	Chromium, to water	5.07%		
Methane, dichlorodifluoro-, CFC-12	4.06%	Mercury, to air	2.18%		
Methane, tetrachloro-, CFC-10	2.45%				
*Refrigerant R134a		*Slag from iron and steel production processes		*Treatment of spent nuclear fuel from electricity production	
Photochemical ozone formation		**Acidification**		**Terrestrial eutrophication**	
Elementary flow	*Contr. (%)*	*Elementary flow*	*Contr. (%)*	*Elementary flow*	*Contr. (%)*
Nitrogen oxides*	73.72%	Sulfur dioxide*	74.51%	Nitrogen oxides*	92.00%
Sulfur dioxide	10.98%	Nitrogen oxides	22.92%	Ammonia	8.00%
NMVOC, unspecified origin	8.58%				
1-Propanol	4.11%				
*Electricity mix (EU)		*Electricity mix (EU)		*Electricity mix (EU)	
Freshwater eutrophication		**Marine eutrophication**		**Resource depletion**	
Elementary flow	*Contr. (%)*	*Elementary flow*	*Contr. (%)*	*Elementary flow*	*Contr. (%)*
Phosphate*	98.93%	Nitrogen oxides*	66.86%	Indium*	51.4%
		Nitrate	18.68%	Gold	16.7%
		Ammonium, ion	12.53%	Silver	8.8%
		Nitrogen	1.24%	Nickel	6.4%
		Ammonia	0.43%	Cadmium	6.2%
*Sulfidic tailings from gold and copper mine operations		*Electricity mix (EU)		*Extraction of zinc used for the dishwasher	
Land occupation		**Water resource depletion**		**Freshwater ecotoxicity**	
Elementary flow	*Contr. (%)*	*Elementary flow*	*Contr. (%)*	*Elementary flow*	*Contr. (%)*
Occupation, forest, intensive*	47.94%	Water, cooling, DE*	20.96%	Zinc to water	24.14%
Occupation, dump site	10.31%	Water, cooling, PL	15.97%	Chromium VI to water	11.57%
Occupation, arable	6.94%	Water, cooling, FR	9.01%	Chromium to air	8.64%
Occupation, mineral extraction site	5.96%	Water, cooling, ES	8.40%	Copper to water	5.90%
Occupation, industrial area	5.25%	Water, cooling, UA	6.10%	Antimony to air	5.52%
Occupation, arable, non-irrigated, intensive	4.90%	Water, cooling, SA	6.00%	Chromium VI to soil	5.26%
Occupation, traffic area, road network	3.77%	Water, cooling, BE	5.35%	Vanadium to air	5.12%
Occupation, arable, non-irrigated, extensive	3.66%	Water, coolingCZ	5.18%	Copper to air	4.99%
*Wood chips used to produce electricity		Water, cooling, BG	4.82%	Zinc to air	4.04%
Land transformation		Water, cooling, IT	3.67%	Antimony to water	3.66%
Elementary flow	*Contr. (%)*	Water, river, Europe without Switzerland	1.89%	Copper to soil	2.58%
from forest to mineral extraction site**	40.09%	Water, cooling, CN	1.84%	Zinc to soil	2.37%
from pasture and meadow to industrial area	11.41%	Water, cooling, MT	1.25%	Arsenic to water	1.76%
from unknown to industrial area	6.94%			Barium to water	1.52%
				Chromium to water	1.46%
**Onshore well, oil/gas		*Electricity mix (DE)		*Production of gold used in PCB	

Finally, 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 and the high characterisation factor assigned to zinc and partially to the very high characterisation factor for indium when the ADP reserve based model (van Oers, 2002) is applied. 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. A specific sensitivity analysis on the impact of resource depletion has been run, using the indicators recommended for the EF2 3.0[7]. These indicators assess the impact of minerals and metals and of energy carriers separately. Moreover, for metals and minerals, the "ultimate reserve" approach is adopted, moving from an economic perspective of depletion to a physical only one. The contribution by elementary flows for the indicators that are different between the ILCD method and the EF 3.0 method (namely resources, water, land use, human toxicity cancer and non-cancer, freshwater ecotoxicity, and particulate matter) is reported in Table 28.

Table 28. Most relevant elementary flows for particulate matter, land occupation, land transformation, water scarcity and resource depletion, when applying EF 3.0 method

Resource depletion, minerals and metals		**Resource depletion, energy carriers**		**Particulate matter**	
Elementary flow	*Contr. (%)*	*Elementary flow*	*Contr. (%)*	*Elementary flow*	*Contr. (%)*
Gold*	80.9%	Uranium*	30.4%	Particulates, < 2.5*	65.7%
Cadmium	3.0%	Coal, hard	27.5%	Sulfur dioxide	26.8%
Silver	2.3%	Gas, natural/m3	19.0%	Nitrogen oxides	4.2%
Tellurium	2.6%	Coal, brown	14.7%	Ammonia	3.2%
		Oil, crude	7.4%		
*Gold used for the integrated circuit in printed wiring board		*Electricity mix, DE		*Electricity mix, IN	
Water scarcity (country)		**Land occupation**		**Land transformation**	
Elementary flow	*Contr. (%)*	*Elementary flow*	*Contr. (%)*	*Elementary flow*	*Contr. (%)*
Net water use in Europe*	58.2%	Occupation, forest, intensive*	67.0%	From forest to mineral extraction site*	45.8%
Net water use in RoW	30.5%	Occupation, dump site	5.9%	From pasture and meadows to industrial area	16.0%
		Occupation, industrial area	4.1%	From unknown to indutrial area	7.1%
		Occupation, mineral extraction site	3.6%		
*Tap water use in washing machine		*Wood chips for energy production		*Onshore well for the extraction of oil and gas	
Human toxicity, cancer		**Human toxicity, non cancer**		**Freshwater ecotoxicity**	
Elementary flow	*Contr. (%)*	*Elementary flow*	*Contr. (%)*	*Elementary flow*	*Contr. (%)*
Chromium to air*	34.7%	Mercury to air*	42.5%	Aluminium toi air*	45.8%
Benzo(a)pyrene to air	14.8%	Chlorine to water	14.5%	Aluminium to water	17.8%
Chromium VI to water	12.2%	Lead to air	10.2%	Aluminium to soil	16.4%
Mercury to air	10.8%	Arsenic to air	4.9%	Chloride to water	9.1%
		Carbon monoxide to water	4.9%		
*Production of ferrochromium used in washing machines		* Gold production used in the PCB		*Blasting for the extraction of raw materials used for the PCB	

([7]) Available at: http://eplca.jrc.ec.europa.eu/

5.3 Contribution by product groups

The larger contribution to the overall impacts generated by the BoP appliances comes from the following product groups: dishwasher, washing machine, refrigerator, lighting, and TV screen. Each product group contributes with a different share, depending on the impact category (Figure 7 and Table 29). This contribution is partly due to inherent properties of the life cycle of the products considered and partly to the amount of each product in the BoP (Table 3).

The washing machine has the major contribution on all the impact categories with the exception of ozone depletion, ionizing radiation, and freshwater eutrophication. On human toxicity, non-cancer effect, its contribution is 28%, due to the disposal of detergent used in the washing cycles. Moreover, the disposal of washing machine detergents, together with the production of chromium, steel, and cast aluminium used in the product, are responsible for the high contribution of washing machine on human toxicity, cancer effects (42%) and freshwater ecotoxicity (29%). The second major contributor is the LCD TV screen, due to the gold production used in the PCBs. Lighting, refrigerator, and dishwasher are among the major contributors to some impact categories.

The large contribution of washing machine to particulate matter is mainly due to the electricity used in the production process of cast aluminium used in the product, whereas the high contribution of this product to the photochemical ozone formation (24%), acidification (19%), marine eutrophication (37%), and terrestrial eutrophication (21%) depends on the electricity consumed in the use phase. The contribution of washing machine (25%) and of dishwasher (21%) to resource depletion is due to the extraction of zinc used in the machine components. However, the issue associated to the zinc-indium-lead mine operation, as mentioned in 5.2, needs to be considered.

The contribution of washing machines and dishwashers to marine eutrophication is due to the use of detergents and related wastewater treatment.

For the ozone depletion, the highest impact is coming from the room air conditioner and refrigerators (56% and 15%, respectively) and this is due to the refrigerant and to the leakage by the room air conditioner in the use phase. Refrigerator and lighting are responsible for the major impact on ionizing radiation (respectively 18% and 21%) being the most electricity-consuming product categories in the BoP (considering the number of pieces in the BoP and the electricity consumption by the single piece). For the same reason, they are the most important contributor on water resource depletion (respectively 17% and 20%).

The highest contribution to freshwater eutrophication comes from the LCD TV screen (37%). This arises from the treatment process of sulfidic tailing (from copper and gold mine operation) needed for the production of the PCBs. It is important to highlight that the PCBs used in the LCD TV screens are quite relevant in weight compared to the PCBs used in other products.

The representative products considered have the same contribution to the results of system S+R (Figure 7) and of system S (Figure 8), because the relative difference between S+R and S is similar for all the product groups.

Figure 7. Contribution by product groups at the characterization stage (System S+R)

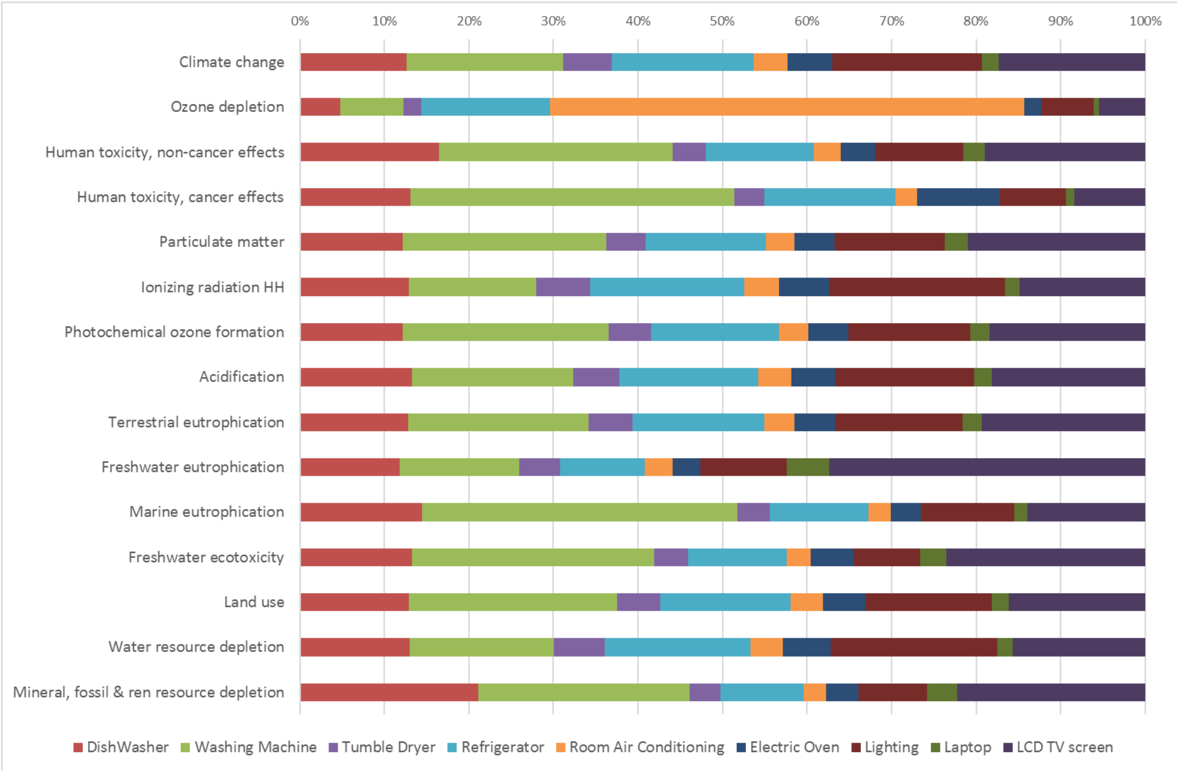


Figure 8. Contribution by product groups at the characterization stage (System S)

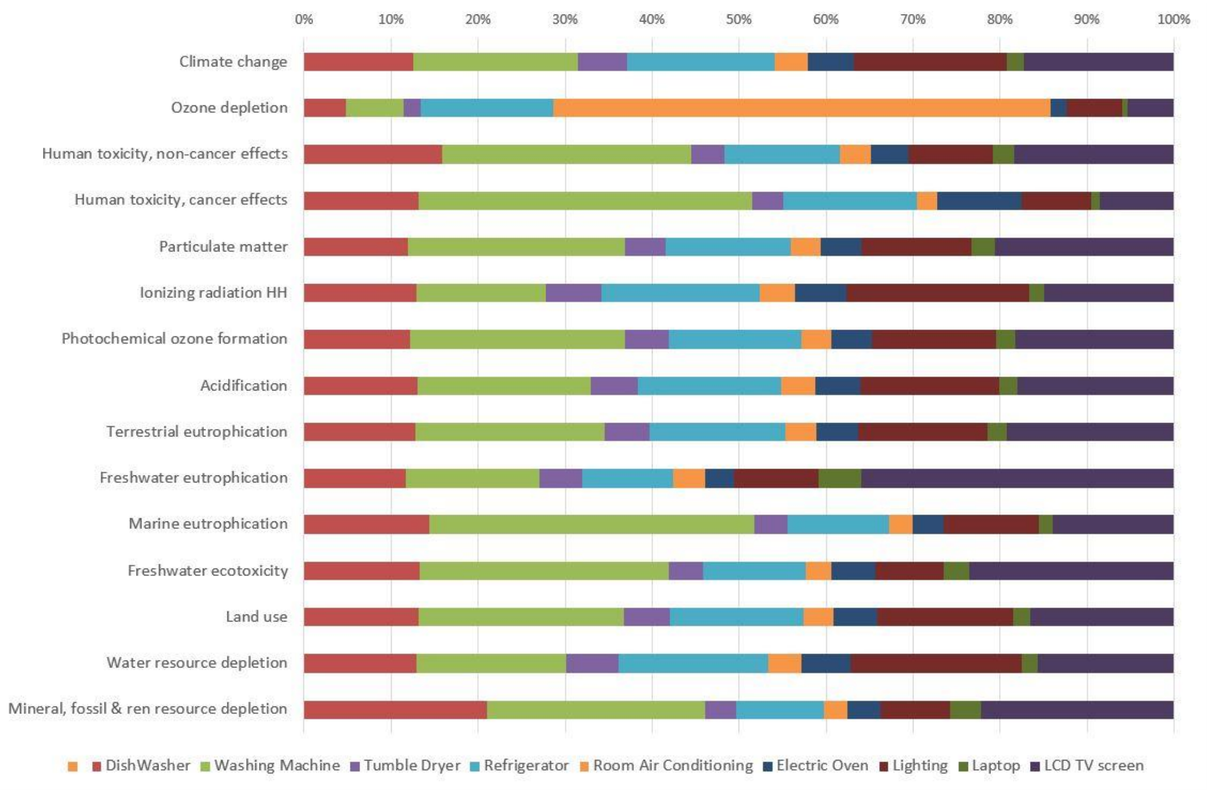


Table 29. Contribution of each sub-product group to the characterized results of the BoP appliances (System S+R). A colour scale is applied, from red (highest contributor) to green (lowest contributor), for each impact category

Impact category	Dishwasher	Washing machine	Tumble dryer	Refrigerator	Room air condit	Electric oven	Lighting	Laptop	LCD TV screen
Climate change	13%	19%	6%	17%	4%	5%	18%	2%	17%
Ozone depletion	5%	8%	2%	15%	56%	2%	6%	1%	5%
Human toxicity, non-cancer effects	16%	28%	4%	13%	3%	4%	10%	3%	19%
Human toxicity, cancer effects	13%	42%	3%	16%	3%	10%	8%	1%	6%
Particulate matter	13%	29%	5%	15%	4%	5%	14%	1%	14%
Ionizing radiation HH	13%	15%	6%	18%	4%	6%	21%	2%	15%
Photochemical ozone formation	12%	24%	5%	15%	3%	5%	14%	2%	18%
Acidification	13%	19%	5%	16%	4%	5%	16%	2%	18%
Terrestrial eutrophication	13%	21%	5%	16%	4%	5%	15%	2%	19%
Freshwater eutrophication	12%	14%	5%	10%	3%	3%	10%	5%	37%
Marine eutrophication	14%	37%	4%	12%	3%	4%	11%	2%	14%
Freshwater ecotoxicity	13%	29%	4%	12%	3%	5%	8%	3%	24%
Land use	13%	25%	5%	15%	4%	5%	15%	2%	16%
Water resource depletion	13%	17%	6%	17%	4%	6%	20%	2%	16%
Mineral, fossil & ren resource depletion	21%	25%	4%	10%	3%	4%	8%	4%	22%

5.4 Relevance of impact categories

Normalisation and weighting phases of LCA are used to express results after characterisation using a common reference impact and then aggregating the results into a single score, giving weights to impact categories. Results after normalisation allows for assessing how important is the contribution of the system under study within that impact category. Results after weighting help to identify what is the relevance of impact categories to the overall impact of the system under study.

The selection of the weighting approach and related weighting factors to be used is highly debated. Weighting sets have been developed in the context of the Environmental Footprint (Sala et al., 2017). In the present study, equal weighting is applied as default option for the assessment of the baseline scenario.

If the results of the BoP appliances per citizen are normalised referring to the average impact per person in EU-27 (Benini et al., 2014) and applying equal weighting, the impact category water resources depletion assumes the highest relevance (30%) compared to the others (Figure 9). The second most important impact category is abiotic resource depletion (ADP) (29%) and the third is human toxicity, cancer effects (13%). However, the overestimation of the contribution of metals to the toxicity-related impact categories is a known problem and further analyses should be performed using the most updated charateristion factors (Saouter et al., 2018).

As already mentioned before, ILCD EU-27 normalisation factors for the water resource depletion is based on average EU values, whereas the characterization factors are country-specific. When applying the country-specific EU normalization factors (ILCD EU-27 NFs) the relevance of the water resource depletion drops to 4%.

Figure 9. Results of normalization EU-27 and equal weighting of impact categories for the BoP household appliances

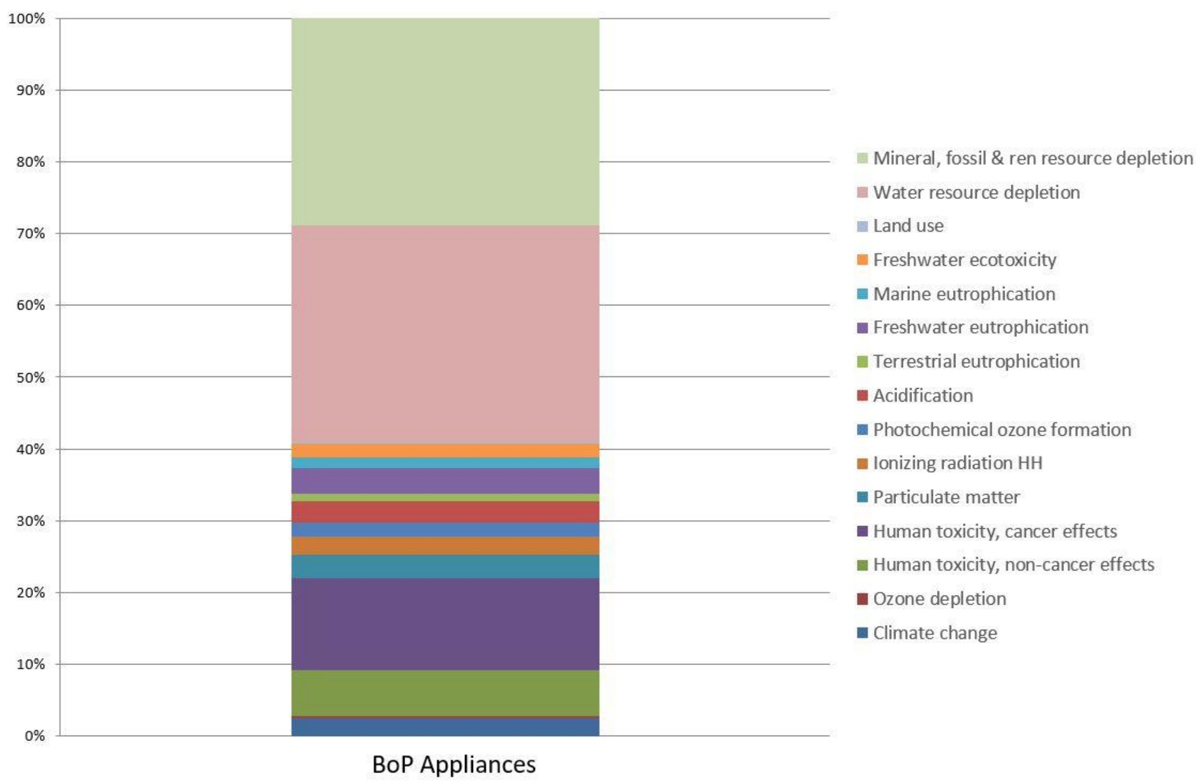


Table 30. Results of normalisation with EU-27 references and equal weighting of impact categories for the main product groups of the BoP appliances. A colour scale is applied for each column, from red (highest contribution) to green (lowest contribution).

Impact category	Dishwasher	Washing machine	Tumble dryer	Refrigerator	Room air condit	Electric oven	Lighting	Laptop	LCD TV screen
Climate change	4.61E-03	6.80E-03	2.08E-03	6.16E-03	1.45E-03	1.95E-03	6.47E-03	7.27E-04	6.35E-03
Ozone depletion	2.37E-04	3.75E-04	1.03E-04	7.57E-04	2.79E-03	9.84E-05	3.08E-04	3.31E-05	2.71E-04
Human toxicity, non-cancer effects	1.58E-02	2.66E-02	3.76E-03	1.23E-02	2.99E-03	3.97E-03	1.00E-02	2.45E-03	1.82E-02
Human toxicity, cancer effects	2.50E-02	7.30E-02	6.75E-03	2.96E-02	4.76E-03	1.86E-02	1.50E-02	1.93E-03	1.60E-02
Particulate matter	5.97E-03	1.18E-02	2.30E-03	6.95E-03	1.66E-03	2.34E-03	6.37E-03	1.34E-03	1.03E-02
Ionizing radiation HH	4.78E-03	5.61E-03	2.36E-03	6.77E-03	1.52E-03	2.21E-03	7.74E-03	6.22E-04	5.52E-03
Photochemical ozone formation	3.39E-03	6.75E-03	1.39E-03	4.21E-03	9.66E-04	1.30E-03	4.01E-03	6.45E-04	5.10E-03
Acidification	5.86E-03	8.46E-03	2.42E-03	7.26E-03	1.73E-03	2.29E-03	7.26E-03	9.57E-04	8.01E-03
Terrestrial eutrophication	2.19E-03	3.65E-03	8.86E-04	2.65E-03	6.12E-04	8.32E-04	2.57E-03	3.91E-04	3.30E-03
Freshwater eutrophication	6.33E-03	7.58E-03	2.63E-03	5.36E-03	1.79E-03	1.76E-03	5.48E-03	2.69E-03	2.00E-02
Marine eutrophication	3.23E-03	8.35E-03	8.50E-04	2.61E-03	5.89E-04	8.01E-04	2.46E-03	3.64E-04	3.11E-03
Freshwater ecotoxicity	3.69E-03	7.95E-03	1.09E-03	3.26E-03	7.75E-04	1.41E-03	2.19E-03	8.43E-04	6.53E-03
Land use	6.98E-04	1.33E-03	2.77E-04	8.34E-04	2.06E-04	2.73E-04	8.07E-04	1.07E-04	8.72E-04
Water resource depletion	5.80E-02	7.64E-02	2.71E-02	7.70E-02	1.72E-02	2.52E-02	8.80E-02	8.02E-03	7.02E-02
Mineral, fossil & ren resource depletion	9.11E-02	1.07E-01	1.57E-02	4.26E-02	1.14E-02	1.63E-02	3.50E-02	1.55E-02	9.57E-02

Table 31. Results of normalization with global references and equal weighting of impact categories for the main product groups of the BoP appliances. A colour scale is applied for each column, from red (highest contribution) to green (lowest contribution).

Impact category	Dishwasher	Washing machine	Tumble dryer	Refrigerator	Room air condit	Electric oven	Lighting	Laptop	LCD TV screen
Climate change	8.68E-13	1.28E-12	3.92E-13	1.16E-12	2.73E-13	3.67E-13	1.22E-12	1.37E-13	1.20E-12
Ozone depletion	3.17E-14	5.02E-14	1.38E-14	1.01E-13	3.74E-13	1.32E-14	4.13E-14	4.44E-15	3.63E-14
Human toxicity, non-cancer effects	2.57E-12	4.32E-12	6.12E-13	2.00E-12	4.87E-13	6.46E-13	1.63E-12	3.99E-13	2.96E-12
Human toxicity, cancer effects	3.48E-12	1.01E-11	9.38E-13	4.12E-12	6.61E-13	2.59E-12	2.08E-12	2.68E-13	2.22E-12
Particulate matter	2.13E-13	4.20E-13	8.21E-14	2.48E-13	5.91E-14	8.34E-14	2.27E-13	4.78E-14	3.66E-13
Ionizing radiation HH	2.65E-12	3.11E-12	1.30E-12	3.75E-12	8.42E-13	1.22E-12	4.29E-12	3.44E-13	3.06E-12
Photochemical ozone formation	3.84E-13	7.66E-13	1.57E-13	4.78E-13	1.10E-13	1.47E-13	4.54E-13	7.31E-14	5.78E-13
Acidification	7.25E-13	1.05E-12	2.99E-13	8.98E-13	2.14E-13	2.84E-13	8.98E-13	1.18E-13	9.91E-13
Terrestrial eutrophication	3.16E-13	5.27E-13	1.28E-13	3.83E-13	8.84E-14	1.20E-13	3.71E-13	5.64E-14	4.76E-13
Freshwater eutrophication	5.32E-13	6.37E-13	2.21E-13	4.51E-13	1.50E-13	1.48E-13	4.60E-13	2.26E-13	1.69E-12
Marine eutrophication	2.80E-13	7.24E-13	7.37E-14	2.26E-13	5.10E-14	6.94E-14	2.13E-13	3.15E-14	2.69E-13
Freshwater ecotoxicity	3.97E-13	8.56E-13	1.18E-13	3.51E-13	8.35E-14	1.52E-13	2.36E-13	9.08E-14	7.03E-13
Land use	5.21E-14	9.90E-14	2.07E-14	6.22E-14	1.54E-14	2.03E-14	6.02E-14	8.00E-15	6.51E-14
Water resource depletion	6.15E-14	8.09E-14	2.87E-14	8.16E-14	1.83E-14	2.67E-14	9.33E-14	8.50E-15	7.44E-14
Mineral, fossil & ren resource depletion	2.49E-12	2.93E-12	4.30E-13	1.16E-12	3.11E-13	4.45E-13	9.58E-13	4.23E-13	2.61E-12

Figure 10. Relevance of impact categories (according to normalisation EU-27 and equal weighting) in the main product groups of the BoP appliances

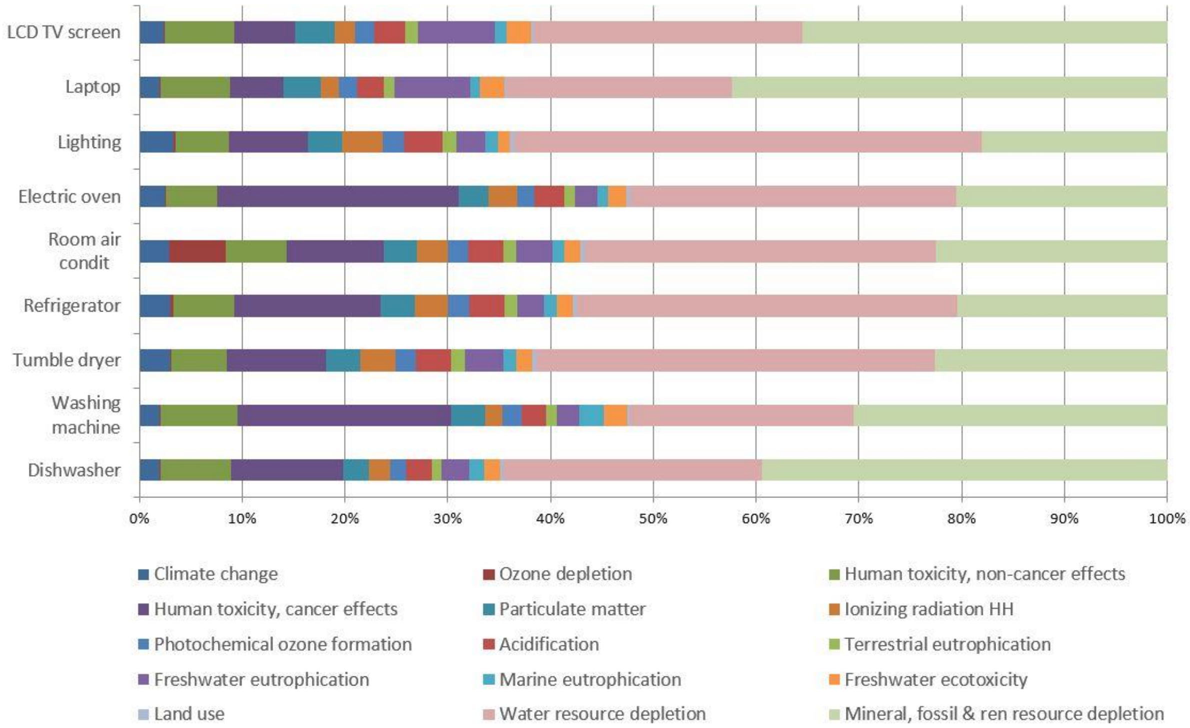
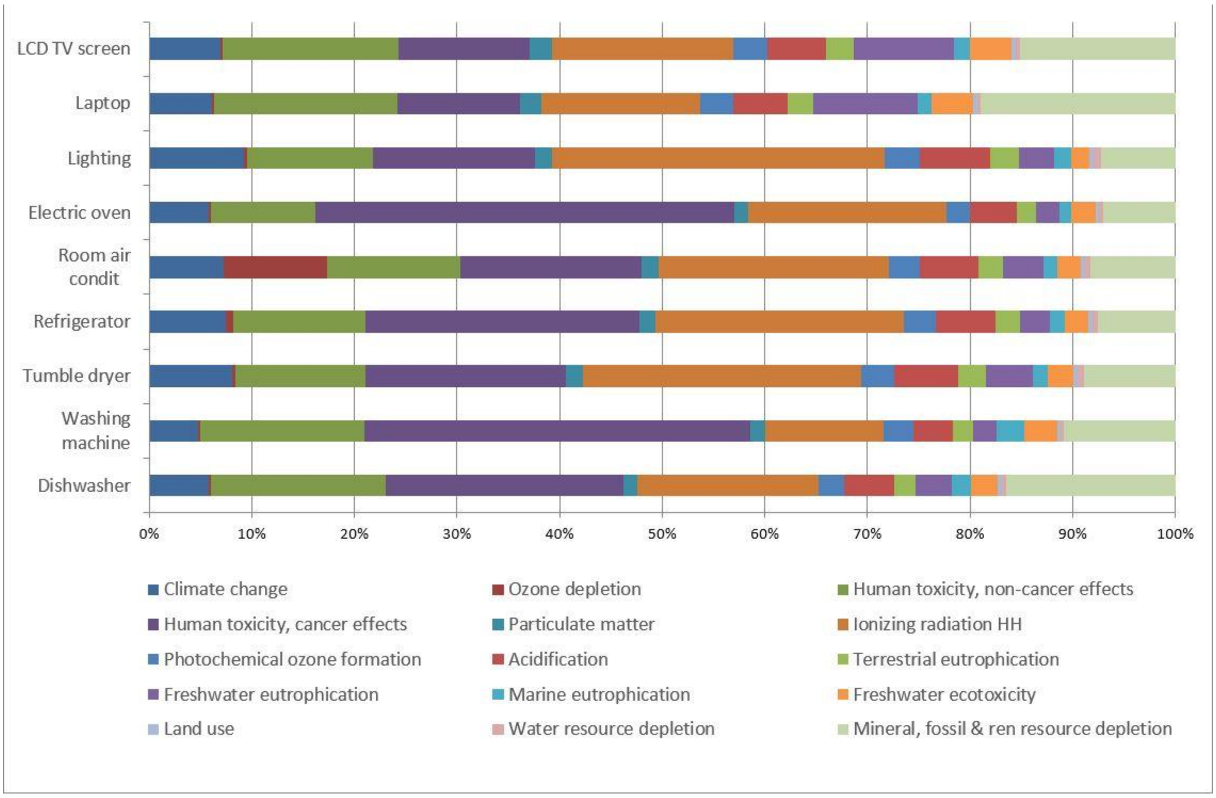


Figure 11. Relevance of impact categories (according to global normalisation and equal weighting) in the main product groups of the BoP appliances



5.5 Hotspot analysis of PV system

The inventory of the representative product for the PV system (reference flow: 1 m^2 of a 3 kWp PV system) has been characterized using ILCD v. 1.08 (EC-JRC, 2011) (Table 32) and normalised using ILCD EU-27 normalisation factors (Benini et al., 2014) (Table 33) and ILCD Global normalisation factors (Crenna et al., 2019) (Table 34). Impacts of long-term emissions have been excluded in the calculation.

Results in Table 32 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 32. Characterised results for the PV system (1m^2 of a 3kWp PV system)

Impact category	Unit	System S+R	System S	System R
Climate change	kg CO_2 eq	4.87E+02	5.52E+02	6.50E+01
Ozone depletion	kg CFC-11 eq	1.29E-04	9.80E-05	-3.12E-05
Human toxicity, non-cancer effects	CTUh	8.15E-05	1.06E-04	2.49E-05
Human toxicity, cancer effects	CTUh	7.85E-06	9.35E-06	1.50E-06
Particulate matter	kg $PM_{2.5}$ eq	3.74E-01	4.82E-01	1.07E-01
Ionizing radiation HH	kBq U^{235} eq	3.24E+01	2.90E+01	-3.35E+00
Photochemical ozone formation	kg NMVOC eq	2.46E+00	2.63E+00	1.68E-01
Acidification	molc H+ eq	3.15E+00	3.82E+00	6.70E-01
Terrestrial eutrophication	molc N eq	8.01E+00	8.63E+00	6.27E-01
Freshwater eutrophication	kg P eq	3.63E-02	5.86E-02	2.22E-02
Marine eutrophication	kg N eq	7.78E-01	8.26E-01	4.78E-02
Freshwater ecotoxicity	CTUe	7.23E+02	7.51E+02	2.79E+01
Land use	kg C deficit	1.20E+03	1.03E+03	-1.73E+02
Water resource depletion	m^3 water eq	3.67E+01	4.01E+01	3.42E+00
Resource depletion	kg Sb eq	1.17E-01	1.19E-01	1.90E-03

Table 33. Normalized results, ILCD EU-27, PV system (1m^2 of a 3kWp PV system)

Impact category	System S+R	
	Normalisation (values)	**Normalisation (%)**
Climate change	1.06E-10	2%
Ozone depletion	1.20E-11	0%
Human toxicity, non-cancer effects	3.03E-10	6%
Human toxicity, cancer effects	4.18E-10	8%
Particulate matter	1.97E-10	4%
Ionizing radiation HH	5.74E-11	1%
Photochemical ozone formation	1.56E-10	3%
Acidification	1.33E-10	3%
Terrestrial eutrophication	9.14E-11	2%
Freshwater eutrophication	4.91E-11	1%
Marine eutrophication	9.22E-11	2%
Freshwater ecotoxicity	1.62E-10	3%
Land use	3.17E-11	1%
Water resource depletion	9.03E-10	18%
Resource depletion	2.32E-09	46%

The relative relevance of some impact categories varies quite significantly depending on the set of normalisation references used. When using the ILCD EU-27 normalisation factors the most relevant impact category is resource depletion (46%) followed by water depletion (18%) and human toxicity, cancer effects (8%).

Table 34. Normalized results, ILCD Global, PV system (1m^2 of a 3kWp PV system)

Impact category	System S+R	
	Normalisation (values)	Normalisation (%)
Climate change	9.83E-12	6%
Ozone depletion	3.87E-13	0%
Human toxicity, non-cancer effects	1.38E-11	8%
Human toxicity, cancer effects	2.33E-11	14%
Particulate matter	4.04E-12	2%
Ionizing radiation HH	3.39E-11	21%
Photochemical ozone formation	8.77E-12	5%
Acidification	8.22E-12	5%
Terrestrial eutrophication	6.57E-12	4%
Freshwater eutrophication	3.27E-12	2%
Marine eutrophication	5.78E-12	4%
Freshwater ecotoxicity	1.25E-11	8%
Land use	1.36E-12	1%
Water resource depletion	4.78E-13	0%
Resource depletion	3.12E-11	19%

The considerable relevance of resource depletion is due to the mineral and metals resources used in the production of the appliances as well as to the use of fossil resources for the production of energy primalry utilised in the use phase. When applying the ILCD Global normalisation factors, the contribution is more spread across impact categories. Ionising radiation becomes the most relevant impacts (21%), followed by resource depletion (19%) and human toxicity cancer effects (14%). The considerable share of impacts associated with ionising radiation is justified by the fact that, at the global scale, a considerable share of the electricity from nuclear is produced in the EU. As a sensitivity analysis, the PV system has been analysed using the EF 3.0 impact assessment method. Results are presented in Table 35.

Table 35. Results of characterization and normalization (using global normalization factors) of the inventory of PV system with EF 3.0 method, applied to the system S+R

Impact category	Unit	Characterisation	Normalisation (values)	Normalisation (%)
Climate change	kg CO_2 eq	5.00E+02	8.96E-12	6.4%
Ozone depletion	kg CFC-11 eq	1.22E-04	3.29E-13	0.2%
Human toxicity, non-cancer effects	CTUh	1.13E-05	7.14E-12	5.1%
Human toxicity, cancer effects	CTUh	3.39E-07	2.91E-12	2.1%
Particulate matter	Disease incidence	3.27E-05	7.97E-12	5.7%
Ionizing radiation	kBq U235 eq	3.24E+01	1.11E-12	0.8%
Photochemical ozone formation	kg NMVOC eq	2.49E+00	8.89E-12	6.4%
Acidification	molc H^+ eq	3.15E+00	8.22E-12	5.9%
Terrestrial eutrophication	molc N eq	8.01E+00	6.57E-12	4.7%
Freshwater eutrophication	kg P eq	3.61E-02	3.26E-12	2.3%
Marine eutrophication	kg N eq	7.78E-01	5.78E-12	4.1%
Freshwater ecotoxicity	CTUe	7.82E+03	2.66E-11	19.1%
Land use	Pt	3.43E+03	4.77E-13	0.3%
Water use	m^3 water eq	5.48E+02	6.95E-12	5.0%
Resource use, fossil	MJ	8.21E+03	1.83E-11	13.1%
Resource use, minerals and metals	kg Sb eq	1.14E-02	2.60E-11	18.6%

5.5.1 Contribution by life cycle stages of the PV system

Details on the contribution of life cycle stages to each impact category are provided in Table 36 (system S+R), Figure 12 (system S+R) and Figure 13 (only System S).

Table 36. Contribution of different life cycle stages of the PV system to the impact categories (based on the characterized inventory results of System S+R before normalization and weighting).

Climate change	
Life cycle stage	*Contrib. (%)*
PV system manufacture	61.4%
PV modules	48.9%
Distribution & retail	1.1%
Maintenance & repair	0.9%
Packaging	0.2%
End of life	-12.4%

Human tox, non-cancer effects	
Life cycle stage	*Contrib. (%)*
PV modules	88.4%
PV system manufacture	39.8%
Maintenance & repair	1.1%
Distribution & retail	0.8%
Packaging	0.2%
End of life	-30.3%

Particulate matter	
Life cycle stage	*Contrib. (%)*
PV modules	85.4%
PV system manufacture	40.3%
Distribution & retail	1.3%
Maintenance & repair	1.2%
Packaging	-0.4%
End of life	-27.8%

Ozone depletion	
Life cycle stage	*Contrib. (%)*
PV system manufacture	40.5%
PV modules	33.5%
End of life	24.5%
Distribution & retail	0.7%
Maintenance & repair	0.7%
Packaging	0.0%

Human toxicity, cancer effects	
Life cycle stage	*Contrib. (%)*
PV modules	82.5%
PV system manufacture	33.8%
Maintenance & repair	0.7%
Distribution & retail	0.4%
Packaging	0.1%
End of life	-17.6%

Ionizing radiation HH	
Life cycle stage	*Contrib. (%)*
PV modules	46.1%
PV system manufacture	40.4%
End of life	11.6%
Distribution & retail	1.1%
Maintenance & repair	0.7%
Packaging	0.1%

Photochemical ozone formation	
Life cycle stage	*Contrib. (%)*
PV modules	60.1%
PV system manufacture	43.2%
Distribution & retail	2.4%
Maintenance & repair	0.7%
Packaging	0.0%
End of life	-6.5%

Acidification	
Life cycle stage	*Contrib. (%)*
PV system manufacture	68.3%
PV modules	48.6%
Distribution & retail	2.7%
Maintenance & repair	0.9%
Packaging	0.1%
End of life	-20.6%

Terrestrial eutrophication	
Life cycle stage	*Contrib. (%)*
PV modules	66.0%
PV system manufacture	38.1%
Distribution & retail	2.7%
Maintenance & repair	0.6%
Packaging	0.0%
End of life	-7.4%

Freshwater eutrophication	
Life cycle stage	*Contrib. (%)*
PV system manufacture	132.8%
PV modules	25.7%
Maintenance & repair	1.4%
Distribution & retail	0.2%
Packaging	0.1%
End of life	-60.2%

Marine eutrophication	
Life cycle stage	*Contrib. (%)*
PV modules	62.6%
PV system manufacture	39.8%
Distribution & retail	2.5%
Maintenance & repair	0.6%
Packaging	0.1%
End of life	-5.7%

Freshwater ecotoxicity	
Life cycle stage	*Contrib. (%)*
PV system manufacture	54.1%
PV modules	47.2%
Distribution & retail	1.5%
Maintenance & repair	0.4%
Packaging	0.1%
End of life	-3.4%

Land use	
Life cycle stage	*Contrib. (%)*
PV system manufacture	55.0%
PV modules	27.9%
End of life	15.3%
Distribution & retail	1.5%
Maintenance & repair	0.5%
Packaging	-0.1%

Water resource depletion	
Life cycle stage	*Contrib. (%)*
PV system manufacture	85.2%
PV modules	21.4%
Maintenance & repair	1.5%
Distribution & retail	0.2%
Packaging	0.0%
End of life	-8.3%

Resource depletion	
Life cycle stage	*Contrib. (%)*
PV system manufacture	68.8%
PV modules	31.1%
Maintenance & repair	1.2%
Packaging	0.4%
Distribution & retail	0.1%
End of life	-1.7%

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%.

The production of PV modules and the manufacture of the PV system are the most contributing phases for all the impact categories considered in the ILCD method. Regarding components manufacture, their relevance is due to the production of the silicon and the extraction and processing of metals used in the modules. The impact coming from the manufacture of the PV system is generated mainly by the transport of modules to the manufacturing site. In fact, the modules are produced mainly outside Europe (in China, Asia and America) and the system is assembled in Europe. Therefore, the electricity used for the assembly is far less contributing than the transoceanic transport.

Distribution and retail and maintenance and repair have generally a limited contribution to the overall impact of the system. The impact of maintenance becomes more relevant for freshwater eutrophication, water depletion, and resource depletion. However, the contribution of this phase remains below 1.5%. The end of life of the PV system has a different relevance depending on the impact category considered. For most of the impact categories, the recycling of materials at the end of life of the PV system generates benefits. The only exceptions are the effect on land use, due to the occupation of areas for the treatment plants, the effect on ozone depletion, due to the use of chlorodifluoromethane in the treatment of aluminium scraps after dismantling, and the effect on ionising radiation, due to the treatment of radioactive waste coming from the production of the heavy fuel oil, again used in the treatment of the aluminium scraps (see Figure 12). When only the system S is taken into account, i.e. when the benefits from recycling are not accounted for, the end of life becomes a positive contributor for all the impact categories considered. However, the contribution is always very small, as shown in Figure 13.

Figure 12. Contribution of different life cycle stages of PV system to the impact categories (based on the characterized inventory results before normalization and weighting) (System S+R).

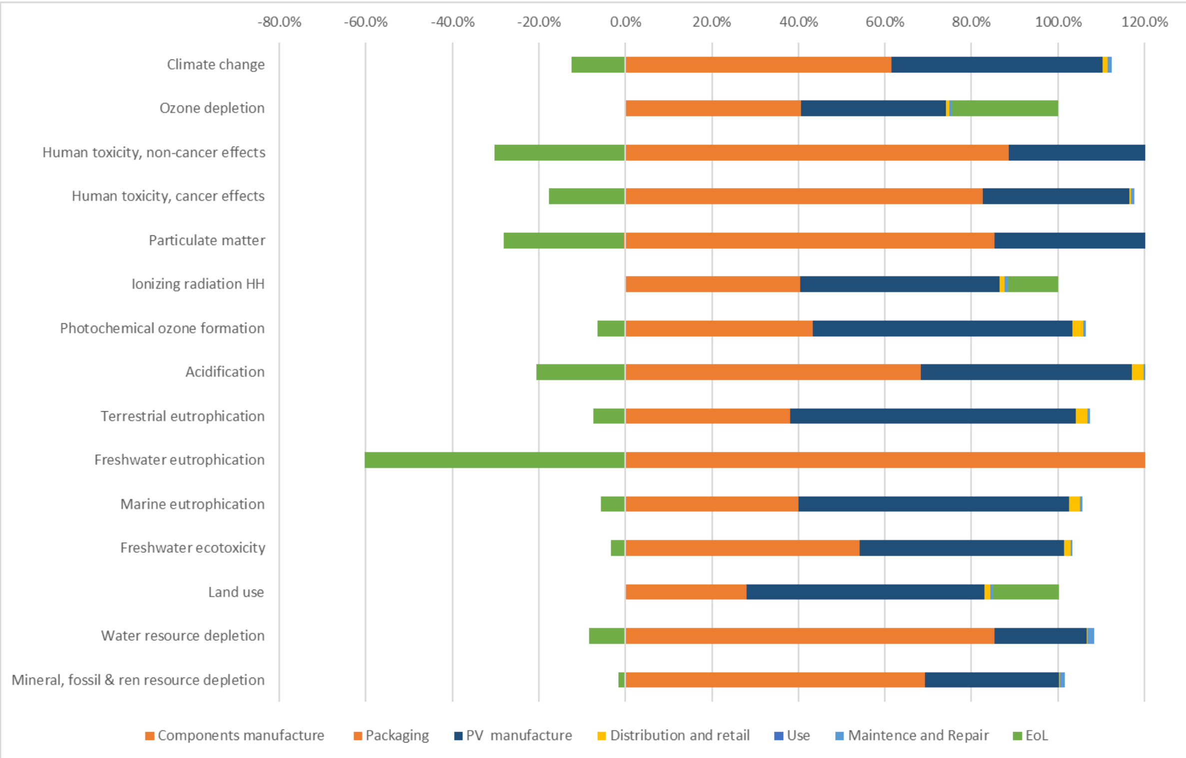
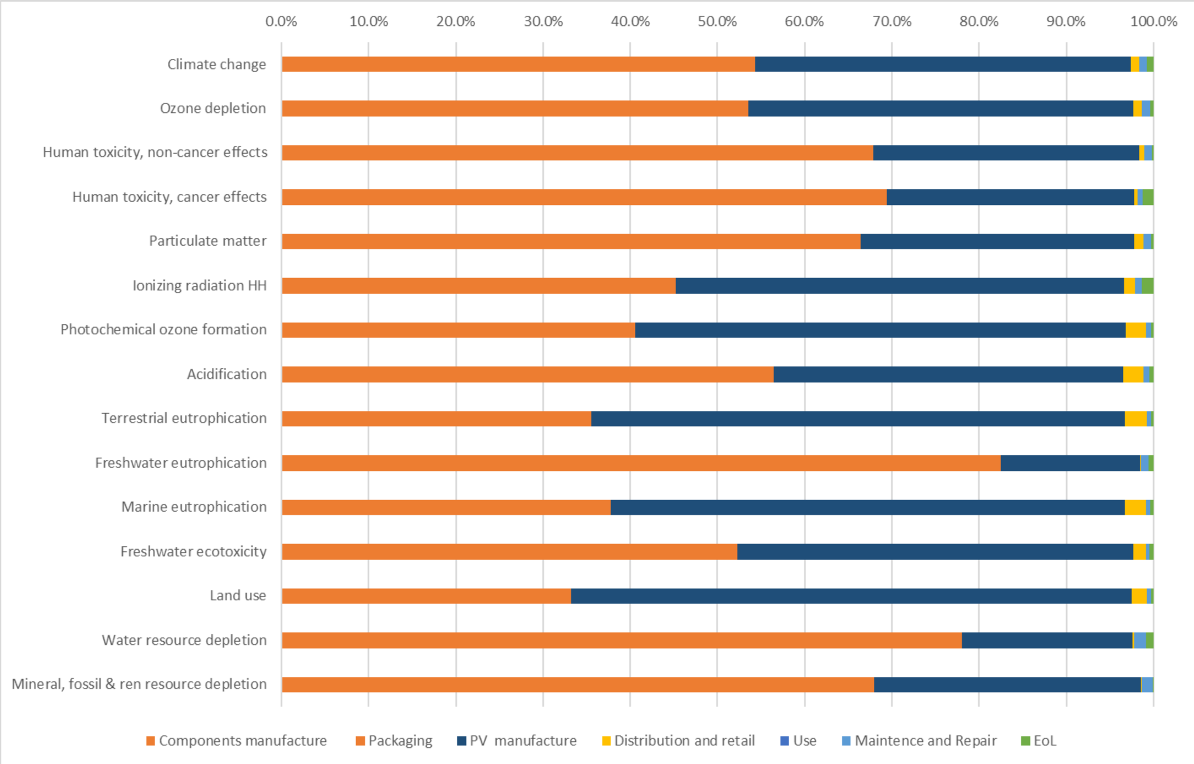


Figure 13. Contribution of different life cycle stages of PV system to the impact categories (based on the characterized inventory results before normalization and weighting) (System S).



5.5.2 Most relevant elementary flows of the PV system

Table 37 reports the most relevant elementary flows for each impact category. Within each impact category, for the flow that contributes the most, the main process from which it originates is specified (marked with *).

Emissions coming from the transport of the component of the PV system (i.e. the modules and the structure) to the installation site are the most relevant contributor for almost half of the impact categories considered. As explained before, the production of module is assumed to happen outside the EU, so the transport from the production site to the installation site covers a transoceanic distance. Brake wear emissions (and particularly the emission of antimony to air), contribute to freshwater ecotoxicity.

Petroleum production contributes as well to some impact categories, namely to ozone depletion (due to the emission of Halon 1301) and to ionising radiation (due to the emission of Carbon-14). The impact on particulate matter is mostly due to the emission of PM < 2.5 from the electricity mix of India (again, because the production of the modules happens partly in Asia). The water used for cooling in the German electricity mix (part of the EU mix) contributes to water depletion for around 30%. As mentioned before, the inclusion of cooling as a contributor to water depletion is currently debated. If the impact of cooling is excluded (not consistently with the original method) when assessing the PV system with ILCD, the most contributing elementary flow is "Water, river, RoW".

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 note that the ILCD method includes the assessment of minerals and metals and of energy carriers under the same indicator. A specific sensitivity analysis on the impact of resource depletion has been run, using the indicators recommended for the PEF[8], i.e. EF 3.0. These

(8) Available at: http://eplca.jrc.ec.europa.eu/

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 EF 3.0 method (namely resources, water, land use, toxicity-related, and particulate matter) is reported in Table 38.

Table 37. Contribution of elementary flows to each impact category considered in ILCD method

Climate change		**Human tox, non-cancer effects**		**Particulate matter**	
Elementary flow	*Contrib.*	*Elementary flow*	*Contrib.*	*Elementary flow*	*Contrib.*
Carbon dioxide, fossil*	92.4%	Silver to air*	27.4%	Particulates, < 2.5*	73.7%
		Zinc to air	22.2%	Sulfur dioxide	22.3%
		Lead to air	16.7%		
		Mercury to air	16.3%		
*Transport of PV modules		*Production of PV modules		*Electricity mix, IN	
Ozone depletion		**Human toxicity, cancer effects**		**Ionizing radiation HH**	
Elementary flow	*Contrib.*	*Elementary flow*	*Contrib.*	*Elementary flow*	*Contrib.*
Methane, bromotrifluoro-, Halon 1301*	35.3%	Chromium VI to water*	52.0%	Carbon-14*	96.0%
Methane, chlorodifluoro-, HCFC-22	24.1%	Chromium to water	26.9%		
Methane, dichlorodifluoro-, CFC-12	18.0%	Chromium to air	13.8%		
Methane, tetrachloro-, CFC-10	12.1%				
*Petroleum production		*Production of raw materials		*Petroleum production	
Photochemical ozone formation		**Acidification**		**Terrestrial eutrophication**	
Elementary flow	*Contrib.*	*Elementary flow*	*Contrib.*	*Elementary flow*	*Contrib.*
Nitrogen oxides*	73.6%	Sulfur dioxide *	55.4%	Nitrogen oxides*	96.3%
NMVOC	20.1%	Nitrogen oxides	42.5%		
*Transport of PV modules		*Production of PV modules		*Transport of PV modules	
Freshwater eutrophication		**Marine eutrophication**		**Resource depletion**	
Elementary flow	*Contrib*	*Elementary flow*	*Contrib.*	*Elementary flow*	*Contrib.*
Phosphate to water*	98.2%	Nitrogen oxides*	90.4%	Indium*	60.8%
				Silver	13%
				Cadmium	7.3%
*Treatment of tailings from mining		*Transport of PV modules		*Zinc-lead extraction	
Land occupation		**Water resource depletion**		**Freshwater ecotoxicity**	
Elementary flow	*Contrib*	*Elementary flow*	*Contrib.*	*Elementary flow*	*Contrib.*
Occupation, traffic area, road network*	33.4%	Water, cooling, DE*	33.0%	Antimony to air*	25.2%
Occupation, forest, intensive	30.6%	Water, cooling, SA	25.4%	Antimony to water	23.3%
Occupation, traffic area, rail/road embankment	7.5%	Water, cooling, RoW	10.4%	Silver to air	9.8%
Occupation, industrial area	7.2%			Zinc to water	8.5%
Occupation, dump site	3.8%			Chromium VI to water	5.6%
Occupation, mineral extraction site	3.5%			Copper to air	4.9%
*Transport of PV modules					
Land transformation					
Elementary flow	*Contrib.*				
From forest to mineral extraction site*	64.0%				
*Onshore well, oil/gas production		*Electricity mix, DE		*Brake wear emissions (lorry)	

Table 38. Most relevant elementary flows for resource depletion, water scarcity, land use and particulate matter, when applying EF 3.0 method

Resource use, minerals and metals		**Resource use, fossils**		**Particulate matter**	
Elementary flow	*Contrib.*	*Elementary flow*	*Contrib.*	*Elementary flow*	*Contrib.*
Gold*	21.9%	Oil, crude*	42.0%	Particulates, < 2.5*	76.3%
Silver	18.6%	Coal, hard	21.4%	Sulfur dioxide	15.4%
Tellurium	15.0%	Gas, natural/m^3	18.7%	Nitrogen oxides	6.9%
Cadmium	10.6%	Uranium	11.6%		
Lead	7.1%				
Tin	3.7%				
*Silver mining		*Transport of PV modules		*Electricity mix, IN	
Water scarcity (country)		**Land occupation**		**Land transformation**	
Elementary flow	*Contrib.*	*Elementary flow*	*Contrib.*	*Elementary flow*	*Contrib.*
Water balance in RoW*	73.4%	Occupation, forest, intensive*	38.80%	From forest to mineral extraction site*	61.0%
Water balance in EU	19.6%	Occupation, traffic area, road network	37.70%	From pasture and meadow to industrial area	4.0%
		Occupation, traffic area, rail/road embankment	6.20%		
		Occupation, industrial area	4.40%		
		Occupation, forest, extensive	4.10%		
*Production of Argon, liquid		*Silicon production		*Onshore well, oil/gas production	
Human toxicity, cancer		**Human toxicity, non cancer**		**Freshwater ecotoxicity**	
Benzo(a)pyrene to air*	32.39%	Silver to air*	27.03%	Aluminium to air*	50.4%
Formaldehyde to air	15.43%	Lead to air	22.15%	Chloride to water	16.1%
Chromium to air	11.62%	Mercury to air	17.89%	Aluminium to soil	12.4%
Chromium VI to water	11.23%	Carbon monoxide to air	6.40%	Sulfur to water	5.8%
Chromium to water	11.13%	Acrolein to air	4.08%		
*Production of magnesium used in aluminium production		*Production of PV modules		*Blasting	

6 Main hotspots identified in the BoP on appliances

The hotspot analysis of the BoP appliances clearly identified the use phase of the products analysed as the most relevant one. This is not surprising, since the BoP is composed by energy-related products, which were selected as object of the Ecodesign Directive (EC, 2009a) in relation to their energy intensity in the use phase.

Consequently, electricity production in the EU electricity mix results as the most contributing process to a relevant number of impact categories, namely photochemical ozone formation, acidification, terrestrial, and marine eutrophication. Other contributions from electricity mixes of specific countries (inside and outside the EU), such as on climate change, particulate matter, and ionising radiation are related to the use of electricity in the production of components (frequently happening outside the EU territory) and in the manufacturing of products. Indeed, the production of components is the second most relevant life cycle phase for most of the impact categories considered (and the most relevant one for the PV system).

Another hotspot, even if less contributing than electricity, is the extraction of metals used in the appliances, and especially of gold contained in the PCBs. Gold is also resulting as the most relevant elementary flow when resource depletion is assessed with the EF 3.0 method using the ultimate resources approach.

Large appliances, especially washing machines, dishwashers, refrigerators, TV screens, and lighting systems are the product groups that contribute the most to the overall impact of the BoP appliances. This is partially due to their specific impact per unit and partially to the high number of those appliances owned by EU households.

For what concerns the relevance of impact categories, resource depletion and water depletion are the ones that contribute the most to the overall impact of the BoP, when characterized with the ILCD method and normalised with ILCD EU-27 normalisation factors. Resource depletion results as the most relevant impact categories also when applying ILCD global normalisation factors, whereas the relevance of water depletion is not confirmed by the sensitivity analyses run with different normalisation references. This could also be due to the different approaches (i.e. withdrawal and consumptive) adopted by the ILCD and EF 3.0 methods: when applying ILCD, the largest contribution comes from the withdrawal of water used for cooling, which is not accounted for when applying EF 3.0.

Running a sensitivity with a different method for minerals and metals resource assessment (EF 3.0), the key products leading the impact are TV screens, washing machines, dishwashers, and laptops.

The environmental profile of the PV system included in the study is dominated by the impacts coming from the production of PV modules and the manufacture of the PV system.

7 Eco-innovations relevant for the BoP Appliances

This section illustrates the main findings of a literature review on eco-innovation for the area of consumption covered by the BoP appliances. It is summarized as a list of areas of improvement, some of them specifically related to one product, others cross-cutting among products, and the related information needed to drive the further selection. Based on the areas of concern identified by the hotspot analysis of the baseline scenario, and focusing on product categories that emerged as more critical (i.e. the most relevant categories in terms of impacts), possible improvements and eco-innovations were identified first of all in the area of energy and water consumption (if any) in the use phase.

The first group of innovation issues addresses the reduction of the impacts from water-consuming appliances. The list includes specifically the introduction of alternative heating systems for the water, the optimization of the laundry as well as the re-use of (at least part of) water. However, some of these changes are attended by a clear increase of the materials used in the production of the respective devices. Also changes in consumer behaviour may result in a relevant reduction of the impacts of these appliances – like e.g. an increased use of eco-programmes, a reduced temperature for washing cycles (up resp. down to "cold" washing – i.e. washing at 20°C) or an optimization of the cycles through increasing the load of a single cycle; the latter in both cases, i.e. for clothes as well as for dishes.

The second group of documents addresses impacts from refrigerators, room air conditioners and washing machines that are strictly related to the efficiency of these appliances (improved coefficient of performance – COP -, higher efficiency of the washing machine motor, reduced cooling losses). A scenario specifically concerning the electricity consumption by lighting, through an increased use of LED, is reported.

Another possibility for an increase in efficiency is the replacement of devices. Especially in the area of ICT (laptop, TV) this trend could be very well observed. This issue is therefore addressed in a further group of documents.

As refrigerating appliances are responsible for a significant contribution to the impact on the category ozone depletion in the baseline calculation, a third group of eco-innovation studies addresses specifically this aspect. It includes the use of more eco-friendly refrigerants (i.e. ideally of a substance that has a low or inexistent ozone depletion potential and in the same time also has a global warming potential as low as possible), a reduction of the refrigerant amount in a single device as well as the reduction of refrigerant leakage rates over the entire use phase and the regular maintenance cycles of such devices.

Eco-innovations targeting the end of life management of all products in the BoP are identified for the resource efficiency and concern the increased share of products that are reused at end of life, the increasing share of compact fluorescent lamps that are properly treated at end of life, strategies for increasing the quality of recycled metals and reducing the losses of precious metals. For instance, the battery durability and or its manual disassembly for substitution is identified in literature as an option to allow for a longer operative time of laptops. Some technological evolutions for which the penetration rate is increasing are reported for the laptop market, due the potential positive effects on the reduction of precious metals and Critical Raw Materials (CRM) use.

Specific eco-innovations for the area of CRM are mentioned and address the recovery of indium and the recycling rate of tantalum. Similarly, the increasing of the recycled content (from post-consumer plastic) is identified in literature as an option to mitigate the impacts from plastic use.

Table 39 summarizes the main areas of improvement and related eco-innovations in the sector of household appliances. It has to be noted that those are options identified in literature or technical reports, often referring to a specific issue to be addressed. This means that the overall benefits due to their implementation need to be evaluated in order to unveil possible trade-offs (e.g. reducing energy consumption while increasing use of chemicals; or need of a specific additional device whose production may lead to impacts).

Table 39. Summary of areas of improvement and eco-innovation for the appliance sector

Areas of eco-innovation and related keywords	Specific options	Eco-innovation	References
Technological Innovation for Energy/Electricity/Water saving in the use stage for water consuming appliances	Alternative heating system: supplying of hot fill to dishwashing and washing machine	Adding an hot fill intake to water consuming appliances	Saker et al., 2015. Working document EU Ecodesign for Dishwashers, 2015a. Boyano et al., 2017a Working document EU Ecodesign for washing machines, 2015b Boyano et al., 2017b
	Alternative heating system: heating the dishwasher cabinet, dishware and washing water	Adding a heat pump system using an energy storage unit with water	Bengtsson et al., 2015
	Alternative heating system: Heating the dishwasher and washing machine	Adding a hot water circulation loop	Persson, 2007
	Optimizing of laundering	Balancing temperature, time and mechanical action	Bao et al., 2017. EU Ecodesign for washing machines, 2015b Boyano et al., 2017b
	Optimizing of laundering (to be better investigated)	Water inlet to spray freshwater in the center of laundry	SPRAY, 2013
	Reusing last rinsing water of a dishwashing cycle for pre-rinsing in the following cycle	To equip the dishwasher with a resource-saving water management, where the water of the last rinse is stored to be reused (water tank)	Working document EU Ecodesign for dishwashers, 2015a Boyano et al., 2017a
Consumer Behaviour for Energy/Electricity/Water saving in the use stage for water consuming appliances	Increasing the load and reducing the temperature in washing cycles		Pakula and Stamminger, 2015.
	Alternative (ownership) models – resulting in a higher use of a single machine		Ellmer et al., 2017
	Load the Dishwasher to its full capacity		Working document EU Ecodesign for Dishwashers, 2015a
	Higher use of Eco-programmes in dishwashers and standard programmes in washing machines		EU Ecodesign for washing machines, 2015b Working document EU Ecodesign for Dishwashers, 2015b
	Cold (i.e. 20°C) washing		Josephy and Bush, 2017

Areas of eco-innovation and related keywords	Specific options	Eco-innovation	References
Technological Innovations for Energy/Electricity/ saving in the use stage	Reducing cooling losses in refrigerators	Increasing the insulation thickness (polyurethane cyclopentane foam used as reference insulation) or using Vacuum insulated panels in door area/lateral-back side	VHK, 2015
	Improving the energy efficiency of refrigerators	Compressor COP (coefficient of performance) improvement	VHK, 2015 CLASP, 2013
	Saving energy in washing machines	Higher motor efficiency	EU Ecodesign for washing machines, 2015b Barthel and Götz, 2013 CLASP, 2013
	Improving the energy efficiency of room air conditioner	Improving the energy efficiency ratio (EER) and coefficient of performance)	ARMINES, 2008 Grignon-Massé et al., 2011.
Consumer Behaviour for Electricity saving in the use stage of lighting system	Increased use of high energy efficiency lamp	Increased use of LED (trend induced by Ecodesign regulations)	
		Combining energy efficient lamps and smart technologies (Domotics)	Bhati et al., 2017 Fundación San Valero, 2014b
Consumer Behaviour for Energy/Electricity saving through multifunctional product use	Increased use of light, mobile devices for use pattern that have been made with bigger devices before	Tablet and smartphone being used for watching television	Hicks, 2017 Park et al., 2017
Technological Innovations for reducing the ozone depletion	Using less impacting refrigerants in room air conditioners	Use of R32, N40, L41a	Beshr et al. 2017 Danfoss, 2017, Jia et al., 2017.
	Using less refrigerant	For R410a, according manufacturers, reduction of refrigerant mass is possible, by a % from 20 to 50 (not technological specifications provided)	ARMINES, 2008
	Reducing refrigerant leakages	For R410a, according manufacturers, reduction of refrigerant yearly refrigerant leakage is possible, from 3% (current average) down to 1% (not technological specifications provided)	ARMINES, 2008
Extended lifetime	Improving/allowing durability, upgradability, reparability	Improving battery durability and/or allow for its manual extraction for substitution	Clemm et al., 2016 Tecchio et al., 2017
WEEE Management _Reuse	Increasing the rate of products that are reused at their EoL	Reuse of products having a remaining functionality (implementation of a "preparation for reuse" policy)	Parajuly and Wenzel, 2017a and 2017b Bovea et al., 2016.

Areas of eco-innovation and related keywords	Specific options	Eco-innovation	References
		Lowering barriers for a re-use of devices	Kissling et al., 2013 Prakash et al., 2016
WEEE Management _Recycling	Improving the quality of recycled metals (by reducing contamination by alloying elements)	Active disassembling fastener (ADF)	Nakamura and Yamasue, 2010.
	Reducing the quantity of precious metals entering the shredder, so as to reduce the losses	Adjusting *(including, ndr)* the manual sorting step to remove most precious metal-rich materials/*components (ndr)*	Chancerel et al., 2009
Recycling rate/recycled content	Reducing the impact from plastics	Increasing the post-consumer recycled content (case study on laptop enclosure)	Meyer and Katz, 2016.
Improving the implementation of policies on EoL products	Increasing the share of EoL lamps (CFLi and LED) addressed to proper disposal treatment (effect on recycling of copper, glass, aluminium and steel)		VITO, 2015a
CRM	Recovering indium from LCD (still under study, promising)	Indium recovery process with acidic leaching, followed by a zinc cementation (promising in the context of circular economy)	Amato et al., 2016
		Indium recovery process through Active disassembly (AD) (promising in the context of circular economy)	Peeters et al., 2012
	Improving the recycling rate (currently 1%) for tantalum from PCBs from computers (under discussion. It is feasible but some barriers still exist).		Ueberschaar et al., 2017
Expected technological evolutions with positive effects on precious metals/CRM use	Substituting of storage components, in Laptop, with other ones characterized by minor content (or no content) of CRM	Increasing use of SSD in comparison to HDD, with following reduction of use of Neodymium and other CRMs included in PCB of HDD (e.g. gallium, tantalum). It has to be considered that technological improvement (e.g. silicon die reduction dimension for unit of functionality (kWh, GB, MB) can be offset by a higher consumption pattern. In addition, in case of laptops, the	Tecchio et al., 2017 Kasulaitis et al., 2015 Cucchiella et al., 2015 Based on the adopted composition for SSD and HDD (Tecchio P., Ardente F., Mathieux F., 2017; Cucchiella, F. et al. 2015)

Areas of eco-innovation and related keywords	Specific options	Eco-innovation	References
		BoM variation is much more affected by the screen size variation (laptop of different size) rather than by change over time (same product-size)	
	Phasing out of optical disk drive (ODD) in Laptop	No use of ODD, with following no use of resources, namely metals (copper, aluminium, steel), and precious metals/CRM included in PCB of ODD (e.g. gold, palladium, gallium, etc). It has to be considered that technological improvement (e.g. silicon die reduction dimension for unit of functionality, kWh, GB, MB) can be offset by a higher consumption pattern. In addition, in case of laptops, the BoM variation is much more affected by the screen size variation (laptop of different size) rather than by change over time (same product-size).	Tecchio et al., 2017. Kasulaitis et al., 2015 Based on the adopted composition for SSD and HDD (Tecchio P., Ardente F., Mathieux F., 2017; Cucchiella, F. et al. 2015).

8 Scenarios of eco-innovation in the area of consumption Household Appliances

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

1. scenarios that are expected to address the most relevant hotspots identified in the baseline;
2. scenarios able to simulate the effect of European policies, especially in relation to the hotspots of the consumption sector as emerged from the assessment of the BoP baseline;
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 growing of the market share for electric vehicles for the mobility sector.

The results of the baseline scenario for 2010 show that only two of the life stages along the life cycle of household appliances are actually of relevance – the stages "production of materials/components" and "use phase" for all the examined impact categories with one exception – in the case of the category "ozone depletion" the stage "maintenance and repair" is as a third stage also of relevance. A first conclusion that can be taken from this is that an investigation of detailed scenarios for different "end-of-life" treatment options would be of minor relevance in case of household appliances.

When looking to the analysis of the contribution of the various product groups – five of them can be identified as more relevant than the others – these are dishwasher, washing machine, refrigerator, LCD television and lighting systems. For all these product groups the use phase is the one that dominates their respective impact along the life cycle, while all of them underwent and are undergoing a – more or less fast – continuous technological development towards a reduced energy consumption in their use phase. When focussing on the impact category "ozone depletion" the product group "room air conditioner" is responsible for more than 50% of the overall impact.

Based on this short analysis of the results above, the use phase and therewith the issue of electricity production is of crucial relevance; hence the first scenario settings are focusing on this issue – one time from the point of view of the (energy) consumer (i.e. the different product groups), one time from the point of view of the (energy) producer (i.e. the electricity supply). In details, this translates as following:

- shift of the European electricity mix towards a higher share of renewable energy sources [in the following shown as **Scenario 1**];
- improved energy efficiency of the average products in the market – investigated separately for the following (individual and/or various) product groups:
- dishwasher and Washing Machine. Actually this scenario investigates not only the actual development of the energy consumption but is taking into account further changes like e.g. the increasing capacity of the washing machine, various product innovations for water saving and its consequences, or the issue of a reduction of the washing temperature (due to new detergents and/or user settings) and its consequences (on water, energy) [**Scenario 2**];
- refrigerator [**Scenario 3**];
- television. Again a product group where not only the actual development of the energy consumption are taken into account, but also the parallel development of an increasing of the (average) screen size [**Scenario 4**].

With the main focus on the impact category "ozone depletion" (but evaluating not only this impact category), the following scenarios, related mainly to the product groups "air conditioning appliances" and "refrigerators", are investigated in a second part of this scenario analysis here:

- the reduction of refrigerant leakages in the use phase of air conditioning appliances [**Scenario 5**];
- the substitution of current refrigerants by more ecological alternatives (with lower GWP and/or ODP values) [**Scenario 6**].

In a third part, scenarios taking into account developments and changes of the "user behaviour" will be investigated. A user can be – due to a variety of reasons, including e.g. education – incented to purchase more or less such devices as well as he can be incented to use those devices more or less times (i.e. daily use as well as the overall use lifetime of these devices). Some users want to re-use devices that have not reached their (technical) lifetime due to e.g. financial reasons (such devices are usually sold for a much lower price). Legal requirements, as well as the rising concerns about environmental issues make the users also taking care when disposing off their devices at the end of life; leading to higher amounts of such devices ending up in appropriate recycling schemes. With the following four scenarios all these aspects can be covered in a schematic, but nevertheless comprehensive manner, allowing in the end to get an overall idea of the potential laying within the user behaviour:

- development (increase) of the number of devices per household until 2030 for the various product groups covered by this study [**Scenario 7**];
- a "End-of-Life" improvement scenario – looking in a first part on an increased reuse of products (via second-hand markets) [**Scenario 8a**], then in a second part on an increased collection rate of such WEEE devices [**Scenario 8b**], and finally in a third step on an increase of the material recovery rates during the various recycling processes for the different fractions (e.g. metals, plastics) [**Scenario 8c**].

The fourth part consists of a specific focus on the lighting sector, with a scenario that analyses the effect of an increased use of LED lighting, in substitution of other light sources that are planned to be phased out in the future [**Scenario 9**].

Fifth, by combining these various scenarios described above, the overall potential improvements/changes concerning the environmental impacts from household appliances will be investigated. For this, the following, additional scenarios are here established:

- in a first phase, all the effects due to improvements of the various devices – as modelled in the scenarios 2 to 6 (including the results from a scenario in the area of lighting) – are summed up and examined [**Scenario 10a**]; then, in a second step, the improvements for the end-of-life phase (as modelled in the scenarios 8a to 8c) are then added to this combination [**Scenario 10b**]; and in a third step, this is combined with the growing amount of devices per household (i.e. with the outcome of scenario 7) [**Scenario 10c**] ;
- and finally, the results of this last stage of scenario 9 (i.e. scenario 9c) are combined with those of the very first scenario, examining the development of the electricity production side, to get what can be considered as the overall potential for the area of household appliances [**Scenario 11**].

The aim of the scenarios 1 to 6 and 9 is it to show the maximum reduction potential that can be expected from a technical point of view in the various areas the scenarios are dealing with in comparison to the situation described in the baseline scenario (2010). Scenarios 7 and 8a to 8c then take into account in a simple but comprehensive way various aspects of the user behaviour. Scenario 11, which combines all these issues into a single, combined scenario it is considered as a reasonable estimation (i.e. a best guess of the average) of the overall potential that can be expected in the area of household appliances.

- In an additional (even more hypothetic) step – using outcomes of the LIFE+DOMOTIC project (Fundación San Valero, 2014a and 2014b) together mainly with the results from the future scenario for the area of lighting – the influence of the covered product groups for the so-called "domotics" (i.e. for systems that automate buildings and improve the energy performance while increasing comfort and security) are evaluated [**Scenario 12**] at the very end of this report.

Apart from the previous ones, **Scenario 13** consists of an update of the baseline scenario, which models the average EU situation in the baseline year 2010, in order to take into consideration the most recent available data on the actual stock. Therefore, this scenario aims at developing a new baseline model, referring to the baseline year 2015.

Scenario 14 is intended as a sensitivity analysis on the electricity mix used in the use phase of products and, specifically, on the electricity mixes representative of the three climatic zone of BoP housing (warm zone, moderate zone, and cold zone).

Finally, **Scenario 15** analyses the effect of an increase in installation of PV systems on the roof of private houses. The scenario makes use of the model of the PV system developed in the context of the BoP on appliances, implemented on the housing stock modelled in the BoP on housing.

All these scenarios are characterized by default with the ILCD v1.08 method (EC-JRC 2011) – remaining on the level of the actual characterisation factors (i.e. not applying any kind of normalisation factors). In addition, the sensitivity in the area of resource depletion is examined by applying two separate factors for energy-related, fossil resources (in the following called FRD, fossil resource depletion) and for mineral and metallic resources (i.e. the MRD, mineral resource depletion), using the factors according to EF 3.0 method. These latter two impact categories are shown at the end of the various figures and tables of the various scenarios within this report.

8.1 List of scenarios tested in the BoP

The following table (Table 40) summarizes the key points of the various scenarios that have been investigated in the framework of the BoP Appliances. A detailed description on how these scenarios have been established, where the chosen values are coming from and what the results/consequences of all the changes in each of the scenario are is shown, scenario-by-scenario, in the subsequent chapters.

Table 40. List of scenarios selected for the BoP Appliances.

Area of intervention	Possible kinds of action	Scenario analysed
Reduction of impacts in use phase	Production of energy with less impacts	Scenario 1 – Use of a more renewable electricity mix (EU Electricity Mix 2030 used on EU stock of appliances in 2010)
	Use of more energy efficient devices	Scenario 2 – Improved efficiency of dishwasher and washing machine (stock 2010)
		Scenario 3 – Improved efficiency of refrigerator (stock 2010)
		Scenario 4 – Improved efficiency of TV (stock 2010)
Reduction of ozone depletion	Less emissions	Scenario 5 – Reduction of refrigerant leakages during the use of air conditioners (stock 2010)
	Less harmful substance(s)	Scenario 6 – Substitution of current refrigerants (stock 2010)
Changes of user behaviour	Density of devices in our society	Scenario 7 – Amount of devices per inhabitant (stock 2030)
	Increase of reusability	Scenario 8 – [a] increasing remanufacturing and reuse (parts, whole devices) (stock 2010), [b] increase of the collection rate (stock 2010), and [c] increase of the recycling rate (stock 2010)
Changes of stock characteristics	Increased use of LED lighting	Scenario 9 – Increased share of LED lighting sources, in substitution of older ones, that will be phased out (stock 2010)
Combining several aspects together	Scenario 10 – The "devices-related potential" – with [a] summing up all more energy efficient devices as well as devices less harmful for ozone layer (stock 2010); [b] adding to this all the increased "reusability" scenarios (stock 2010); and [c] combining all this with the changing amount of devices in use (stock 2030)	
	Scenario 11 –The "overall potential" scenario – combining all the above described scenarios together (i.e. scenario 1 to 10c) (stock 2030)	
"Industry 4.0"	Domotics	Scenario 12 – Influences of the covered product groups for domotics (i.e. systems that automate buildings and improve energy performance while increasing comfort and security) (stock 2010)
"Baseline 2015"	Closer baseline year	Scenario 13 – Updated baseline scenario, referring to baseline year 2015 (stock 2015)
"Electricity mix"	Sensitivity on electricity mixes	Scenario 14 – Use of specific electricity mixes for European climatic zones, applied to RAC use phase (stock 2010)
"PV system"	Increased installation of PV systems	Scenario 15 - Increased installation of PV systems on the roof of private houses

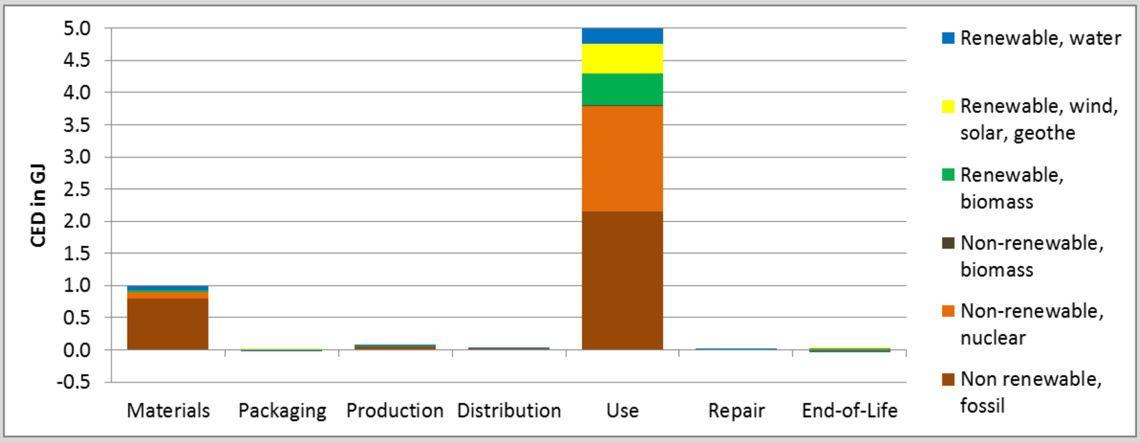
8.2 Scenario 1: More renewable European Electricity Mix

Description and aim: Scenario 1 is taking up the main issue from the analysis of the baseline, i.e. the use phase of the devices being the most relevant life stage among almost all impact categories. Within the use phase, there is clearly one dominating issue and this is the energy (i.e. electricity) consumption of the different household appliances in this life stage. Hence, within Scenario 1, the influence of a change of the electricity mix towards a more sustainable mix on the overall results is investigated.

Area of intervention: The future EU electricity mix is applied to the use phase only. As shown in the box below, the only other life cycle stage of relevance is the production of the materials and components. However for that stage, an application of this mix does not make sense as parts of the appliances in use have been produced much earlier (with a different mix) and parts of the appliances have been produced abroad EU.

Box 3. CED Analysis of Baseline Scenario

The following picture reported the results obtained by applying the method for the "Cumulative Energy Demand" (CED), described in Hischier et al. (2010)..



The main phase of energy consumption is the use phase, which is responsible for about 82% of the overall impact, the production of the materials for another 16% which leaves only about 2% for all the remaining life cycle stages.

Policy relevance: Energy Efficiency Directive (EU, 2012b), and Roadmap to a Resource Efficient Europe (EC, 2011b).

Rationale for building the scenario: Based on the EC's report "EU Reference Scenario 2016 – Energy, transport and greenhouse gas emissions Trends to 2050" (European Commission 2016), the mix for the gross electricity generation by source in the year 2030 is used here (according to the way shown in Table 41).

Based on the general modelling structure in the electricity sector within ecoinvent version 3 (described in Treyer and Bauer, 2016), market datasets for the various voltage levels (i.e. high, medium and low) have been established. With the exception of the amount from "solar" and "waste", all other production activities are linked to the high voltage market. For "waste" this is done on the medium voltage level, while "solar" production is modelled as electricity, low voltage, from various types of photovoltaics installations. For the subsequent transformation from high to medium and then to low voltage, the parameters from the current German electricity mix datasets in ecoinvent are used here. In total, this leads to the following five new datasets for such a future electricity mix in the EU, whereof in this study here, the first dataset will be the linking element to the examined scenarios:

- market for electricity 2030, low voltage/EU-28;
- electricity 2030 voltage transformation, from medium to low voltage/EU-28;

- market for electricity 2030, medium voltage/EU-28;
- electricity 2030 voltage transformation, from high to medium voltage/EU-28;
- market for electricity 2030, high voltage/EU-28.

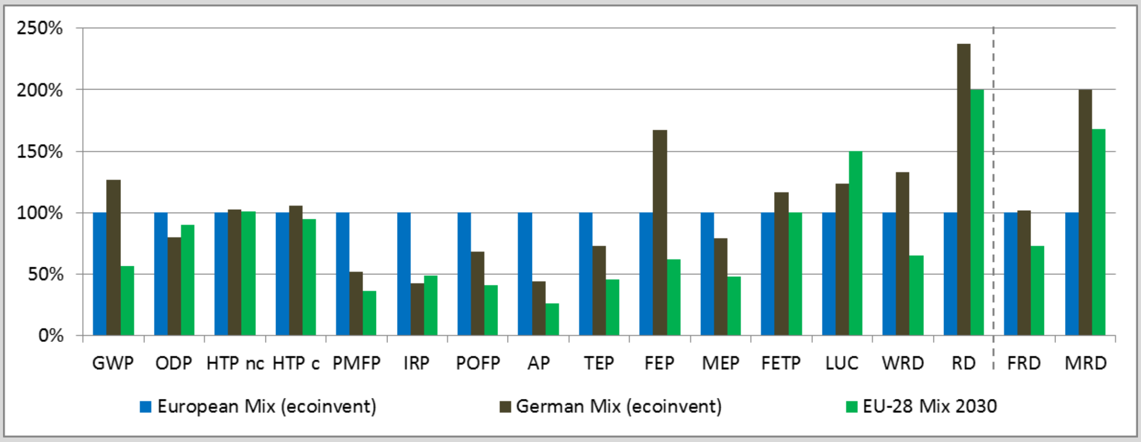
Table 41. Applied future, more sustainable EU electricity mix (2030) and its translation into the LCA model of this study

Energy Source	**Gross Electricity generation** (1)		**Used dataset** (2)
	in GWh_e	**in %**	
Nuclear energy	777’743	22.0	Electricity production, nuclear, pressure water reactor/FR
Solids	562’741	16.0	Electricity production, hard coal/DE *and* Electricity production, lignite/DE (3)
Oil (incl. refinery gas)	19’341	0.5	Electricity production, oil/DE
Gas (incl. derived gas)	654’930	18.6	Electricity production, natural gas, combined cycle power plant/DE
Biomass-waste	283’469	8.0	Electricity out of heat and power co-generation, bio-gas, gas engine/DE *and* Electricity out of heat *and* power co-generation, wood chips, 6667 kW, state-of-the-art 2014/DE *and* Electricity, from municipal waste incineration to generic market/DE (4)
Hydro (no pumping)	378’979	10.7	Electricity production, hydro, reservoir, alpine region/ CH *and* Electricity production, hydro, river-of-river/CH (5)
Wind	608’460	17.3	Electricity production, wind, >3MW turbine, onshore/ DE *and* Electricity production, wind, 1-3MW turbine, offshore/DE (6)
Solar	232’129	6.6	Electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel mounted/DE *and* Electricity production, photovoltaic, 3kWp slanted-roof installation, single-Si, panel mounted/DE *and* Electricity production, photovoltaic, 570kWp open ground installation, multi-Si/DE (7)
Geothermal (& others)	9’736	0.3	Electricity production, deep geothermal/DE

(1) Values for EU for the year 2030. *Source:* EC (2016).
(2) Data from the background database ecoinvent v3.2. Due to a lack of respective average data for EU, the here mentioned “national” datasets have been chosen as respective proxy for an “average” EU dataset.
(3) Based on the EU Power Statistics 2015 spreadsheet, 49% Hard Coal and 51% Lignite are expected in 2030 (Source: http://www.eurelectric.org/factsdb/).
(4) Based on the EU Power Statistics 2015 spreadsheet, 49% Biomass (here represented by the “wood” dataset), 36% Biogas & Bioliquids (“biogas” dataset) and 15% from Waste incineration (“waste” dataset) are expected in 2030 (Source: http://www.eurelectric.org/factsdb/).
(5) Based on the EU Power Statistics 2015 spreadsheet, 65% Reservoir and 35% Run-of-River are expected in 2030 (Source: http://www.eurelectric.org/factsdb/).
(6) Based on the EU Power Statistics 2015 spreadsheet, 73% Onshore and 27% Offshore Production of Wind electricity are expected in 2030 (Source: http://www.eurelectric.org/factsdb/).
(7) According to the EU Power Statistics 2015 spreadsheet, also 2030 less than 0.5% of solar-based electricity is expected to be produced in concentrated solar plants (CSP); hence, here 100% PV-based production is assumed – split (based on the outlook for 2030 in IEA (2010) and the modelling of PV in this study here) in 34% open ground, 31% Mono-Si and 35% Multi-Si (Source: http://www.eurelectric.org/factsdb/).

Box 4. Analysis of the established "electricity Mix 2030"

An analysis and comparison of this new, future electricity mix with the current mix for EU (used in the baseline scenario for the use phase) as well as with the German mix gives – on the level of low voltage – the following picture.



Actually a rather typical picture for a "more renewable" electricity mix could be observed; i.e. while for climate change (GWP), the reduction potential of such a future mix is quite high – there are several other environmental aspects where this so-called more renewable electricity mix shows hardly any reaction (e.g. HTP c, FETP), or even an increase (see e.g. LUC, RD) of the respective impact.

The sensitivity analysis, splitting resource depletion into two separate factors for fossil resources (FRD) and metallic/mineral resources (MRD) shows for the latter still a similar picture (i.e. an increase of the impacts) – originating to large amounts from the consumption of the resource "Zinc" (more than 54% of this impact) in the dataset "Electricity out of heat and power co-generation, bio-gas, gas engine/DE". For the second factor (i.e. FRD) a reduction slightly lower than the one for GWP can be observed.

Parameters modified in the model: From the baseline model, all the datasets of the use phase (e.g. "WashingMachine_E_Use Phase") have been copied and the electricity mix has been replaced by the newly created, above shown, more sustainable future EU electricity mix (i.e. by "market for electricity 2030, low voltage/EU-28"). These new datasets are named as 'Scenario1' (e.g. "WashingMachine_E_UsePhase_Scenario1") in order to distinguish them clearly from the baseline scenario. Afterwards, these new datasets for the use phase have then been combined with the original baseline datasets for all other life stages (before/after use) in the new dataset for the whole life cycle (like e.g. "WashingMachine_TOTAL LIFE CYCLE_Scenario1") in order to calculate the results for this Scenario 1.

Results: In the following two figures (i.e. Figure 14 and Figure 15), the results of this scenario are compared with the respective results from the baseline scenario; in Figure 14 they are split into the contributions from the different product groups, in Figure 15 they are split into the shares of the different life cycle stages distinguished here. Each of the two figures is going along with a table (Table 42 and Table 43), showing the relative changes (in %) in the different product groups and the different life cycle stages, respectively.

Figure 14. Scenario 1 in comparison with the baseline scenario (with total from the baseline set as 100%) – split into the contributions of the various product groups. (For the abbreviations in both figures see table note of Table 42)

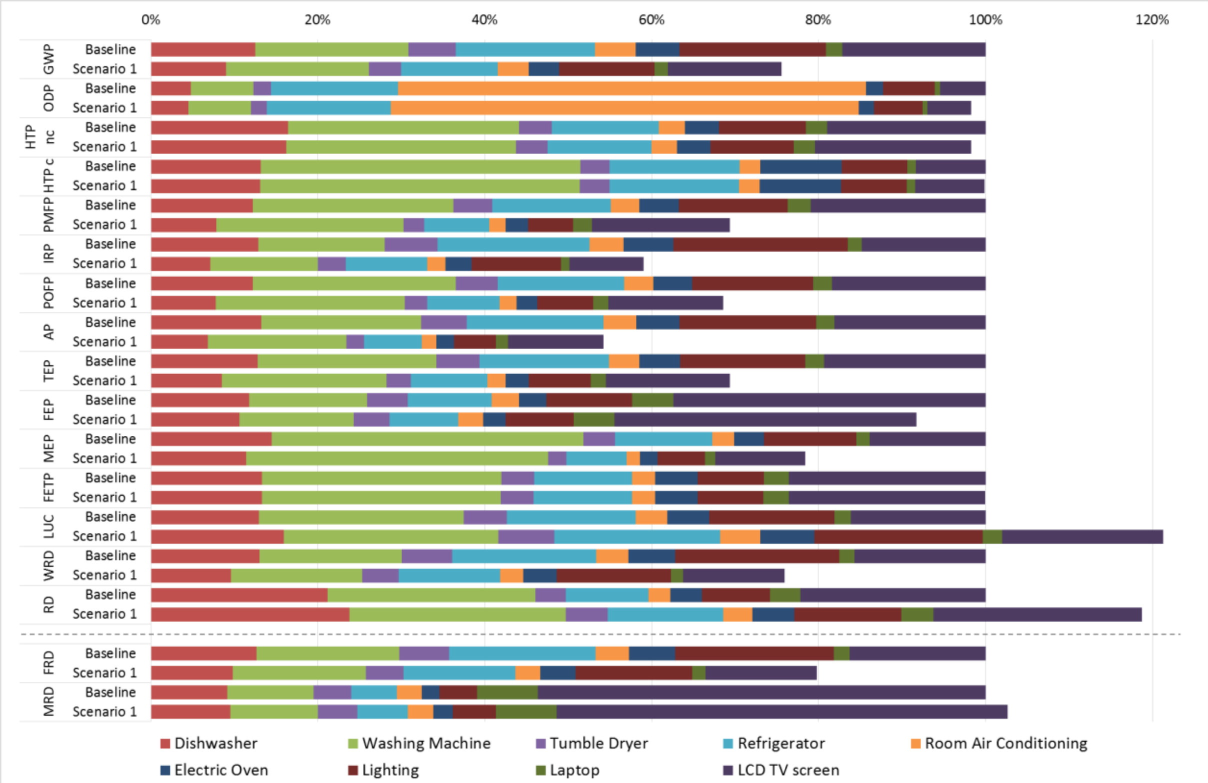


Figure 15. Scenario 1 in comparison with the baseline scenario (with the total impacts of the baseline set as 100%) – split into the contributions of the various life stages

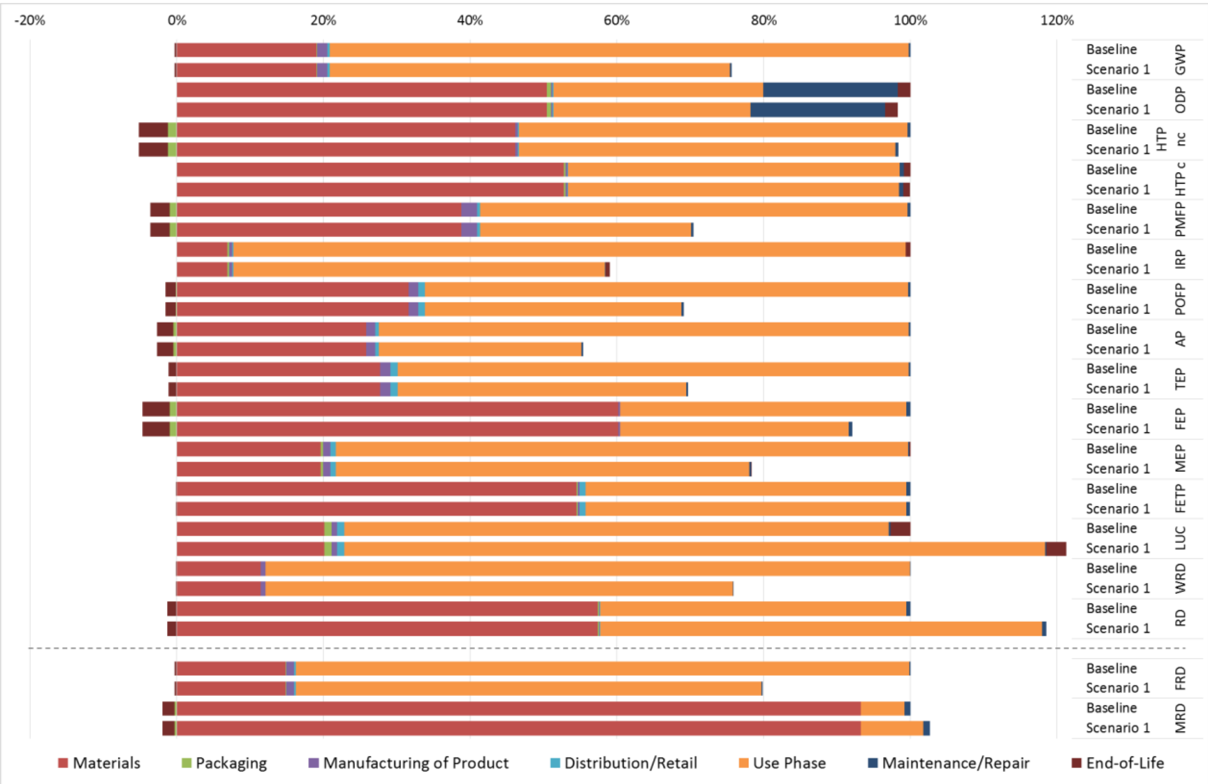


Table 42. Relative changes of the various product groups when comparing Scenario 1 with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	Total	Dish-washer	Washing Machine	Tumble Dryer	Refrige-rator	Room Air Cond.	Electric Oven	Lighting	Laptops	LCD TV Screen
GWP	-24.4%	-27.6%	-7.3%	-31.6%	-30.4%	-23.1%	-31.8%	-34.5%	-19.8%	-20.7%
ODP	-1.7%	-5.1%	-1.3%	-6.1%	-2.4%	-0.1%	-6.0%	-6.9%	-4.2%	-4.7%
HTP_nc	-1.7%	-1.5%	-0.3%	-3.3%	-2.8%	-2.6%	-2.9%	-4.2%	-1.1%	-1.3%
HTP_c	-0.1%	-0.1%	-0.0%	-0.2%	-0.1%	-0.2%	-0.1%	-0.3%	-0.1%	-0.2%
PMFP	-30.6%	-35.4%	-7.0%	-47.4%	-44.9%	-41.7%	-44.0%	-58.3%	-17.9%	-21.3%
IRP	-40.9%	-44.8%	-14.8%	-47.0%	-46.7%	-46.1%	-47.2%	-48.6%	-39.1%	-40.1%
POFP	-31.4%	-36.2%	-7.1%	-45.8%	-43.0%	-41.6%	-46.1%	-53.8%	-21.6%	-24.9%
AP	-45.8%	-48.7%	-13.1%	-60.9%	-58.0%	-53.9%	-60.6%	-69.0%	-33.8%	-36.9%
TEP	-30.6%	-33.6%	-7.8%	-43.0%	-41.0%	-39.4%	-43.2%	-50.4%	-21.4%	-23.1%
FEP	-8.3%	-9.9%	-3.2%	-12.3%	-17.3%	-11.5%	-17.4%	-20.1%	-2.6%	-3.2%
MEP	-21.6%	-21.1%	-3.2%	-41.4%	-38.6%	-37.9%	-41.5%	-48.6%	-21.3%	-22.7%
FETP	-0.1%	-0.1%	-0.0%	-0.1%	-0.1%	-0.1%	-0.1%	-0.2%	-0.0%	-0.0%
LUC	21.3%	23.1%	4.7%	30.1%	28.6%	25.6%	28.9%	35.2%	17.1%	19.2%
WRD	-24.1%	-26.1%	-7.7%	-29.0%	-29.1%	-28.8%	-29.3%	-30.3%	-21.5%	-22.4%
RD	18.7%	12.5%	4.1%	37.3%	39.4%	32.7%	34.0%	56.9%	8.3%	12.3%
FRD	-20.2%	-22.5%	-6.5%	-24.7%	-23.9%	-23.6%	-25.0%	-26.4%	-16.9%	-18.1%
MRD	2.7%	4.1%	1.4%	4.3%	10.1%	4.1%	8.6%	14.6%	0.6%	0.7%

([1]) 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 (Mineral, fossil & renewable resource depletion), all from the ILCD v1.08 method (EC-JRC 2011) and – as a kind of sensitivity analysis – FRD (fossil resource depletion) and MRD (mineral resource depletion) according to the EF 3.0 method.

Table 43. Relative changes of the various life stages when comparing scenario 1 with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	Total	Materials	Packaging	Production	Distribu-tion	Use	Main-tenance	End-of-Life
GWP	-24.4%	-	-	-	-	-30.9%	-	-
ODP	-1.7%	-	-	-	-	-6.1%	-	-
HTP_nc	-1.7%	-	-	-	-	-3.1%	-	-
HTP_c	-0.1%	-	-	-	-	-0.2%	-	-
PMFP	-30.6%	-	-	-	-	-50.7%	-	-
IRP	-40.9%	-	-	-	-	-44.7%	-	-
POFP	-31.4%	-	-	-	-	-47.0%	-	-
AP	-45.8%	-	-	-	-	-61.8%	-	-
TEP	-30.6%	-	-	-	-	-43.5%	-	-
FEP	-8.3%	-	-	-	-	-20.3%	-	-
MEP	-21.6%	-	-	-	-	-27.7%	-	-
FETP	-0.1%	-	-	-	-	-0.1%	-	-
LUC	21.3%	-	-	-	-	28.6%	-	-
WRD	-24.1%	-	-	-	-	-27.4%	-	-
RD	18.7%	-	-	-	-	44.3%	-	-
FRD	-20.2%	-	-	-	-	-24.1%	-	-
MRD	2.7%	-	-	-	-	44.4%	-	-

([1]) Abbreviations, see table note at Table 42

As it could clearly be seen in Table 43, all the changes result from the use phase; as only for the use phase this new, future electricity mix has been applied here. And the use phase actually shows a rather similar pattern for the reduction as the comparison of the electricity mixes in Box 4 above; i.e. while there are categories with a clear reduction (e.g. for GWP almost one third), there are categories with almost no changes as well as a few categories with even increasing results (e.g. LUC, RD). As soon as the resource consumption is split – as with FRD and MRD – also for this case the opposite behaviour of these two factors (i.e. total reduction of about 20% for FRD, slight increase of about 3% for MRD) gets clearly visible.

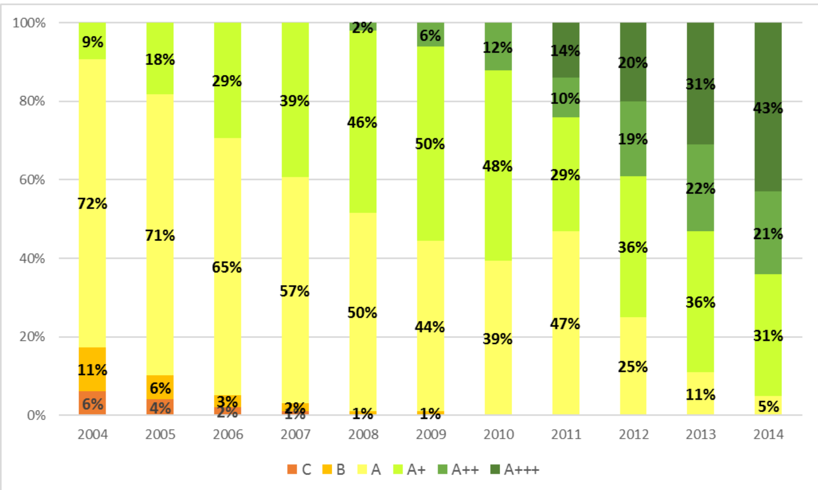
This reduction looks less important (expressed in %) when focussing on the whole life cycle (e.g. for GWP the total reduction is of about 24.5% while in the use phase this reduction is almost 31%), as the use phase is not the only life stage contributing to the overall impacts. However, this overall picture gets more complex and less clear to read when the total impact is split into the contributions of the various devices (see Table 42); again the reduction comes from the use phase of each of the devices and this is then summing up to the overall reduction.

8.3 Scenario 2: Improved efficiency dishwasher and washing machine

Description and aim: The aim of Scenario 2 is to investigate the (maximal) overall potential that lies within the area of water-using household appliances, i.e. the dishwasher and the washing machine, in view of reducing the overall environmental impacts related to the use of household appliances as a whole.

These two types of household appliances are among the most contributing ones to the environmental impacts in the base case calculations, and, as the impact from both of them is coming to a large extent from the use phase with its electricity and water consumption, a single scenario for both of them is established. The developments of these type of appliances have been steadily increasing over the past years – e.g. the average energy consumption has considerably decreased between 2010 and 2015 as highlighted clearly in Figure 16 – showing that in 2015 more than three quarter of all washing machines belong to efficiency classes that barely had any kind of relevance in the market 5 years earlier. The picture looks rather similar for the dishwasher as well.

Figure 16. Efficiency classes of washing machine sales across the EU[9]. Modified from Michel et al. (2016).



[9] This figure refers to sales. However, it is to be noted that there is a mismatch between models on the market and sales. For example, in the case of the DWs, the penetration of models of higher classes (A+++) progresses faster than the sales. This means that the percentage of models put on the market classified with A+++ is higher that the percentage of models sold and classified with A+++.

Apart from the energy efficiency, these types of machines have gone through a number of further improvements in the same time period (i.e. from 2010 to 2015), therefore, a combined scenario, taking into account all these different issues, is examined here. The topic is thought not taking into account eventual changes of the lifetime of such a device (this is an issue Scenario 8 is dealing with – see later in this report).

Dishwasher. The recently published final report of the preparatory study for eco-design and energy labels of dishwashers (Boyano et al., 2017a) confirms the conclusion from former studies (e.g. CLASP, 2013, or Gensch et al., 2013) that the key environmental impacts are related to the energy and water consumption during the use phase, while the used amount of detergent is of minor relevance. In 2014, an average dishwasher in the EU consumed 1.04 kWh/cycle (13ps model) 0.97 kWh/cycle (10ps model) of electricity respectively under actual use conditions and 10.9 l/cycle and 12.1 l/cycle of water respectively (Boyano et al. 2017a). These values are clearly below the values used for the base case calculations of 1.42 kWh/cycle electricity and 18.5/cycle l water, respectively. In the same report, a comprehensive overview of a variety of future options for a further reduction of the energy and/or the water consumption is given, showing a further reduction potential in the order of up to 34% of the electricity and – on a more moderate level – a respective potential up to 7% for the water consumed; in both situations assuming again the "real-life" conditions.

Washing Machine. According to (Boyano et al 2017b), the average washing machine in 2013 has a nominal capacity of 7 kg, has a load of 3.3 kg (under actual use conditions), and consumes 0.8 kWh of electricity and 43.5 l of water per cycle; values that are in the same order of magnitude as the 0.638 kWh and 50 l, respectively, that are used in the base case calculations here in this study. In the past years, the European Commission funded two further projects (Atlete and Atlete II) that had as objective to "evaluate energy labelling and ecodesign of washing machines". For the first time in the EU, models actually have been tested (62 machines covering actually 50 different models, in the frame of Atlete II). The results of Stamminger and Schmitz (2016) show an average consumption of 0.78 kWh/cycle (with a range going from 0.56 kWh/cycle to 1.04 kWh/cycle) of electricity and 41.9 l/cycle of water (i.e. the respective range going from 26 l/cycle to 63 l/cycle of water) for the 50 different models; values are very close to the baseline data used in this study.

In the report from Boyano et al. (2017b) various technical options for washing machines are shown to further improve such an appliance up to a BAT device resulting all in all in a (further) reduction potential in the order of up to 48% of the electricity compared to the base case (0.84 kWh/cycle), a (more moderate) potential of up to 17% for the water consumed as well as a reduction in the consumption of detergents up to 15%; while the life time remains the same, and the weight of the machine can increase up to 20% due to the integration of additional components (e.g. heat pumps) that are required for some of the examined scenarios (Boyano et al., 2017b).

Another relevant issue is the "user"; as he can influence the washing process in a manifold way. In fact, it is the user that is choosing the programme (and with this the energy and the water amount needed); is adding the detergent (i.e. has the control over the quantity of the washing agent used) and is also deciding about the amount of dirty clothes that is put in such a machine; which influences in the end again the energy and water consumption of the washing cycle. A recent publication of the group of Prof. Stamminger (Schmitz et al., 2016) shows that especially for this latter point, the consumer is currently not behaving in an appropriate way; a fact that is already taken into account in the JRC study, saying that under actual use conditions a 7 kg-machine is loaded with only 3.4 kg of clothes (see above). However, under such conditions, the efficiency is much less good; i.e. Stamminger measured a reduction of only 17% for the energy consumption and of 22% of the water used when the machine is loaded with 50% of its rated capacity (Stamminger and Schmitz, 2016). Hence, the fact that industry brings machines on the market with higher and higher capacities leads most probably to a less optimized use of this kind of machines; and the energy and water saving measures of a new model are maybe even compensated by the less optimal use of the machine.

Area of intervention: Obviously, these developments have an influence on the key parameters of the use phase of dishwashers (both sizes) and washing machines, respectively. In addition, the composition of the two machines can be influenced due to additional components that are required in order to realize the savings in energy and/or water. Finally, a reduction of the number of cycles per year should result for the washing machine due to the increasing load capacities in order to be able to profit from the higher energy and water efficiency of a new model. As pointed out in the preparatory study for dishwashers (Boyano et al., 2017a), there is a rule of thumb for the dishwashers, according to which 1/3 of the energy is used to heat water, 1/3 for heating up the appliance itself and 1/3 for the dishware. This means that the potential of energy saving due to half load is reduced because the water does not decrease proportionally to the load and the appliance should be heated up anyhow. Therefore, the user behaviour regarding the loading is not so crucial.

Policy relevance: Ecodesign Directive (EC, 2009a), Energy Efficiency Directive (EU, 2012b), and Roadmap to a Resource Efficient Europe (EC, 2011b)

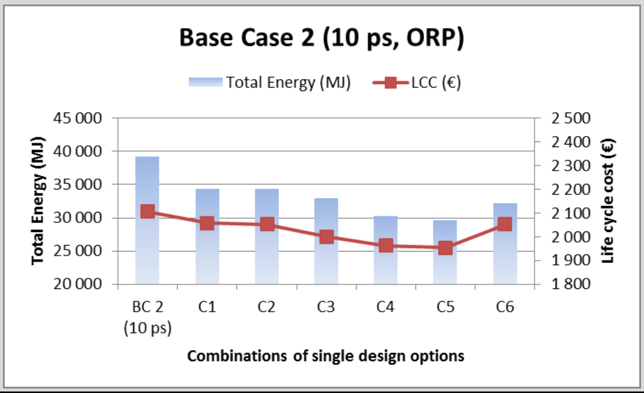
Rationale for building the scenario: This scenario takes into account the following elements in each of the two covered categories of household appliances:

Dishwasher

- Energy consumption: 0.72 kWh/cycle (13ps model) and 0.66 kWh/cycle (10ps model) – based on the design option "C5" in Boyano et al. (2017a). This scenario has been chosen as it shows the most favourable combined results for energy savings and life cycle costs in case of both examined sizes of dishwashers (see Box 5 below).
- Water consumption: 10.2 l/cycle (13ps model) and 11.3 l/cycle (10ps model) respectively – again, based on the scenario "C5" in the study from Boyano et al. (2017a), in order to be consistent for both values.
- All the technical improvements and changes comprised within the scenario "C5" result in an additional amount of polypropylene[10] of 0.5 kg (13ps model) and 0.4 kg (10ps model) respectively, in the composition of the "improved" dishwashers, while all the other materials (type and amount) remain constant.

Box 5. Comparison of Environmental Impacts and Life Cycle Costs for various design options for a future dishwasher (10ps)

The following figure – Figure 6.8 from Boyano et al. (2017a) – shows in one diagram the overall life cycle costs and the related environmental impacts (total energy consumption over the life cycle) for the various combinations of single design options described in that report. It shows that the optimum lies with option C5.



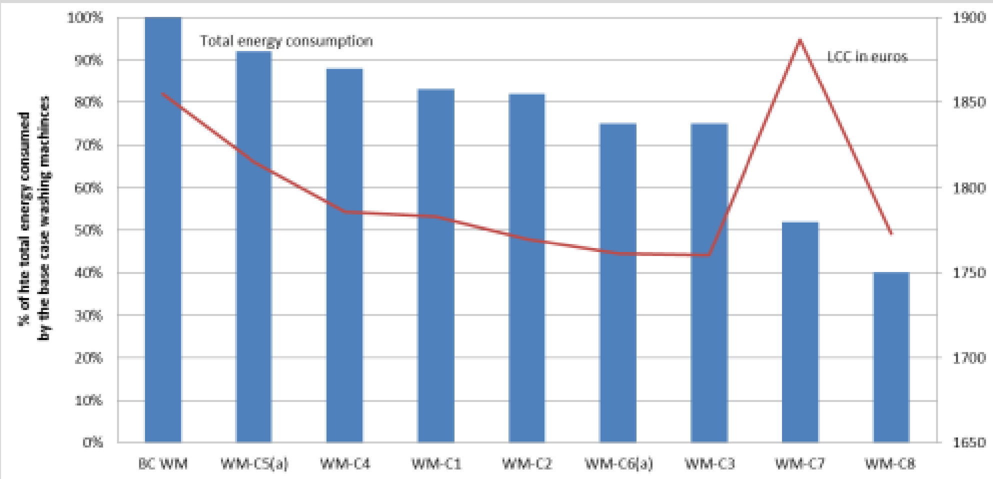
[10] Plus the "working" of this material – i.e. in this case here the process "injection moulding"

Washing Machine

- Energy consumption: 0.4368 kWh/cycle (equals to 52% of the 2013 average) – based on the combined design option "C7" from Boyano et al. (2017b). This scenario has been chosen as it shows again the most favourable combined results for energy savings and life cycle costs (see Box 6). This scenario is not requiring any changes in the composition and weight of a washing machine.
- Water consumption: 36.1 l/cycle – again (and similarly as for the dishwasher) based on a consistent choice, i.e. the combined scenario "C7" in Boyano et al. (2017b).
- Detergent: making use of the combined scenario "C7" for this BAT washing machine results also in a 15% reduction of the amount of detergent used. This latter is reduced to an amount of 64 g (powder) and 64 ml (liquid) respectively.
- Capacity of machine: a further increase of the capacity is rather counter-productive (as shown also by the very first, individual BAT measures in Boyano et al. (2017b)); as this would result in more efficiency only when consumers change/adapt their behaviour. Thus, no increase of the capacity is assumed here. Similarly, the load factor in scenario 2 is the same as in the baseline.

Box 6. Comparison of environmental impacts and Life Cycle Costs for various design options for a future washing machine

The following figure – Figure 6.6 from Boyano et al., 2017b – shows in one diagram the overall life cycle costs and the related environmental impacts (total energy consumption over the life cycle) for the various combinations of single design options described in that report. It shows that the optimum lies with option WM-C8 (i.e. the option at the right end of the diagram).



The combined design option WM-C8 includes the following design improvements: permanent magnet motor, improved load detection and adaptation, improved drenching, automatic detergent dosage, consumer feedback on loading and hot-cold filling (it is assumed that the load does not change).

As commented by the authors of the report, this option scored very well regarding GWP if all heating energy comes for free (solar heating) and without considering additional system aspects (i.e. heating system, alternative supply of energy, water supply network, losses of energy). In case of hot-fill and average mix of electricity, natural gas and oil for water heating, estimated energy saving for WM-C8 would be comparable to that of WM-C7. In addition, the use of machines with a cold-hot fill system implies substantial retrofitting of existing infrastructure in old buildings and cannot be assumed to be feasible in 100% of the houses. Therefore, option WM-C7 is considered in scenario 2.

The combined design option WM-C8 includes the following design improvements: permanent magnet motor, improved load detection and adaptation, improved drenching, automatic detergent dosage, consumer feedback on loading and heat pump.

Parameters modified in the model: Table 44 summarizes the modifications that have been made in baseline model, for each product affected by this scenario.

Table 44. Summary of the new datasets necessary for the modelling of scenario 2 "Improved efficiency dishwasher and Washing Machine".

Life Cycle Stage	**Made modifications to**		
	Dishwasher 10ps	**Dishwasher 13ps**	**Washing Machine**
Manufacturing of components	Adding of an amount of 0.4 kg polypropylene, injection moulded	Adding of an amount of 0.5 kg polypropylene, injection moulded	No modification
Manufacturing of the product	No modification	No modification	No modification
Packaging	No modification	No modification	No modification
Distribution and retail	No modification	No modification	No modification
Use phase	Correction to a use of 11.3L of water and of 0.66 kWh electricity per cycle	Correction to a use of 10.2L of water and of 0.72 kWh electricity per cycle	Correction to a use of 36.1L of water, of 0.064L detergent and of 0.4368 kWh electricity per cycle
Maintenance and repair	No modification	No modification	No modification
EoL of the product	Adding EoL treatment of additional amount of plastics: 10% incineration, 10% landfill, 80% recycling	Adding EoL treatment of additional amount of plastics: 10% incineration, 10% landfill, 80% recycling	No modification

Results: In Figure 17 and Figure 18 the results of this scenario are compared with the results from the baseline scenario. In Figure 17 they are split into the contributions from the different product groups, in Figure 18 they are split into the shares of the different life cycle stages distinguished here. Each of the two figures is going along with a table, showing the relative changes (in %) in the different product groups and life cycle stages (Table 45 and Table 46).

Figure 17. Scenario 2 in comparison with the baseline scenario (with total from the baseline set as 100%) – split into the contributions of the various product groups. (For the abbreviations see table note of Table 42)

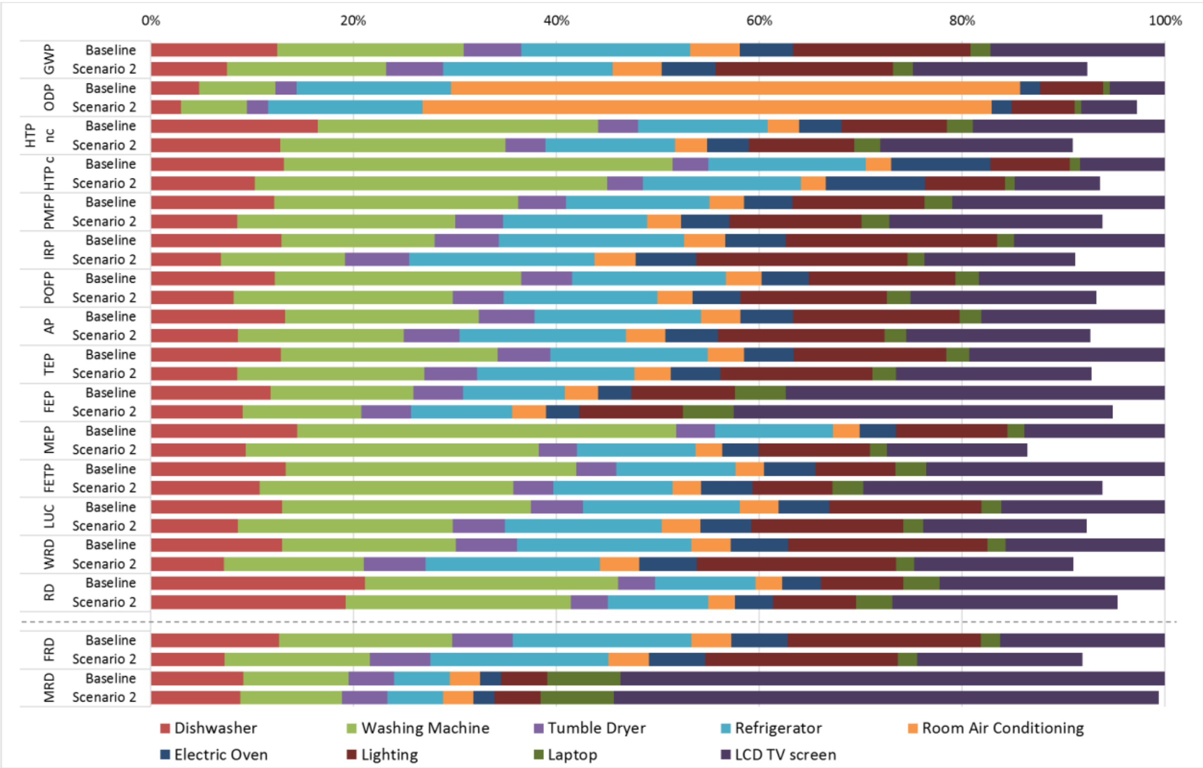


Figure 18. Scenario 2 in comparison with the baseline scenario (with the total impacts of the baseline set as 100%) – split into the contributions of the various life stages. (For the abbreviations see table note of Table 42)

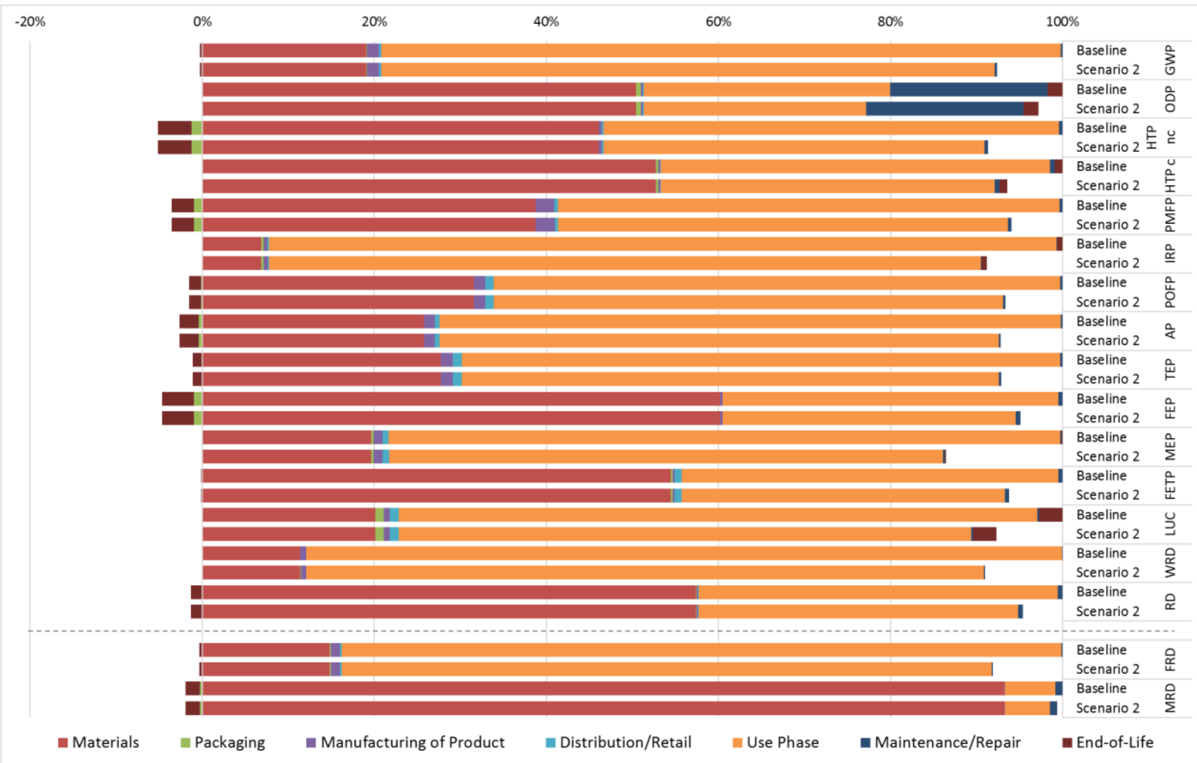


Table 45. Relative changes of the various product groups when comparing Scenario 2 with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	Total	Dish-washer	Washing Machine	Tumble Dryer	Refrige-rator	Room Air Cond.	Electric Oven	Lighting	Laptops	LCD TV Screen
GWP	-7.7%	-39.7%	-14.7%	-	-	-	-	-	-	-
ODP	-2.8%	-36.9%	-13.8%	-	-	-	-	-	-	-
HTP nc	-9.1%	-22.3%	-19.7%	-	-	-	-	-	-	-
HTP c	-6.4%	-21.8%	-9.3%	-	-	-	-	-	-	-
PMFP	-6.2%	-29.9%	-10.6%	-	-	-	-	-	-	-
IRP	-8.8%	-46.0%	-19.2%	-	-	-	-	-	-	-
POFP	-6.8%	-33.1%	-11.1%	-	-	-	-	-	-	-
AP	-7.4%	-34.9%	-14.5%	-	-	-	-	-	-	-
TEP	-7.2%	-33.2%	-13.9%	-	-	-	-	-	-	-
FEP	-5.2%	-23.1%	-17.3%	-	-	-	-	-	-	-
MEP	-13.6%	-35.2%	-22.7%	-	-	-	-	-	-	-
FETP	-6.2%	-19.1%	-12.8%	-	-	-	-	-	-	-
LUC	-7.7%	-33.3%	-13.8%	-	-	-	-	-	-	-
WRD	-9.0%	-44.5%	-18.9%	-	-	-	-	-	-	-
RD	-4.7%	-9.1%	-11.0%	-	-	-	-	-	-	-
FRD	-8.2%	-42.4%	-16.2%	-	-	-	-	-	-	-
MRD	-0.7%	-3.1%	-3.5%	-	-	-	-	-	-	-

([1]) Abbreviations, see table note at Table 42

Table 46. Relative changes of the various life stages when comparing Scenario 2 with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	Total	Materials	Packaging	Production	Distribu-tion	Use	Main-tenance	End-of-Life
GWP	-7.7%	0.032%	-	-	-	-9.7%	-	-0.5%
ODP	-2.8%	0.001%	-	-	-	-9.8%	-	0.0%
HTP nc	-9.1%	0.002%	-	-	-	-16.4%	-	0.0%
HTP c	-6.4%	0.004%	-	-	-	-14.2%	-	-0.1%
PMFP	-6.2%	0.016%	-	-	-	-10.3%	-	-0.1%
IRP	-8.8%	0.022%	-	-	-	-9.7%	-	0.1%
POFP	-6.8%	0.024%	-	-	-	-10.1%	-	-0.2%
AP	-7.4%	0.017%	-	-	-	-10.0%	-	-0.0%
TEP	-7.2%	0.019%	-	-	-	-10.3%	-	-0.2%
FEP	-5.2%	0.002%	-	-	-	-12.6%	-	-0.0%
MEP	-13.6%	0.019%	-	-	-	-17.4%	-	-1.0%
FETP	-6.2%	0.005%	-	-	-	-14.1%	-	-0.8%
LUC	-7.7%	0.015%	-	-	-	-10.4%	-	-0.0%
WRD	-9.0%	0.019%	-	-	-	-10.3%	-	1.2%
RD	-4.7%	0.001%	-	-	-	-11.0%	-	0.0%
FRD	-8.2%	0.061%	-	-	-	-9.7%	-	-1.1%
MRD	-0.7%	0.000%	-	-	-	-10.8%	-	0.0%

([1]) Abbreviations, see table note at Table 42

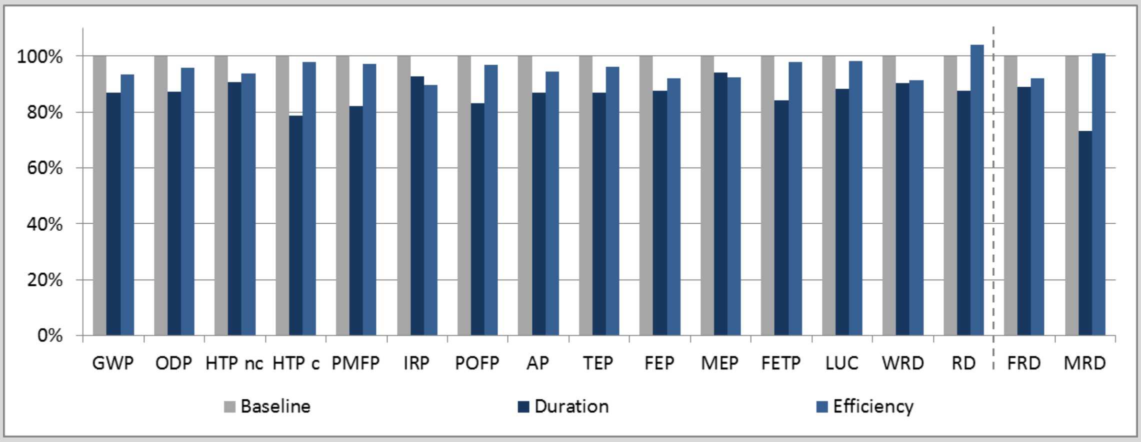
Due to the fact that the increase in efficiency of these devices results in one case also in a change of the material composition (i.e. some more plastics are used), the results are not only related to the use phase, but some small changes are coming from the material as well as the end-of-life treatment (see Table 46). However, the majority of the overall reduction/change is still due to the lowering of the electricity consumption during the use of these two devices.

While a broad majority of the examined impacts shows a reduction in the order of about 8%; there are few exceptions with mineral resource depletion that shows hardly any changes (this is a metal and mineral resource indicator depending on the infrastructure, i.e. the device, and not its electricity consumption level), or ozone depletion and marine eutrophication that show a much less big reduction potential. Again, these indicators can be explained by other dominating effects – e.g. ozone depletion is largely dominated by the air conditioner and its refrigerant gas; and MEP due to nitrogen oxides releases (mainly coming from the coal power plants for the electricity production). Obviously, on the level of the contribution by the different examined devices, only the dishwasher and the washing machine contribute here (see Table 45).

What has actually the higher influence on such a kind of devices, a prolongation of the lifetime (as examined later on in Scenario 8a), or the use of the most energy efficient device? Box 7 shows the results to this question for a washing machine, comparing an increase of the lifetime from 12.5 years to 18.75 years (i.e. plus 50%) with a "new" washing machine, consuming 0.44 kWh/cycle and 46.8 l water/cycle[11].

Box 7. Comparison of a longer lifetime versus an increased efficiency of a new machine (for the example of the washing machine)

The following figure shows a comparison of three different models for the washing machine – the baseline scenario, a 50% longer use of the same machine (scenario called "duration"), and a "new" washing machine that is consuming less energy and water (but again is only used 12.5 years, as in the baseline – i.e. the scenario "efficiency"). Shown are the impacts per washing cycle.



Under the chosen boundaries (increase of 50% of lifetime vs. most efficient energy consumption), if there is a difference between the two options, this is in almost all cases in favor of the "duration" – i.e. a prolongation of the lifetime. Only few impact categories (e.g. ionizing radiation and marine eutrophication) show a slight decrease in favor of a higher energy efficiency – those two impact categories are dominated by 80%, or even more, by the use phase (in the baseline scenario) and thus react more on the reduction of the energy consumption in the "efficiency" scenario.

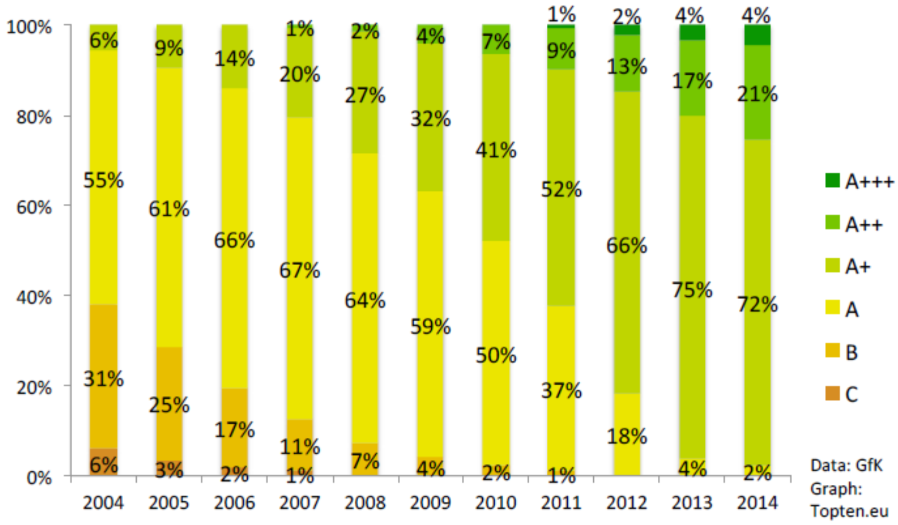
[11] Being the result from the assumption that in average 220 washing cycles per year are made with the most energy efficient washing machine with 8 kg capacity listed on www.topten.eu – consuming 97 kWh/year and 10'300 L water/year (as per End of October 2017).

8.4 Scenario 3: Improved efficiency of the combined refrigerator-freezer

Description and aim: The aim of Scenario 3 is to investigate – in a similar manner as in the preceding case – the (maximal) overall potential that lies within the area of a further, energy "peckish" device – the refrigerator.

Actually, in the base case calculations the refrigerator shows about a similar relevance in terms of environmental impacts as the two preceding types of household appliances (dishwasher and washing machine), being also in this case the result of the electricity consumption in the use phase. Furthermore, also the category of refrigerators has had a steadily development over the past years and the average energy consumption has decreased quite a lot for such devices between 2010 and 2015 as this is highlighted in Figure 19 – showing that in (2015) almost one third of all devices belonged to efficiency classes that barely had any kind of market relevance 5 years earlier (or even have not been on the market).

Figure 19. Efficiency classes of refrigerator sales across the European Union



Source: Michel et al. 2016.

As the environmental impacts of this kind of appliances is almost exclusively depending on the energy consumption in the use phase (e.g. Xiao et al. (2015) shows that the use phase is responsible for 5 times more impacts than the production of such a device – a similar value is shown in VHK and ARMINES 2016, reporting a 74% contribution of the use phase to the overall GWP impacts of an average European refrigerator in 2014), the further investigations and discussions for the third scenario are limited to the issue of "energy consumption during the use phase".

The final (review) report of the preparatory study for eco-design and energy labels of refrigerators (VHK and ARMINES, 2016), published in spring 2016, reports for new devices of combined refrigerator-freezer (with a volume of 215.6L in the refrigerator part and 93.9L in the freezer part) a decreasing, average annual electricity consumption ranging from 324 kWh/year (for the average model, sold in 2005) to 259 kWh/year for the average model in 2014. The value for 2010 of 290 kWh/year, used in the baseline scenario, has been extrapolated from a draft version of this preparatory study (assuming a linear decrease), using for 2005 a slightly higher value (329 kWh/year). A comparison of these values with other reports is quite difficult, as the energy consumption depends on the exact model taken into account in each study. According to the preparatory study for refrigerator (VHK and ARMINES 2016), there is a linear relationship between the volume and the energy consumption of such type of household appliances (looking on the same type of appliances, e.g. a combined refrigerator-freezer).

As for the two preceding product categories (i.e. dishwasher, washing machine), the used report gives in addition also a comprehensive overview of a variety of future options for a further optimization of the impacts of the various types of refrigerators. Individually examined, the various design options could lead for the here used combined refrigerator-freezer a reduction potential for the energy consumption of 4 to 29%, compared to the 2014 value (VHK and ARMINES, 2016). When combining some of this options, the experts behind the mentioned preparatory study end-up with a potential reduction of the energy consumption for a "BAT" device from 259 kWh/year to 112 kWh/a – i.e. a reduction of 57%.

According to the same report, the refrigerator has gained in the time period since then not only in volume, but got also heavier in weight. This is mainly due to the thicker walls and the replacement of the steel-wire shelves by glass shelves. Among the different options for further improvement, the increase of the insulation thickness is one of the most relevant issues. According to VHK and ARMINES (2016), the maximum increase of the (average) wall thickness for a combined refrigerator-freezer is from 5.9 to 10 cm and with this comes – in order to keep the refrigerated volume constant – an increase of the outer dimensions (i.e. 1.8m x 0.68m x 0.68m instead of 1.7m x 0.59m x 0.59m). As the "BAT" device is a combination of various options, it can be assumed that this latter will result in these maximum dimensions.

<u>Area of intervention</u>: Similarly to Scenario 2, these developments have an influence on the key parameters of the use phase of the here covered category, i.e. the refrigerator. Besides this, the composition of the device is influenced by the higher insulation requirements and the resulting changes in the overall dimension of the device.

<u>Policy relevance</u>: Ecodesign Directive (EC, 2009a), Energy Efficiency Directive (EU, 2012b) and Roadmap to a Resource Efficient Europe (EC, 2011b)

<u>Rationale for building the scenario</u>: For the energy consumption in Scenario 3, the value from the "BAT" device in VHK and ARMINES (2016) of 112 kWh/a is used. In order to achieve this low energy consumption, a 70% thicker insulation layer (i.e. 10 cm instead of 5.9 cm) is required and the outer dimension of the device will increase as listed above. Due to a lack of respective information in the examined studies and report, this increase in the dimension is translated as follows into the BoM of the device:

- increase of the amount of insulation material (i.e. PU foam-insulation) of 70%;
- increase of the amount of steel sheets, aluminium, and polystirene of 13% (representing the increase of the refrigerator envelope surface of 13%);
- for the packaging materials, an increase of 24% of the various materials is assumed (in accordance with the increase of the surface of the carton box, as calculated according to an instruction manual of the packaging industry – HPV (2013));
- all remaining elements in the BoM of the baseline scenario have been taken over without any changes (assuming that their amount is actually not depending on the outer dimension, but the refrigerated/frozen inside area of this device).

<u>Parameters modified in the model</u>: Table 47 summarizes the modifications that have been made in baseline model, for the product affected by this scenario, i.e. the refrigerator.

Table 47. Summary of the new datasets necessary for the modelling of scenario 3 "Improved efficiency of the combined refrigerator-freezer".

Life Cycle Stage	**Made modifications to Refrigerator**
Manufacturing of components	Adding 13% of the amount to the following inputs: - steel, low-alloyed, without transport & sheet rolling - zinc (as coating element) - aluminium, primary ingot & sheet rolling - polystyrene, general purpose Adding 70% of the amount of insulation material in form of the PUR dataset (polyurethane, rigid form)
Manufacturing of the product	No modification
Packaging	Adding 24% to all input data into this dataset (to represent the increase in packaging material required for the bigger size of this BAT device) Adding EoL treatment of additional packaging material (same EoL treatment as default amount), i.e. adding 24% to all inputs in the various EoL datasets of the packaging material
Distribution and retail	Correction of all transport efforts (due to the new weight of 86.03 kg for the BAT refrigerator device, including packaging)
Use phase	Correction of energy consumption from 4'352 to 1'680 kWh (for the complete life-time of such a device); Correction of the Transport from 18.626 to 21.501 tkm (taking into account the higher weight of the BAT refrigerator device)
Maintenance and repair	No modification
EoL of the product	Adding EoL treatment of additional amounts of steel, aluminium, polystyrene and polyurethane (i.e. insulation material) keeping the original split between the various EoL treatment options. Correction of energy consumption in the various EoL treatment options in relation to these modified amounts.

Results: In Figure 20 and Figure 21 the results of Scenario 3 are compared with the results from the baseline scenario. In Figure 20 they are split into the contributions from the different product groups, in Figure 21 they are split into the shares of the different life cycle stages distinguished here. Each of the two figures is going along with a table, showing the relative changes (in %) in the different product groups and the different life cycle stages, respectively.

Figure 20. Scenario 3 in comparison with the baseline scenario (with total from the baseline set as 100%) – split into the contributions of the various product groups. (For the abbreviations see table note of Table 42)

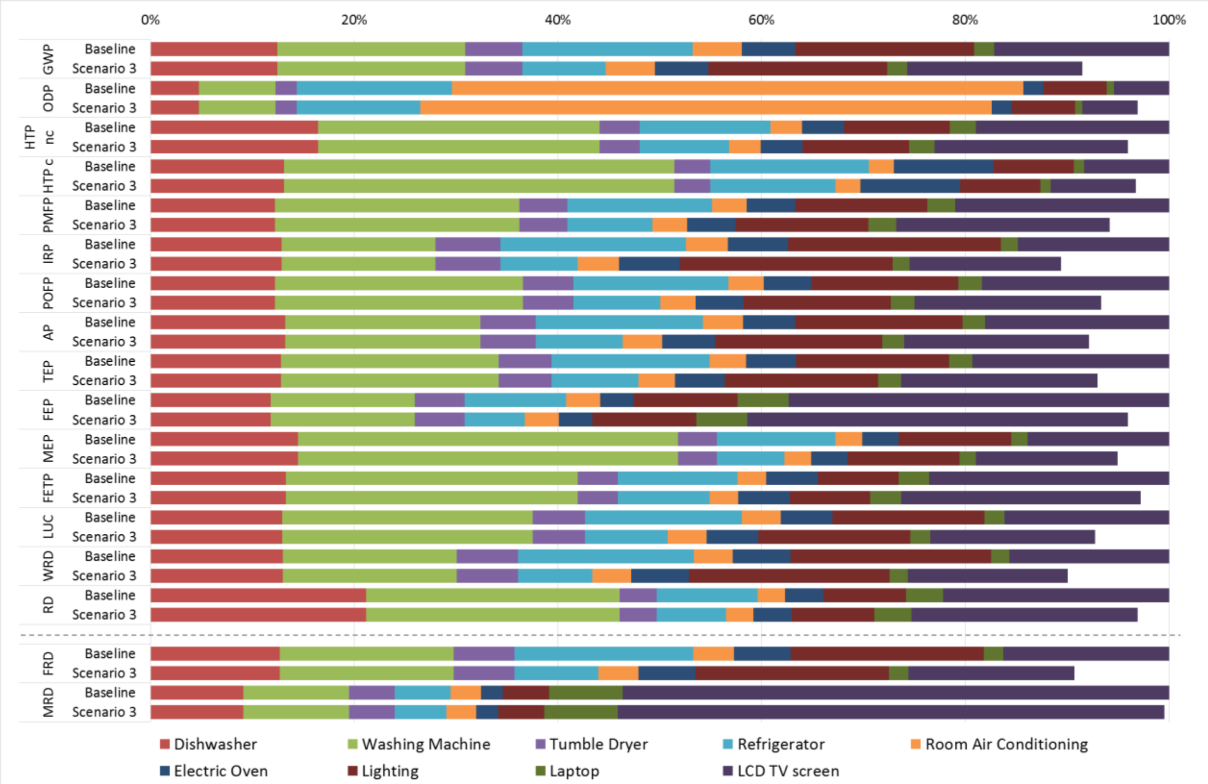


Figure 21. Scenario 3 in comparison with the baseline scenario (with the total impacts of the baseline set as 100%) – split into the contributions of the various life stages. (For the abbreviations see table note of Table 42)

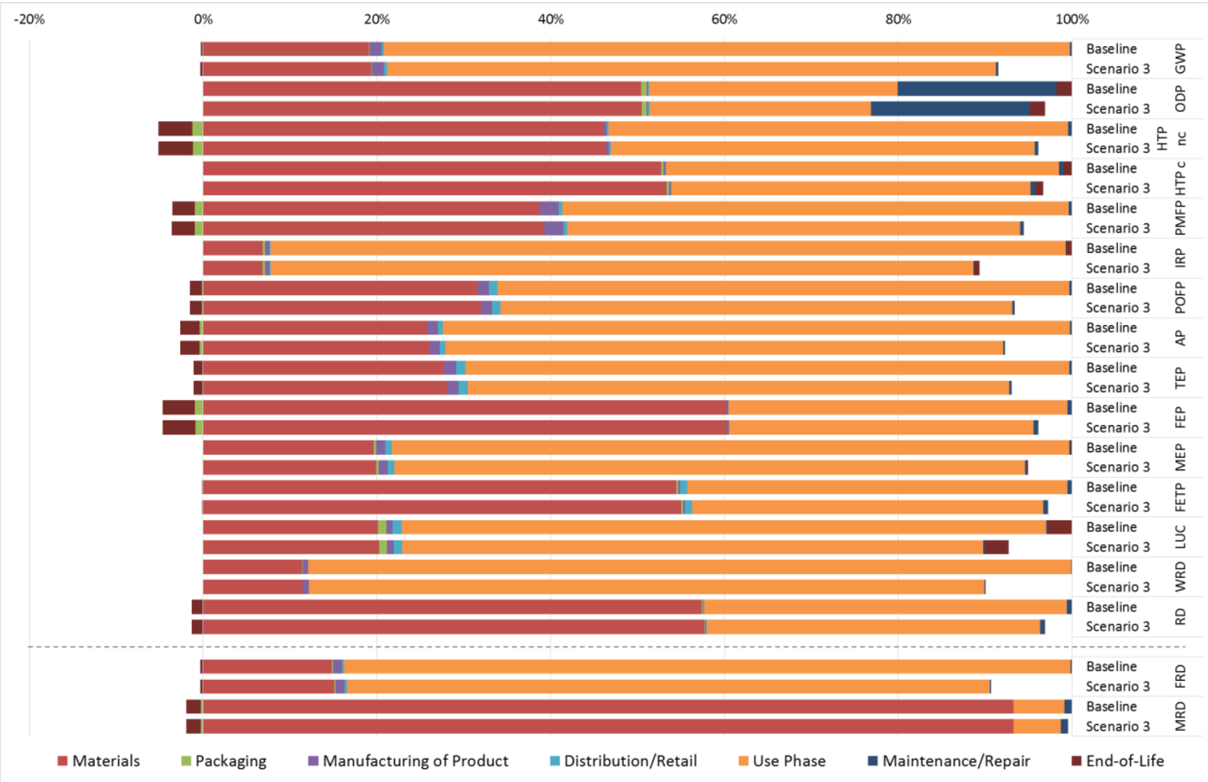


Table 48. Relative changes of the various product groups when comparing Scenario 3 with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	Total	Dish-washer	Washing Machine	Tumble Dryer	Refrige-rator	Room Air Cond.	Electric Oven	Lighting	Laptops	LCD TV Screen
GWP	-8.5%	-	-	-	-51.1%	-	-	-	-	-
ODP	-3.1%	-	-	-	-20.4%	-	-	-	-	-
HTP nc	-4.0%	-	-	-	-31.5%	-	-	-	-	-
HTP c	-3.3%	-	-	-	-21.2%	-	-	-	-	-
PMFP	-5.8%	-	-	-	-41.0%	-	-	-	-	-
IRP	-10.6%	-	-	-	-58.3%	-	-	-	-	-
POFP	-6.7%	-	-	-	-43.9%	-	-	-	-	-
AP	-7.9%	-	-	-	-48.1%	-	-	-	-	-
TEP	-7.0%	-	-	-	-45.1%	-	-	-	-	-
FEP	-4.0%	-	-	-	-40.5%	-	-	-	-	-
MEP	-5.1%	-	-	-	-43.3%	-	-	-	-	-
FETP	-2.8%	-	-	-	-23.5%	-	-	-	-	-
LUC	-7.3%	-	-	-	-47.3%	-	-	-	-	-
WRD	-10.0%	-	-	-	-57.9%	-	-	-	-	-
RD	-3.1%	-	-	-	-31.4%	-	-	-	-	-
FRD	-9.3%	-	-	-	-53.0%	-	-	-	-	-
MRD	-0.5%	-	-	-	-8.4%	-	-	-	-	-

([1]) Abbreviations, see table note at Table 42

Table 49. Relative changes of the various life cycle stages when comparing scenario 3 with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	**Total**	**Materials**	**Packaging**	**Production**	**Distribu-tion**	**Use**	**Main-tenance**	**End-of-Life**
GWP	-8.5%	1.50%	21.8%	-	4.6%	-11.1%	-	-12.8%
ODP	-3.1%	0.03%	0.5%	-	4.6%	-11.0%	-	0.5%
HTP nc	-4.0%	0.50%	0.6%	-	4.4%	-7.7%	-	-0.3%
HTP c	-3.3%	1.15%	2.4%	-	4.6%	-8.6%	-	-1.8%
PMFP	-5.8%	1.29%	0.0%	-	4.8%	-10.4%	-	-1.8%
IRP	-10.6%	0.29%	1.7%	-	4.6%	-11.6%	-	0.8%
POFP	-6.7%	1.16%	15.2%	-	4.9%	-10.6%	-	-2.3%
AP	-7.9%	0.91%	3.4%	-	5.0%	-11.0%	-	-1.1%
TEP	-7.0%	1.03%	34.4%	-	4.9%	-10.4%	-	-2.5%
FEP	-4.0%	0.11%	0.3%	-	4.7%	-10.1%	-	-0.0%
MEP	-5.1%	1.35%	5.5%	-	4.9%	-6.9%	-	10.6%
FETP	-2.8%	0.95%	10.1%	-	4.3%	-7.6%	-	-10.4%
LUC	-7.3%	0.38%	0.2%	-	4.5%	-10.0%	-	0.4%
WRD	-10.0%	0.55%	24.7%	-	4.8%	-11.4%	-	-15.0%
RD	-3.1%	0.42%	20.3%	-	4.3%	-8.0%	-	0.3%
FRD	-9.3%	2.06%	13.1%	-	4.6%	-11.5%	-	-8.0%
MRD	-0.5%	0.04%	0.8%	-	4.4%	-8.4%	-	0.1%

([1]) Abbreviations, see table note at Table 42

Also in this case, the increase in efficiency of the device goes together with a change of the material composition and of its packaging (due to a change of the outer diameters). The results are not only related to the use phase (see Table 49), but changes can be observed also on the level of materials, packaging and distribution (mainly an increase due to the higher weight) as well as on the end-of-life treatment (a higher reduction due to the higher material amount for recycling). Again, the highest changes take place in the area of the use phase due to the lowering of the electricity consumption in the use phase of a refrigerator.

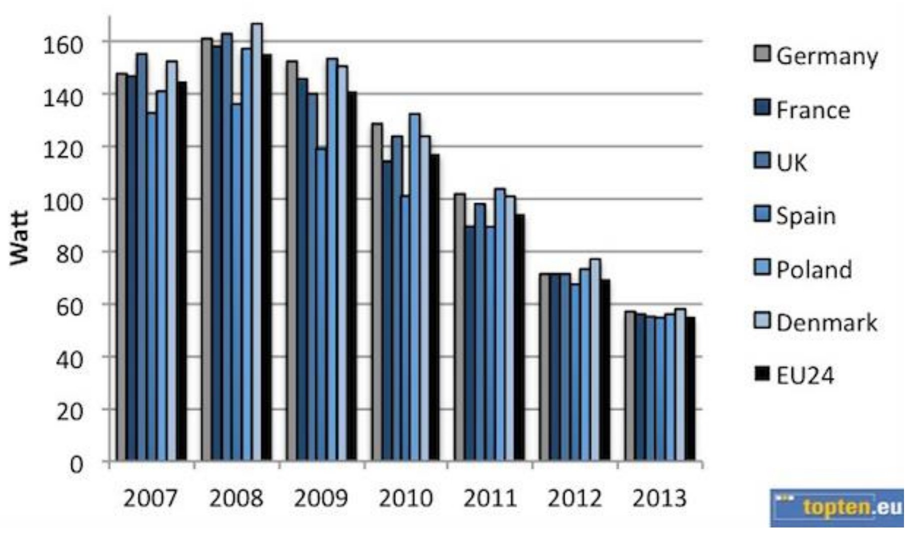
Compared to the Scenario 2, Scenario 3 shows a similar picture – but with a much higher reduction. The majority of the examined impact categories show a reduction in the order of about 45/50%; there are few exceptions with mineral resource depletion that shows only about 10% reduction, or ozone depletion, human toxicity cancer and freshwater eutrophication that show a reduction potential in the order of 20% only. All these indicators can be explained by other dominating effects – e.g. ozone depletion is largely dominated by the air conditioner and its refrigerant gas; human toxicity cancer that is largely dominated by the impacts from the Dishwasher and washing machine and freshwater eutrophication with its impacts dominated by copper releases to water (from the electricity transfer processes in the use phase) and by zinc releases to water (mainly from various mining processes for the used raw materials).

8.5 Scenario 4: Improved efficiency television device

Description and aim: Again similar as in the preceding cases – the aim of Scenario 4 is to investigate the (maximal) overall potential that lies within the area of the most popular ICT device in a household, the television device.

According to a recent study by Hoxha and Jusselme (Hoxha and Jusselme, 2017) about the environmental impacts of furniture and appliances in highly energy efficient buildings, television devices are the third most energy consuming element, just behind refrigerators and kitchen ovens. In the baseline scenario, the television device shows an impact that is about similar to the one of the dishwasher and the refrigerator; but clearly a lower impact than the washing machine. Similar to all these devices, its impact is due to the electricity consumption in the use phase – however, as shown in Figure 22, this energy consumption is steadily decreasing for new devices since 2008, with about 50% reduction between 2010 and 2013.

Figure 22. Average power requirements (in W) of new television devices in the active mode.



Source: Michel et al. (2014) (data for DE,PL,DK are without cathode-ray tube (CRT)).

One reason for this continuing decrease lies in the technological developments; resulting e.g. in changes of the dominant television technology on the market (e.g. LCD television devices with an LED backlight made only about 9% of the sales in 2009 – in 2014 they dominated the market by 92%). The average screen size of the sold television devices increased in the past years – showing an average of 35′′ for 2013, compared to less than 30′′ in 2007 (Michel et al., 2014). Overall, new devices are much more efficient than the older generation. In the same time, sales figures since 2010 show a net decrease of the annually sold number of television devices – i.e. in 2013 41 million units have been sold in the EU, compared to 56 million units 3 years earlier (i.e. in 2010).

The work on an updated version of the preparatory study for television devices from 2007 (e.g. Stobbe, 2007) is currently still on-going; most recent publication is the third revision of a technical report with criteria proposals (Vidal-Abarca Garrido et al., 2014). Opposite than in the preceding two scenarios (for dishwasher, washing machine, and refrigerator), this draft of the technical report does not deal with future options for an optimization of the impacts of television devices. The following deduction of an energy efficiency scenario for this study is therefore based on a literature search in view of "the most (energy) efficient television" (i.e. the BAT technology, identifiable by such a literature search).

A review paper of LCA-related publications dealing with ICT devices (among them also television) has been published recently by Subramanian and Yung (2016). The authors summarized the outcomes of more than 10 different LCA studies about television devices that have been published since 2002. According to this analysis, most of the LCA studies highlight that apart the use phase, also the production of such a device is significantly contributing to the overall impacts. However, all the LCA studies listed there are considering current devices; none of these studies is dealing with the (saving/optimisation) potentials in such a device. Actually, this result is in accordance with the criteria proposed in the on-going preparatory study (Vidal-Abarca Garrido et al., 2014); then this draft is not only containing a part about energy savings, but also a part about hazardous substances and lifetime extension. However, neither the review study nor its "reviewed" documents allow any quantitative statements about how such a BAT television device would look like (i.e. technical composition) and behave (i.e. energy consumption in the use phase).

Park and co-workers at the Lawrence Berkeley National Laboratory (LBNL) in the United States and the "bigEE" initiative of the Wuppertal Institute in Germany published in the past couple of years several documents dealing with the saving potentials related to TVs (Park et al., 2011; Götz, 2015a; Götz, 2015b; Park et al., 2017). According to the most recent analysis of Park and colleagues, an energy-efficient LED-LCD television results in its active mode in an energy consumption of 0.06-0.14 W/in^2 (Park et al., 2017) and of 0.5 W in the stand-by mode. Götz (2015b) reported that the BAT is equal to an average energy consumption of 26.6 kWh/a (for television screens < 32′′), 51.8 kWh/a (screens of 32-46′′), and 84 kWh/a (screens > 46′′) respectively – values based on 4h of active and 20h of standby mode per day. However, when translating the latter data into the consumption per square-inch and vice-versa, an important divergence between the two data sources could be observed, as summarized in the Table 50.

Table 50. Energy consumption of BAT television devices

	Efficient LED-LCD Television				
Screen size [in inches]	28″	32″	39″	46″	55″
Energy consumption: - active mode [in W/in^2] - standby [in W] (reported in Park et al., 2017)	0.06-0.14 0.5				
Calculated annual energy demand [in kWh/a][(1)] (with 4h active, 20h standby)	72.3	93.3	136.9	189.0	268.6
Annual energy demand [in kWh/a] of a BAT-device (reported in Götz, 2015b)	26.6	51.8			84
Calculated active mode consumption [in W/in^2][(2)] (using 0.5W for standby)	0.020	0.032	0.022	0.016	0.018

(1) Calculated by using the average active mode consumption of 0.1 W/in^2, the screen size as indicated in the top line of this table, for an active use of 4h/day over 365 days, plus the remaining time per day in standby with a consumption of 0.5W (independent from the size of the screen).

(2) Calculated the other way around. Again, by using the screen sizes indicated in the top line of this table.

Area of intervention: Similarly as in the last two scenarios, first of all these assumptions for a BAT television device influence the key parameter of the use phase, i.e. the energy consumption. Another area of intervention is the screen size – a continuous increase has to be assumed here, based on the available information/statistics. Last but not least, the decreasing sales numbers can be used as a hint for an increasing lifetime of modern TV devices; an issue that is investigated in an additional calculation run – shown at the end of this section.

Policy relevance: Ecodesign Directive (EC, 2009a), Energy Efficiency Directive (EU, 2012b), and Roadmap to a Resource Efficient Europe (EC, 2011b)

Rationale for building the scenario: The lowest range from the overview in Table 50 – i.e. an amount of 0.02 W/in^2 – is used for the BAT technology in this scenario. Concerning the actual size of such a BAT television, it is assumed (due to a lack of more recent information) that the increase of the average size of sold television devices will continue in a similar manner as it developed in the time from 2007 to 2013, when the average screen size increased by 20%, up to 35 inches (Michel et al., 2014). Using this basic assumption and looking on a time horizon up to 2025, an average screen size of 46 inches is the value that results. This results in an annual energy consumption of the BAT television of 65.4 kWh (assuming 4 hours per day active, and the other 20 hours in standby). Concerning the lifetime of this BAT television, no change in comparison to the baseline scenario is applied – i.e. also such a television device is assumed lasting 6 years.

In accordance with modelling principles applied e.g. in the study of Hischier and Baudin (2010), and due to a lack of more recent information on this topic, the relative composition of a television devices is assumed to be independent from its actual size. Hence, the composition of the baseline device – representing a 32 inch screen – is also applied for the BAT television device in this scenario. Concerning its weight, a short survey of 43 and 49 inch televisions sold on Amazon.DE (and labelled as "model 2017") shows a weight in the order of 9.5 kg for 43″, about 14.5kg for 46″ – which then results in a weight of 12 kg for the BAT television; a value that is rather close to the 11.2 kg of the 32 inch television of the baseline scenario. In a first approach, the values from the baseline scenario are therefore used for this BAT television device without any modifications.

Parameters modified in the model: Table 51 summarizes the modifications that have been made in baseline model, for the product affected by this scenario, i.e. the LCD television.

Table 51. Summary of the new datasets necessary for the modelling of Scenario 4 "Improved efficiency television device".

Life Cycle Stage	**Made modifications to Television Device**
Manufacturing of components	No modification
Manufacturing of the product	No modification
Packaging	No modification
Distribution and retail	No modification
Use phase	Correction of energy consumption from 1161.3 to 392 kWh (for the complete life-time of such a device)
Maintenance and repair	No modification
EoL of the product	No modification

Results: In Figure 23 and Figure 24 the results of this scenario are compared with the respective results from the baseline scenario. In Figure 23 they are split into the contributions from the different product groups, in Figure 24 they are split into the shares of the different life cycle stages distinguished here. Each of the two figures is going along with a table, showing the relative changes (in %) in the different product groups and the different life cycle stages, respectively (Table 52 and Table 53). The effects of an increased lifetime on these results are further investigated and results are shown in Box 8.

Figure 23. Scenario 4 in comparison with the baseline scenario (with total from the baseline set as 100%) – split into the contributions of the various product groups. (For the abbreviations see table note of Table 42)

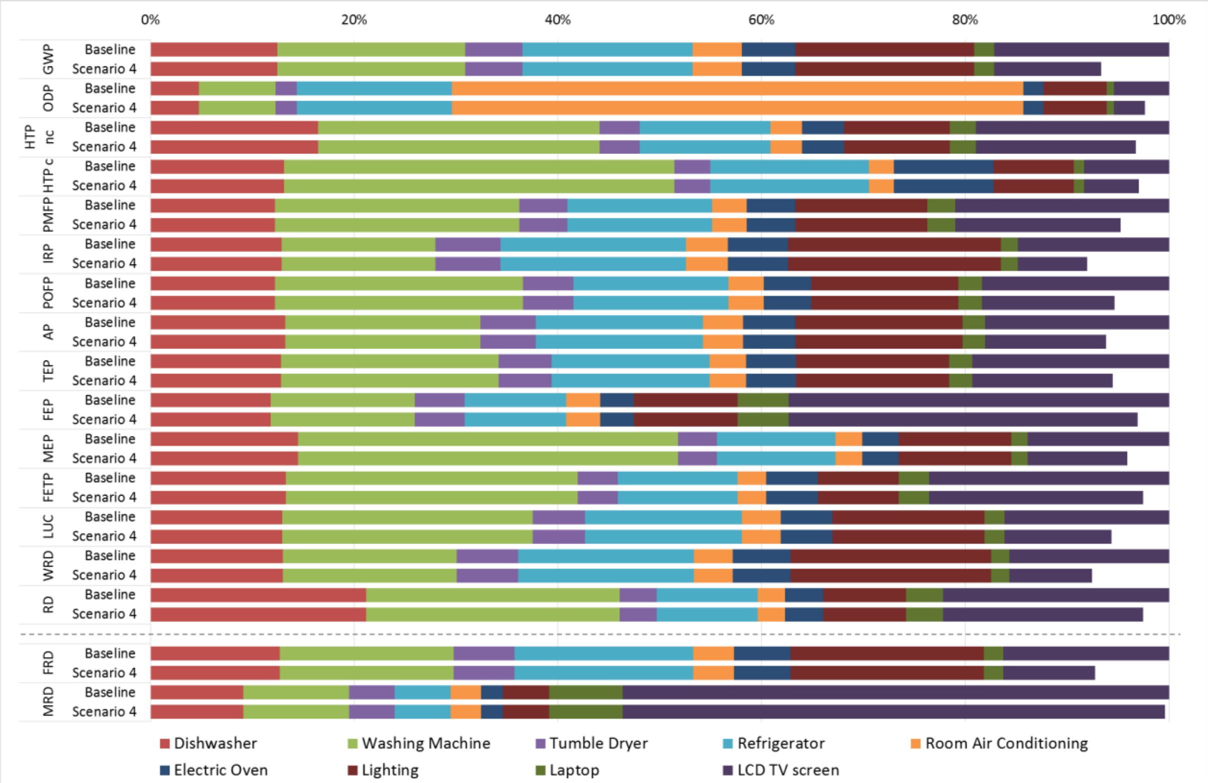


Figure 24. Scenario 4 in comparison with the baseline scenario (with the total impacts of the baseline set as 100%) – split into the contributions of the various life stages. (For the abbreviations see table note of Table 42)

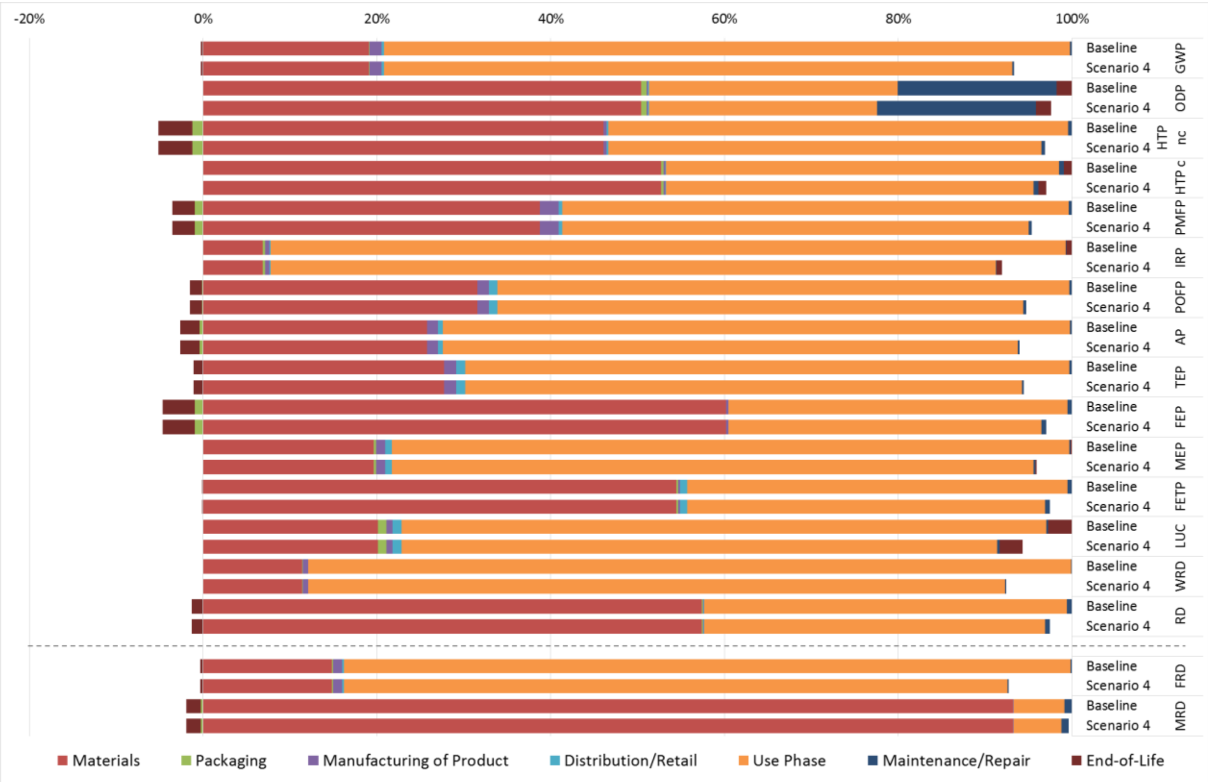


Table 52. Relative changes of the various product groups when comparing Scenario 4 with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	Total	Dish-washer	Washing Machine	Tumble Dryer	Refrige-rator	Room Air Cond.	Electric Oven	Lighting	Laptops	LCD TV Screen
GWP	-6.7%	-	-	-	-	-	-	-	-	-38.8%
ODP	-2.4%	-	-	-	-	-	-	-	-	-43.6%
HTP nc	-3.3%	-	-	-	-	-	-	-	-	-17.1%
HTP c	-2.9%	-	-	-	-	-	-	-	-	-35.2%
PMFP	-4.8%	-	-	-	-	-	-	-	-	-22.8%
IRP	-8.1%	-	-	-	-	-	-	-	-	-54.3%
POFP	-5.4%	-	-	-	-	-	-	-	-	-29.2%
AP	-6.2%	-	-	-	-	-	-	-	-	-34.1%
TEP	-5.6%	-	-	-	-	-	-	-	-	-28.8%
FEP	-3.1%	-	-	-	-	-	-	-	-	-8.3%
MEP	-4.1%	-	-	-	-	-	-	-	-	-29.4%
FETP	-2.5%	-	-	-	-	-	-	-	-	-10.7%
LUC	-5.6%	-	-	-	-	-	-	-	-	-34.9%
WRD	-7.6%	-	-	-	-	-	-	-	-	-48.3%
RD	-2.6%	-	-	-	-	-	-	-	-	-11.5%
FRD	-7.3%	-	-	-	-	-	-	-	-	-44.7%
MRD	-0.4%	-	-	-	-	-	-	-	-	-0.7%

([1]) Abbreviations, see table note at Table 42

Table 53. Relative changes of the various life stages when comparing Scenario 4 with the baseline scenario (relative to the result in the baseline scenario)

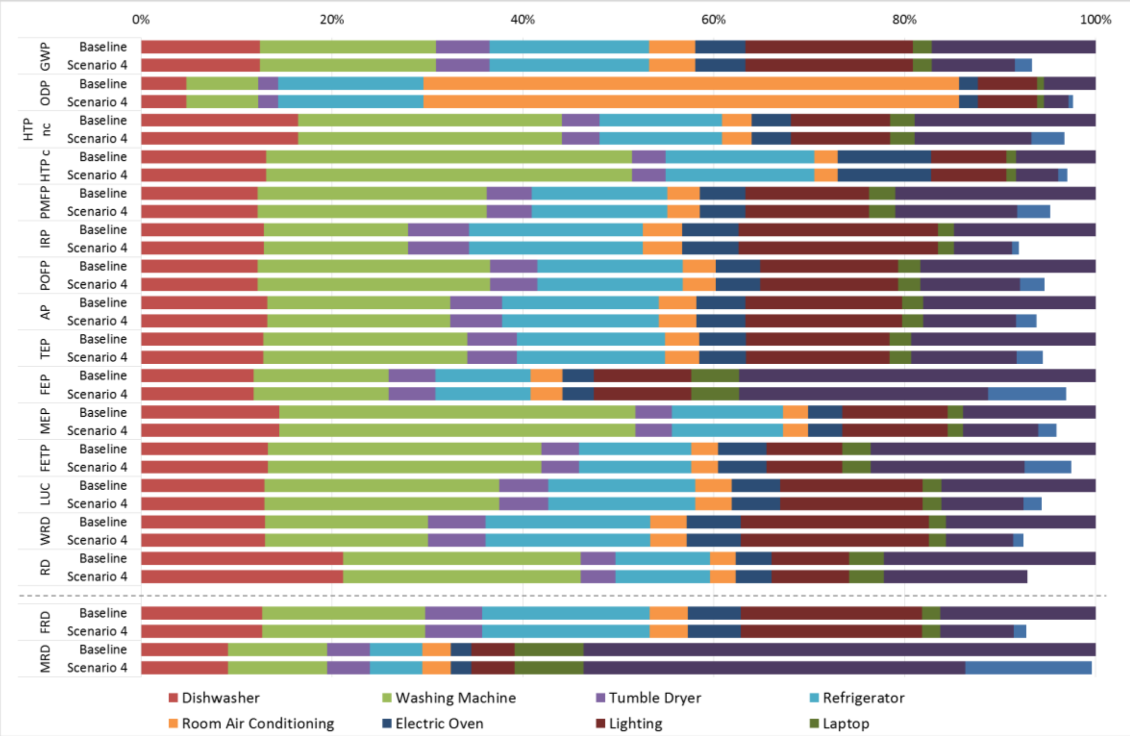
Impact Category([1])	Total	Materials	Packaging	Production	Distribu-tion	Use	Main-tenance	End-of-Life
GWP	-6.7%	-	-	-	-	-8.4%	-	-
ODP	-2.4%	-	-	-	-	-8.3%	-	-
HTP nc	-3.3%	-	-	-	-	-5.8%	-	-
HTP c	-2.9%	-	-	-	-	-6.5%	-	-
PMFP	-4.8%	-	-	-	-	-7.9%	-	-
IRP	-8.1%	-	-	-	-	-8.8%	-	-
POFP	-5.4%	-	-	-	-	-8.0%	-	-
AP	-6.2%	-	-	-	-	-8.3%	-	-
TEP	-5.6%	-	-	-	-	-7.9%	-	-
FEP	-3.1%	-	-	-	-	-7.6%	-	-
MEP	-4.1%	-	-	-	-	-5.2%	-	-
FETP	-2.5%	-	-	-	-	-5.8%	-	-
LUC	-5.6%	-	-	-	-	-7.6%	-	-
WRD	-7.6%	-	-	-	-	-8.6%	-	-
RD	-2.6%	-	-	-	-	-6.0%	-	-
FRD	-7.3%	-	-	-	-	-8.7%	-	-
MRD	-0.4%	-	-	-	-	-6.3%	-	-

([1]) Abbreviations, see table note at Table 42

As it could be seen in Table 53, all the changes result from the use phase; as in this scenario, no other changes than electricity consumption in the use are assumed. As in the overall scenario, the television device is not the most dominating of the devices – the reduction potential is in the order of 8% to 9% for the use phase of all the devices; while when focussing on the LCD TV screen devices (see Table 52) the reduction potential is clearly higher (i.e. in the order of 25 to 35% for most impact categories). Box 8 shows the additional reduction potential that could be achieved by an increase of the lifetime of a television device on 8 years (instead of the initially used 6 years); value that is based on the fact that this is the mean value of the range (from 6 to 10 years) that can be found in the literature (see e.g. Park et al., 2013).

Box 8. Influence of the Lifetime of the Television on the reduction potential (in combination with an increasing energy efficiency of the device)

The following figure highlights – using above Figure 23 as basis – the **additional reduction potential** that could be realized by an increase of the lifetime of the television device from 6 to 8 years (indicated in this figure here as "lifetime potential"), shown with the light part at the very right end of the figures from scenario 4 :



With the support of this figure, a clear distinction between those impact categories dominated by the use phase (and its energy consumption) and those dominated from the production can be made; then all the factors dominated by the latter one (i.e. the production of the device) show a relatively high "lifetime potential" when moving the duration of use from 6 to 8 years. While for MRD this is clearly visible, FETP and FEP show still a rather high influence (i.e. more than 50% of the reduction is due to the lifetime change) from the production step while all the remaining factors are clearly dominated by the electricity consumption in the use phase – resulting in a relatively small further reduction potential when the lifetime is increased.

8.6 Scenario 5: Reduction leakages of air conditioning appliances

Description and aim: Currently, the cooling demand in the EU is growing exponentially (Pardo Garcia et al., 2012). This emphasizes the role of renewable energy sources combined with high-efficiency energy technologies, to meet the cooling demand in the EU more sustainably in the future. But refrigeration and air conditioning systems have high, negative environmental impacts due to refrigerant charge leaks from the system and their corresponding high global warming potential (Beshr et al., 2017) as well as contribution to ozone depletion. As a first strategy to lower these impacts a reduction of these leakages is investigated in Scenario 5 – before in a 2nd step (and Scenario 6) a replacement of the refrigerant by a less harmful alternative is evaluated (details see Scenario 6).

Area of intervention: The area of intervention in this fifth scenario is a reduction of the leakage rates of the refrigerant (i.e. R134a) in the baseline scenario of the room air conditioner (RAC) appliances.

Policy relevance: Ecodesign Directive (EC, 2009a), and Roadmap to a Resource Efficient Europe (EC, 2011b)

Rationale for building the scenario: According to Heinrich et al. (2015), refrigeration technologies in Germany contribute about 5% to the total greenhouse gas emissions every year; and thereof about one fifth is due to direct releases of greenhouse gases (while the remaining 80% are related to the energy consumption of these technologies) – as in average a loss or leakage of 4 to 7% of the refrigerant can be observed. Within the actual cooling demand in Germany, with a consumption of 31 GWh of electricity per year, the building air conditioning is clearly dominating – responsible for almost the same amount of energy consumption per year as food industry and industrial refrigeration together (Heinrich et al., 2015). Split systems have – according to this report – an annual leakage rate of 5%; i.e. with a lifetime of 10 years this corresponds to the here reported 50% leakage rate of the baseline scenario. Due to a lack of reliable information towards the technical possibilities in this area (e.g. the Preparatory Study in this area has just started in beginning of 2017); the limit from the German "Chemikalien-Klimaschutzverordnung" (as reported in Viegand Maagoe and ARMINES, 2017) for HFC containing devices with more than 100 kg of refrigerant of 1% per year is applied in this scenario here to all such devices.

Parameters modified in the model: Table 54 summarizes the modifications that have been made in baseline model, for the product affected by this scenario, i.e. the room air conditioner.

Table 54. Summary of the new datasets necessary for the modelling of scenario 5 "Reduction leakages of air conditioning appliances".

Life Cycle Stage	Made modifications to Room Air Conditioner (RAC)
Manufacturing of components	No modification
Manufacturing of the product	No modification
Packaging	No modification
Distribution and retail	No modification
Use phase	Correction of the amount of "Ethane, 1,1,1,2-tetrafluoro-, HFC-134a emitted to air" from 0.60 kg to 0.18 kg, being the result of 1% of emission each year
Maintenance and repair	Correction of the amount of "Refrigerant R134a" that needs to be re-filled from 0.49*1.2 kg to 0.14*1.2 kg (representing decrease of losses from 50% to 15% (with the remaining 1% being added as part of the input of 1% of the dataset for the manufacturing of components to this life stage here)
EoL of the product	No modification

Results: In Figure 25 and Figure 26 the results of this scenario are compared with the respective results from the baseline scenario; in Figure 25 they are split into the contributions from the different product groups, in Figure 26 they are split into the shares of the different life cycle stages distinguished here. Each of the two figures is going along with a table, showing the relative changes (in %) in the different product groups and the different life cycle stages, respectively (Table 55 and Table 56).

Figure 25. Scenario 5 in comparison with the baseline scenario (with total from the baseline set as 100%) – split into the contributions of the various product groups. (For the abbreviations see table note of Table 42)

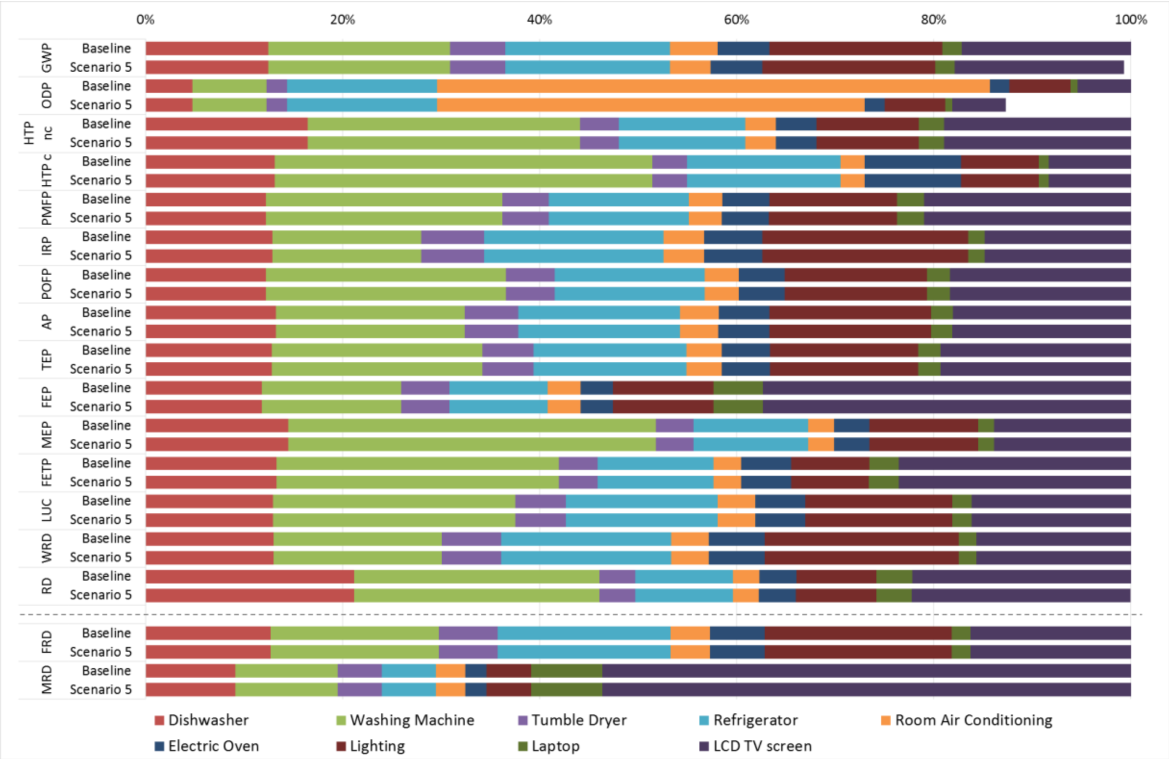


Figure 26. Scenario 5 in comparison with the baseline scenario (with the total impacts of the baseline set as 100%) – split into the contributions of the various life stages. (For the abbreviations see table note of Table 42)

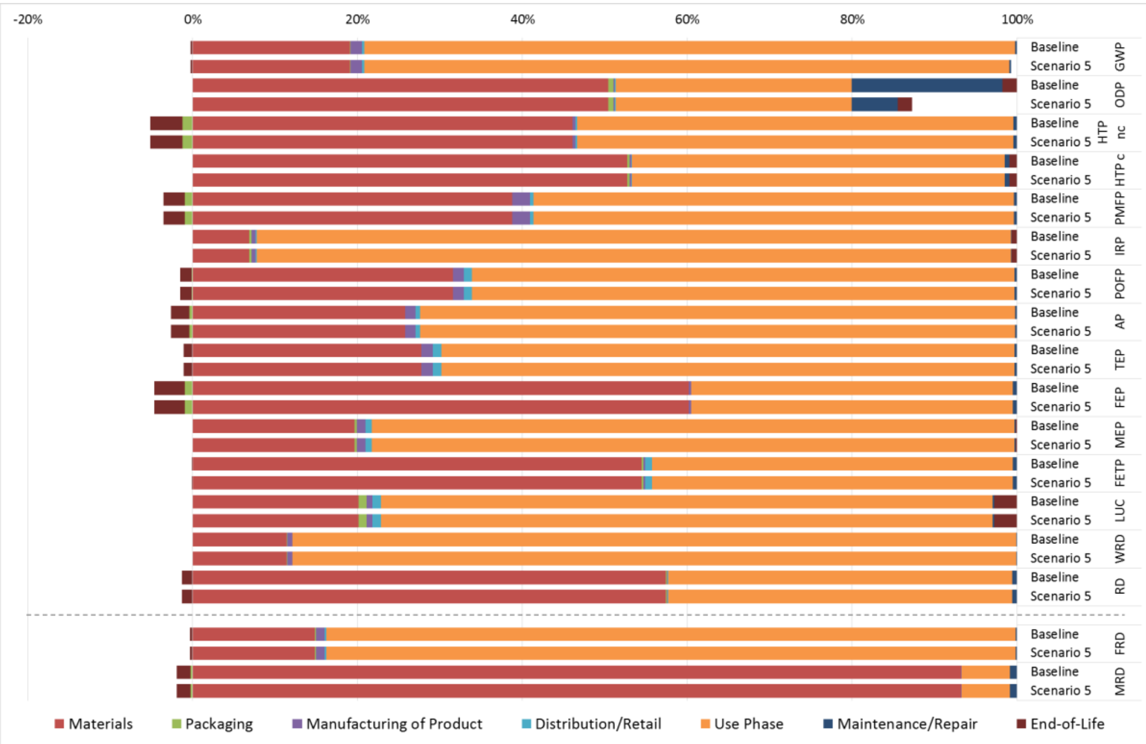


Table 55. Relative changes of the various product groups when comparing Scenario 5 with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	**Total**	**Dish-washer**	**Washing Machine**	**Tumble Dryer**	**Refrige-rator**	**Room Air Cond.**	**Electric Oven**	**Lighting**	**Laptops**	**LCD TV Screen**
GWP	-0.707%	-	-	-	-	-14.5%	-	-	-	-
ODP	-12.7%	-	-	-	-	-22.6%	-	-	-	-
HTP nc	-0.005%	-	-	-	-	-0.148%	-	-	-	-
HTP c	-0.004%	-	-	-	-	-0.142%	-	-	-	-
PMFP	-0.010%	-	-	-	-	-0.307%	-	-	-	-
IRP	-0.001%	-	-	-	-	-0.026%	-	-	-	-
POFP	-0.006%	-	-	-	-	-0.186%	-	-	-	-
AP	-0.007%	-	-	-	-	-0.180%	-	-	-	-
TEP	-0.006%	-	-	-	-	-0.165%	-	-	-	-
FEP	-0.001%	-	-	-	-	-0.034%	-	-	-	-
MEP	-0.004%	-	-	-	-	-0.162%	-	-	-	-
FETP	-0.004%	-	-	-	-	-0.128%	-	-	-	-
LUC	-0.003%	-	-	-	-	-0.081%	-	-	-	-
WRD	-0.002%	-	-	-	-	-0.044%	-	-	-	-
RD	-0.028%	-	-	-	-	-1.069%	-	-	-	-
FRD	-0.003%	-	-	-	-	-0.083%	-	-	-	-
MRD	-0.002%	-	-	-	-	-0.056%	-	-	-	-

([1]) Abbreviations, see table note at Table 42

Table 56. Relative changes of the various life stages when comparing Scenario 5 with the baseline scenario (relative to the result in the baseline scenario)

Impact Category(1)	**Total**	**Materials**	**Packaging**	**Production**	**Distribu-tion**	**Use**	**Main-tenance**	**End-of-Life**
GWP	-0.707%	-	-	-	-	-0.842%	-17.0%	-
ODP	-12.7%	-	-	-	-	-	-69.4%	-
HTP nc	-0.005%	-	-	-	-	-	-1.05%	-
HTP c	-0.004%	-	-	-	-	-	-0.60%	-
PMFP	-0.010%	-	-	-	-	-	-2.73%	-
IRP	-0.001%	-	-	-	-	-	-1.46%	-
POFP	-0.006%	-	-	-	-	-	-2.11%	-
AP	-0.007%	-	-	-	-	-	-2.82%	-
TEP	-0.006%	-	-	-	-	-	-2.20%	-
FEP	-0.001%	-	-	-	-	-	-0.21%	-
MEP	-0.004%	-	-	-	-	-	-2.16%	-
FETP	-0.004%	-	-	-	-	-	-0.67%	-
LUC	-0.003%	-	-	-	-	-	-1.37%	-
WRD	-0.002%	-	-	-	-	-	-1.50%	-
RD	-0.028%	-	-	-	-	-	-4.89%	-
FRD	-0.003%	-	-	-	-	-	-2.26%	-
MRD	-0.002%	-	-	-	-	-	-0.20%	-

(1) Abbreviations, see table note at Table 42

This scenario has a special focus on the impact category ozone depletion – a fact that can be seen e.g. in the results from the life cycle stages (i.e. Table 56), then the ODP of the step of the maintenance/repair shows a reduction of almost 70% of its impacts in the area of this specific impact category due to the lower amounts of refrigerant that need to be replaced (and thus produced). The 2nd relevant impact category for this scenario is climate change; actually this is the only further impact that shows a change of more than 10% when looking to the overall impacts due to the RAC devices in Table 55 (all further impact categories show changes below 1%); being the consequence of the GWP potential of the refrigerant substance itself when released into air.

8.7 Scenario 6: Substitution of refrigerants

Description and aim: According to Beshr et al. (2017), "refrigeration and air conditioning systems have high, negative environmental impacts due to refrigerant charge leaks from the system and their corresponding high global warming potential" (see also Scenario 5, dealing with these leakage rates). A second strategy to lower these impacts, apart from reducing the leakages, is the replacement of the refrigerant by a less harmful alternative. This scenario is investigating this possibility.

Area of intervention: The area of intervention is to find an alternative for the refrigerant used in the baseline scenario (i.e. R134a) that has comparable characteristics concerning the cooling requirements, while showing lower a lower impact on ozone depletion and global warming, when released into the environment.

Policy relevance: Ecodesign Directive (EC, 2009a) and Roadmap to a Resource Efficient Europe (EC, 2011b)

Rationale for building the scenario: According to VHK and ARMINES (2016), in 2013 about 98% of all refrigerators contained R600a (i.e. isobutene) as refrigerant. Isobutene is a substance with a "zero ODP and a very low GWP (3.3)" (VHK and ARMINES 2016). On the other side, the baseline scenario for 2010 here is calculated with R134a (i.e. CH_2FCF_3; or 1,1,1,2-tetrafluoroethane) as refrigerant – a substance with a GWP potential of 1'300 kg CO_2-Eq/kg of substance. Thus, scenario 6 is investigating simply all the consequences that are resulting when replacing R134a by the less harmful R600a. According to Heinrich et al. (2015), the coefficient of performance (COP) of R600a is similar to the one of R134a – across a wide temperature range (i.e. from -30 to 10°C). Due to these similarities, it can be assumed, that a 1:1 replacement of the two different refrigerants can be applied for this study. For the disposal of the refrigerant in the end of life, the dataset for "treatment of spent solvent mixture, hazardous waste incineration CH" is used as proxy, replacing the respective end of life dataset for the R134a treatment.

Box 9. Life Cycle Inventory model for refrigerant R600a (isobutane)

According to Danfoss (2000), isobutane is a part of petrol gases from natural resources with the chemical formula $(CH_3)_3CH$, a molecular weight of 58.1 g/mol and a boiling point at -12°C. But this "naturally" occurring amount is not sufficient to cover the demand side; and thus, petrochemical companies are producing isobutene either by the isomerization of butane (Leonard, 1942) or by a catalytic reaction out of propane (de Simo and McMillan, 1939).

Due to a lack of a respective dataset within the database ecoinvent, a dataset for the production of isobutene via the isomerization of butane is modelled here. Basis for this model is an updated approach for modelling chemicals with weak information (as described in Hischier et al., 2005) – updated according to the procedure and information reported by ecoinvent (see Moreno Ruiz et al., 2017). The stoichiometric equation of such an isomerization process can be written as:

$$CH_3(CH_2)_2CH_3 \xrightarrow{Catalyst} (CH_3)_3CH$$

Applying the above-mentioned general modelling approach for weakly documented chemicals leads then to the following input and output value for the production of 1 kg of isobutene:

[per kg Isobutane]		Total	Remark
INPUTS			
n-Butane	kg	1.053	stoechiometric calc., 95% yield
Electricity, medium voltage	kWh	0.416	default estimation
heat, in chemical industry	MJ	2.35	default estimation
nitrogen	kg	0.019	default estimation
compressed air, 1000 kPa gauge	m3	0.5	default estimation
tap water	kg	2.60E-02	default estimation
Water, cooling, unspecified natural origin	m3	1.64E-02	default estimation
Water, river	m3	8.60E-04	default estimation
Water, well, in ground	m3	8.30E-04	default estimation
Chemical plant, organics	unit	4.00E-10	default estimation
Transport, by train	tkm	6.32E-01	standard distances & means
Transport, by lorry	tkm	1.05E-01	standard distances & means
OUTPUTS			
isobutane	kg	1.000	
wastewater, average	m3	2.70E-06	default estimation
nitrogen, to air	kg	1.90E-02	default estimation
water, to air	m3	1.40E-03	default estimation
n-butane, to air	kg	2.11E-03	0.2% of input
Carbon dioxide, fossil, to air	kg	1.38E-01	from waste water treatment
water, to water	m3	1.67E-02	default estimation
n-butane, to water	kg	5.05E-03	calculated from mass balances
COD, BOD	kg	1.74E-02	calculated from water emissions
TOC, DOC	kg	4.18E-03	calculated from water emissions

Parameters modified in the model: Table 57 summarizes the modifications that have been made in baseline model, for each product affected by Scenario 6.

Table 57. Summary of the new datasets necessary for the modelling of Scenario 6 "Substitution of refrigerants".

Life Cycle Stage	Made modifications to	
	Refrigerator	**Room Air Conditioner (RAC)**
Manufacturing of components	Replacing the amount of "Refrigerant R134a" by the same amount of "Alternative Refrigerant R600a" (isobutane)	Replacing the amount of "Refrigerant R134a" by the same amount of "Alternative Refrigerant R600a" (isobutane)
Manufacturing of the product	No modification	No modification
Packaging	No modification	No modification
Distribution and retail	No modification	No modification
Use phase	No modification	Replacing the amount of "Ethane, 1,1,1,2-tetrafluoro-, HFC-134a emitted to air" by the same amount of "isobutane emitted to air"
Maintenance and repair	No direct modification – but for the input of the replaced parts, the modified dataset for the manufacturing of components (see row above) is used.	Replacement of the amount of "Refrigerant R134a" by the same amount of "Alternative Refrigerant R600a" for the filling; For the input of the replaced parts, the modified dataset for the manufacturing of compo-nents (see row above) is used.
EoL of the product	Replacement of the amount of "treatment of used R134a" by the same amount of "treatment of spent solvent mixture, hazardous waste incineration" (used here as a proxy for the treatment of R600a)	Replacement of the amount of "treatment of used R134a" by the same amount of "treatment of spent solvent mixture, hazardous waste incineration" (used here as a proxy for the treatment of R600a)

Results: In Figure 27 and Figure 28 the results of Scenario 6 are compared with the respective results from the baseline scenario. In Figure 27 they are split into the contributions from the different product groups, in Figure 28 they are split into the shares of the different life cycle stages. Each of the two figures is going along with a table, showing the relative changes (in %) in the different product groups and the different life cycle stages, respectively (Table 58 and Table 59).

Figure 27. Scenario 6 in comparison with the baseline scenario (with total from the baseline set as 100%) – split into the contributions of the various product groups. (For the abbreviations see table note of Table 42)

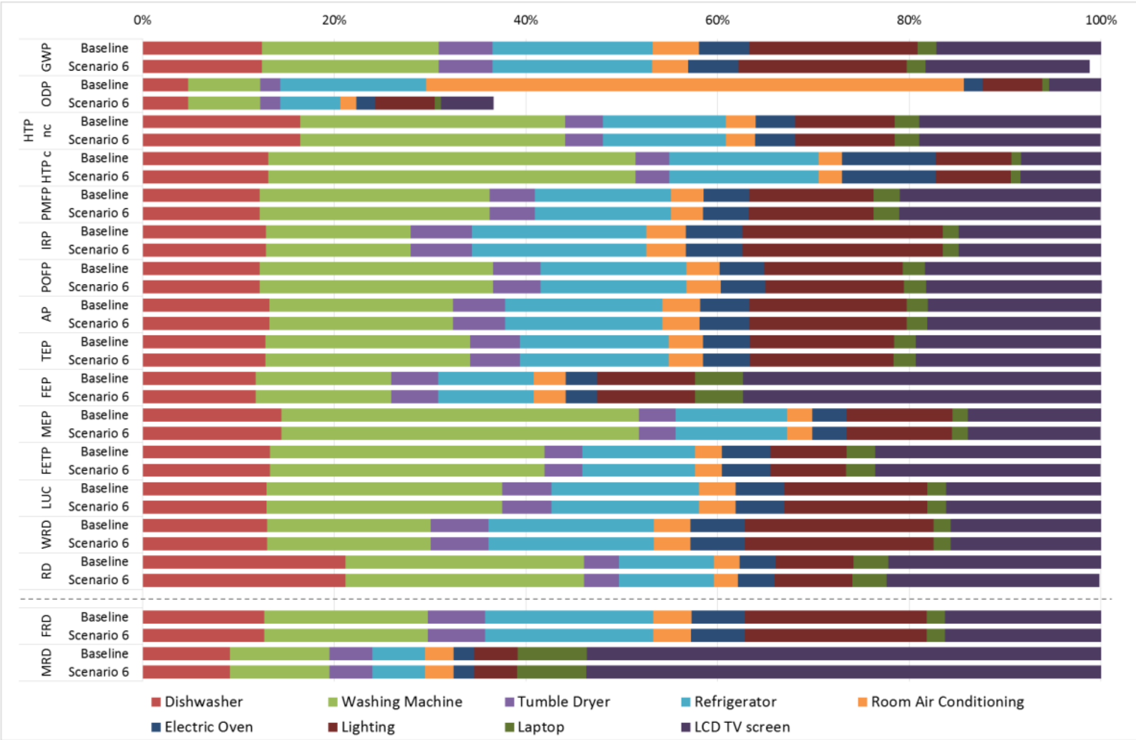


Figure 28. Scenario 6 in comparison with the baseline scenario (with the total impacts of the baseline set as 100%) – split into the contributions of the various life stages. (For the abbreviations see table note of Table 42)

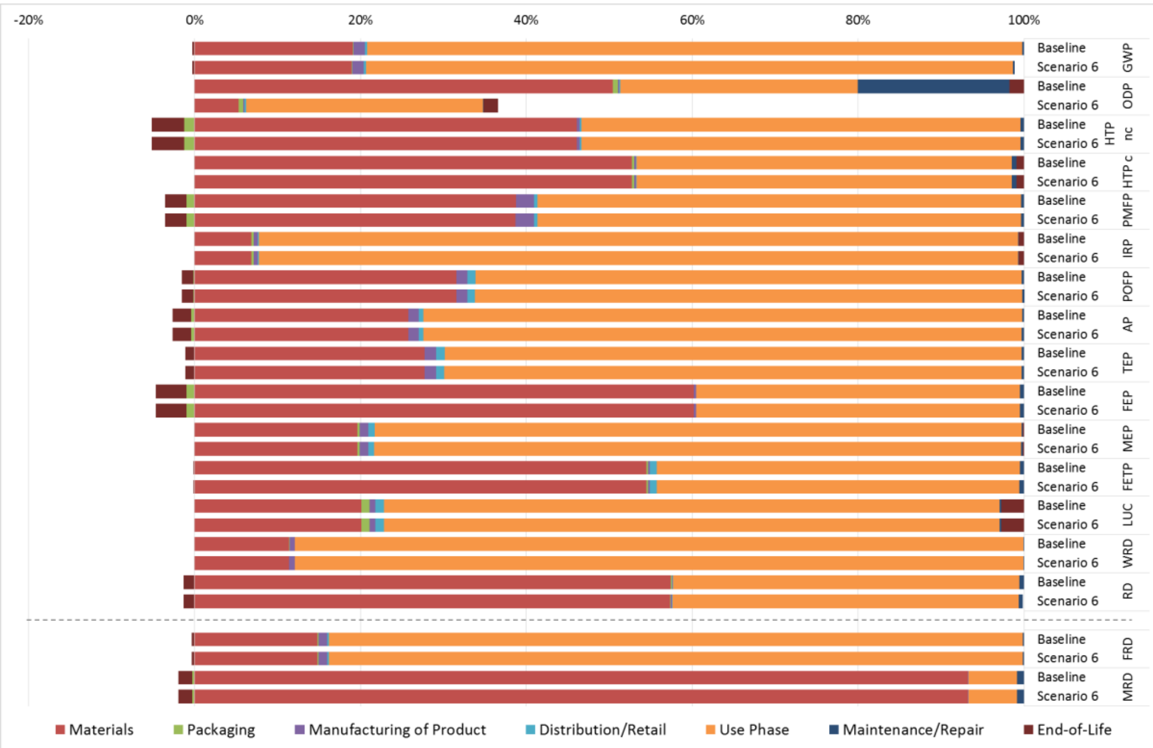


Table 58. Relative changes of the various product groups when comparing Scenario 6 with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	Total	Dish-washer	Washing Machine	Tumble Dryer	Refrige-rator	Room Air Cond.	Electric Oven	Lighting	Laptops	LCD TV Screen
GWP	-1.2%	-	-	-	-0.17%	-23.1%	-	-	-	-
ODP	-63.4%	-	-	-	-58.7%	-97.0%	-	-	-	-
HTP nc	-0.022%	-	-	-	-0.024%	-0.59%	-	-	-	-
HTP c	-0.019%	-	-	-	-0.018%	-0.63%	-	-	-	-
PMFP	-0.046%	-	-	-	-0.047%	-1.17%	-	-	-	-
IRP	-0.004%	-	-	-	-0.003%	-0.09%	-	-	-	-
POFP	0.105%	-	-	-	-0.025%	3.12%	-	-	-	-
AP	-0.030%	-	-	-	-0.026%	-0.66%	-	-	-	-
TEP	-0.027%	-	-	-	-0.024%	-0.64%	-	-	-	-
FEP	-0.005%	-	-	-	-0.007%	-0.12%	-	-	-	-
MEP	-0.019%	-	-	-	-0.023%	-0.62%	-	-	-	-
FETP	-0.019%	-	-	-	-0.025%	-0.56%	-	-	-	-
LUC	-0.011%	-	-	-	-0.010%	-0.24%	-	-	-	-
WRD	-0.007%	-	-	-	-0.006%	-0.15%	-	-	-	-
RD	-0.140%	-	-	-	-0.199%	-4.54%	-	-	-	-
FRD	-0.010%	-	-	-	-0.008%	-0.21%	-	-	-	-
MRD	-0.008%	-	-	-	-0.020%	-0.23%	-	-	-	-

([1]) Abbreviations, see table note at Table 42

Table 59. Relative changes of the various life stages when comparing Scenario 6 with the baseline scenario (relative to the result in the baseline scenario)

Impact Category[1]	Total	Materials	Packaging	Production	Distribu-tion	Use	Main-tenance	End-of-Life
GWP	-1.15%	-0.74%	-	-	-	-1.20%	-23.9%	-0.765%
ODP	-63.4%	-89.5%	-	-	-	-	-99.6%	-0.023%
HTP nc	-0.022%	-0.030%	-	-	-	-	-1.34%	-0.026%
HTP c	-0.019%	-0.019%	-	-	-	-	-0.75%	-0.457%
PMFP	-0.046%	-0.080%	-	-	-	-	-3.40%	-0.055%
IRP	-0.004%	-0.043%	-	-	-	-	-1.63%	-0.022%
POFP	0.105%	-0.059%	-	-	-	-	-2.48%	-0.049%
AP	-0.030%	-0.079%	-	-	-	-	-3.38%	-0.040%
TEP	-0.027%	-0.066%	-	-	-	-	-2.78%	-0.057%
FEP	-0.005%	-0.005%	-	-	-	-	-0.23%	-0.007%
MEP	-0.019%	-0.068%	-	-	-	-	-2.73%	-0.337%
FETP	-0.019%	-0.018%	-	-	-	-	-0.75%	-4.829%
LUC	-0.011%	-0.034%	-	-	-	-	-1.23%	-0.034%
WRD	-0.007%	-0.042%	-	-	-	-	-1.71%	-0.909%
RD	-0.140%	-0.171%	-	-	-	-	-6.95%	-0.010%
FRD	-0.010%	-0.044%	-	-	-	-	-1.82%	-0.172%
MRD	-0.008%	-0.006%	-	-	-	-	-0.26%	-0.002%

([1]) Abbreviations, see table note at Table 42

Similarly to Scenario 5, the impact category ozone depletion (ODP) is in the focus of Scenario 6 – a fact that is even more successfully achieved in this case with an overall reduction of the ODP-related impacts of almost two third (see Table 59). This is directly related to the change from a refrigerant with a high ODP value to a substance that is not contributing at all to the ODP impact anymore – shown by the reduction of the respective impacts in the life stages "materials" and "maintenance/repair" (i.e. the two moments with input of refrigerant). The 2nd impact category that shows some changes is again the GWP; actually this is the only further impact that shows a change of more than 1%. This is due to the lower GWP-value of the alternative refrigerant substance and relates mainly to the RAC devices, as there some leakage during the use takes place (see Table 58). The ODP reduction is due to both categories of devices containing a refrigerant – i.e. the refrigerator and the RAC.

8.8 Scenario 7: Increasing number of devices per household

Description and aim: Within Scenario 7, the issue of "consumer behaviour" is investigated. More precisely, Scenario 7 analyses the influence of an increase in the number of household appliances in a household, and with that "per inhabitant".

Area of intervention: The scenario is dealing with the number of devices per household, and in the end per inhabitant (i.e. the measurement unit used here for the presentation of the results). The area of intervention is therefore on the level of the overall calculations, summing up the effects of the various appliances within this study.

Policy relevance: Ecodesign Directive (EC, 2009a), Energy Efficiency Directive (EU, 2012b), Roadmap to a Resource Efficient Europe (EC, 2011b), and the Circular Economy Package (EC, 2015)

Rationale for building the scenario: In the baseline scenario, data from various Ecodesign preparatory studies have been used in order to estimate the number of such devices that are in use in 2010 in the EU. Similar data (projections) for the stock in 2030 have been searched for in the literature and in other public sources. Table 60 summarizes the found numbers, as well as the approximation procedures applied in order to estimate such a stock for the year 2030; stock used as basis for the calculation of Scenario 7. For the calculation of the results per inhabitant, also the number of inhabitants has been adjusted to the changing reference year (i.e. year 2030) by using the estimated number as reported in Appendix 1 of the European Reference Scenario 2016 document (European Commission, 2016) of 515.9 Million inhabitants for 2030 (representing EU).

Table 60. Stock numbers 2010 and their projection to the year 2030 (given are absolute number of devices and below, in brackets, number of devices per inhabitant)

Product Group	**Stock 2010 - baseline**	**Stock 2030**	**Source /Assumption procedure for the values of the stock 2030**
Dishwasher	82'799'000 (0.165)	148'553'000 (0.288)	Boyano et al., 2017 (Table 2.6)
Washing Machine	185'828'000(1) (0.370)	204'744'000 (0.397)	EC-JRC, 2015a
Tumble Dryer	63'037'000 (0.125)	80'750'000 (0.157)	Assumption (due to lack of reference): In 2030 20% more households than in 2010 own such a tumble dryer (i.e. 36%)
Refrigerator	299'289'000(1) (0.596)	411'000'000 (0.797)	Barthel and Götz, 2012 (Table 3)
Room Air Conditioner	28'077'000 (0.056)	117'000'000 (0.227)	VHK, 2016a, 2016b

Electric oven	216’000’000 (0.430)	246’735’000 (0.478)	Assumption (due to a lack of reference): there is a small increase per household (from 1.03 in 2010 to 1.10 in 2030)
Compact fluorescent lamp	1’485’936’824 (2.957)	2’250’000’000 (4.361)	Total number of lamps in 2030: 7.5 Bn (VHK 2016) – thereof 70% are LED (as stipulated again in VHK, 2016a, 2016b), and for the remaining 30% it is assumed that these are all Compact fluorescent lamps (as all other categories get banned in the current EU legislation)
Halogen lamp, low voltage	902’902’229 (1.797)	0	
Halogen lamp, mains voltage	1’058’346’935 (2.106)	0	
Incandescent lamp	716’225’361 (1.425)	0	
LED	0	5’250’000’000 (10.176)	
Laptop Computer	178’630’000 (0.355)	56’000’000 (0.109)	VHK, 2016 (decrease as shift to tablets)
LCD TV Screen	332’254’364(1) (0.661)	532’803’879 (1.033)	Götz, 2015a (Table 3)

(1) different data for 2010 for the EU reported in Barthel and Götz (2013) (192’853’372 Washing Machines), in Barthel and Götz (2012) (335’000’000 Refrigerators), and in Götz (2015a) (388’743’938 Televisions).

Parameters modified in the model: As for the LED lamp in the baseline, no influence (i.e. 0 LED lamps/household) had been assumed; the life cycle of such a LED lamp had to be adapted for Scenario 7. The datasets from the baseline are used – except for the use phase. Here the baseline dataset has been changed by including a value of 89.9 kWh of electricity consumption (instead of the 0 in the baseline). This value is the result of a consumption of 2.6434 kWh/year (calculated in a top-down approach in the framework of this study) over 34 years, i.e. the life-time of this new technology (according to VITO, 2015a). Table 61 summarizes the modifications that have been made in baseline model, for each product affected by Scenario 7.

Table 61. Summary of the new datasets necessary for the modelling of Scenario 7 “Increasing number of devices per household”.

Life Cycle Stage	**Made modifications to**	
	LED Lamp	**BoP Household Appliances** (i.e. to datasets covering the total of all examined devices)
Manufacturing of components	No modification	In the calculation formula for each of the product groups, the stock 2010 has been replaced by the amount listed in Table 59; and the number of inhabitants has been changed from the value 2010 to the estimation for 2030 (i.e. from 502.5 Mio to 515.9 Mio inhabitants (see above). For the LED Lamp, the new use scenario (see left column) has been included into the calculations for the use phase of all BoP Household Appliances.
Manufacturing of the product	No modification	
Packaging	No modification	
Distribution and retail	No modification	
Use phase	Correction of amount of electricity consumed from ‘0’ to ’89.9 kWh’ for the entire lifetime – representing a consumption of 2.643 kWh/a of a single LED lamp.	
Maintenance and repair	No modification	
EoL of the product	No modification	

Results: In Figure 29 and Figure 30 the results of Scenario 7 are compared with the results from the baseline scenario. In Figure 29 they are split into the contributions from the different product groups, in Figure 30 they are split into the shares of the different life cycle stages. Each of the two figures is going along with a table, showing the relative changes (in %) in the different product groups and the different life cycle stages, respectively (Table 62 and Table 63).

Figure 29. Scenario 7 in comparison with the baseline scenario (with total from the baseline set as 100%) – split into the contributions of the various product groups.

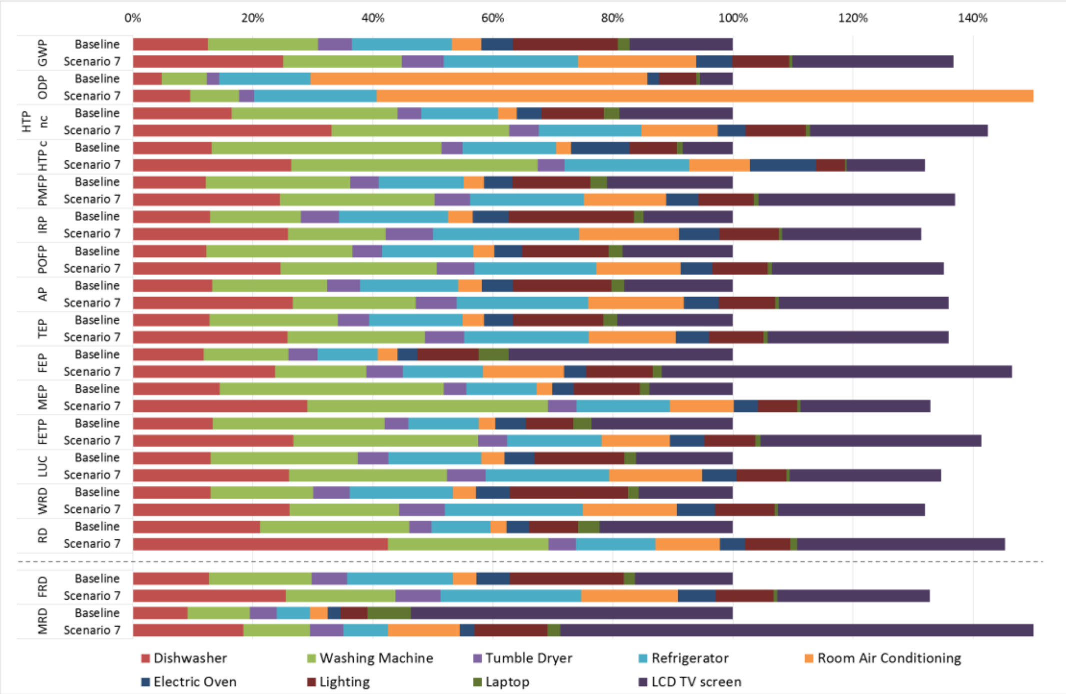


Figure 30. Scenario 7 in comparison with the baseline scenario (with the total impacts of the baseline set as 100%) – split into the contributions of the various life stages (For the abbreviations see table note of Table 42)

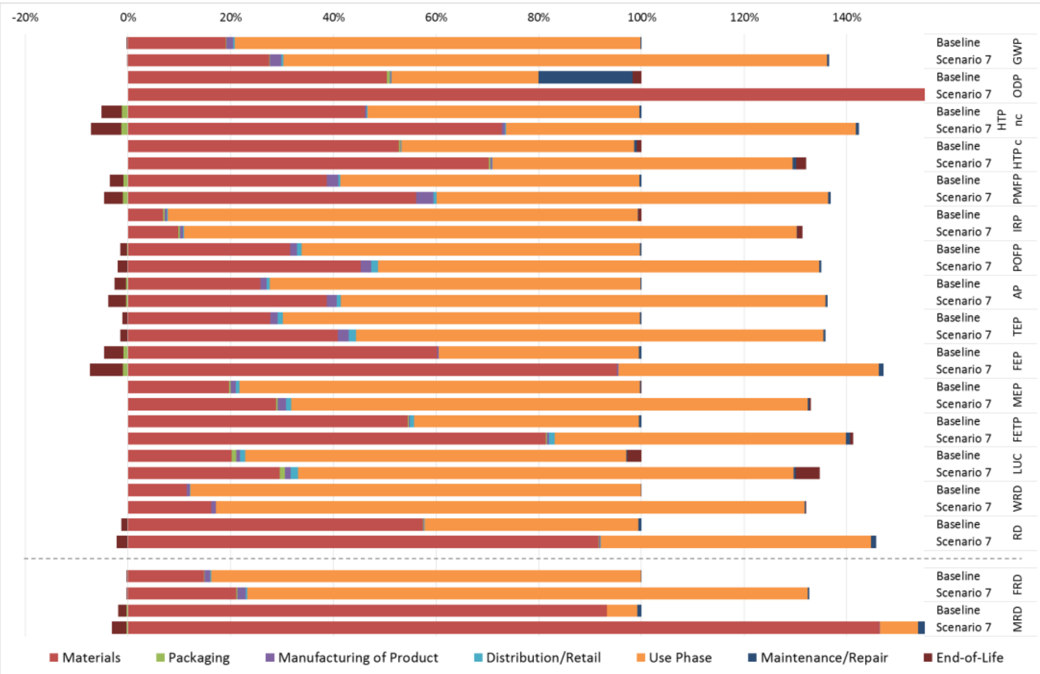


Table 62. Relative changes of the various product groups when comparing Scenario 7 with the baseline scenario (relative to the result in the baseline scenario) (For the abbreviations see table note of Table 42)

Impact Category([1])	**Total**	**Dish-washer**	**Washing Machine**	**Tumble Dryer**	**Refrige-rator**	**Room Air Cond.**	**Electric Oven**	**Lighting**	**Laptops**	**LCD TV Screen**
GWP	36.8%	101.0%	7.3%	24.8%	33.8%	305.9%	12.9%	-46.0%	-69.5%	56.2%
ODP	182.5%	101.0%	7.3%	24.8%	33.8%	305.9%	12.9%	-49.2%	-69.5%	56.2%
HTP nc	42.5%	101.0%	7.3%	24.8%	33.8%	305.9%	12.9%	-3.8%	-69.5%	56.2%
HTP c	32.0%	101.2%	7.3%	24.8%	33.8%	305.9%	12.9%	-38.9%	-69.5%	56.2%
PMFP	37.1%	101.0%	7.3%	24.8%	33.8%	305.9%	12.9%	-29.5%	-69.5%	56.2%
IRP	31.4%	101.0%	7.3%	24.8%	33.8%	305.9%	12.9%	-52.4%	-69.5%	56.2%
POFP	35.1%	101.0%	7.3%	24.8%	33.8%	305.9%	12.9%	-36.6%	-69.5%	56.2%
AP	36.0%	101.0%	7.3%	24.8%	33.8%	305.9%	12.9%	-42.8%	-69.5%	56.2%
TEP	35.9%	101.0%	7.3%	24.8%	33.8%	305.9%	12.9%	-39.7%	-69.5%	56.2%
FEP	46.5%	101.1%	7.3%	24.8%	33.8%	305.9%	12.9%	8.3%	-69.5%	56.2%
MEP	32.9%	101.0%	7.3%	24.8%	33.8%	305.9%	12.9%	-40.5%	-69.5%	56.2%
FETP	41.4%	101.1%	7.3%	24.8%	33.8%	305.9%	12.9%	7.5%	-69.5%	56.2%
LUC	34.7%	101.0%	7.3%	24.8%	33.8%	305.9%	12.9%	-44.5%	-69.5%	56.2%
WRD	32.0%	101.0%	7.3%	24.8%	33.8%	305.9%	12.9%	-49.6%	-69.5%	56.2%
RD	45.4%	101.0%	7.3%	24.8%	33.8%	305.9%	12.9%	-7.7%	-69.5%	56.2%
FRD	32.8%	101.0%	7.3%	24.8%	33.8%	305.9%	12.9%	-49.0%	-69.5%	56.2%
MRD	55.1%	101.3%	7.3%	24.8%	33.8%	305.9%	12.9%	168.0%	-69.5%	56.2%

([1]) Abbreviations, see table note at Table 42

Table 63. Relative changes of the various life stages when comparing Scenario 7 with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	Total	Materials	Packaging	Production	Distribu-tion	Use	Main-tenance	End-of-Life
GWP	36.8%	44.4%	59.1%	60.1%	42.3%	34.0%	103.0%	30.5%
ODP	182.5%	231.5%	8.4%	68.2%	41.8%	30.4%	303.6%	66.8%
HTP nc	42.5%	58.0%	-6.8%	48.5%	39.1%	28.6%	53.5%	-49.5%
HTP c	32.0%	33.2%	12.7%	54.4%	41.7%	29.2%	34.3%	102.9%
PMFP	37.1%	44.8%	-4.4%	52.9%	44.6%	30.8%	49.2%	-41.6%
IRP	31.4%	42.5%	10.6%	35.1%	42.2%	30.3%	44.7%	70.3%
POFP	35.1%	43.4%	29.5%	54.9%	45.5%	30.4%	46.2%	-34.7%
AP	36.0%	50.3%	-0.4%	53.4%	47.4%	30.8%	52.8%	-55.0%
TEP	35.9%	47.3%	61.1%	52.3%	45.9%	30.7%	51.1%	-33.9%
FEP	46.5%	58.1%	-6.8%	40.4%	43.1%	30.1%	54.6%	-72.2%
MEP	32.9%	46.8%	17.0%	51.8%	45.9%	28.9%	50.7%	135.5%
FETP	41.4%	49.3%	24.5%	59.8%	38.3%	29.7%	47.7%	676.5%
LUC	34.7%	46.4%	9.0%	58.4%	40.4%	30.1%	50.6%	74.2%
WRD	32.0%	41.7%	64.3%	41.1%	44.5%	30.6%	40.7%	228.0%
RD	45.4%	59.7%	15.4%	40.9%	38.8%	26.1%	75.9%	-69.4%
FRD	32.8%	42.3%	41.3%	59.8%	42.1%	30.5%	46.9%	19.5%
MRD	55.1%	57.0%	-7.1%	46.1%	38.9%	27.2%	57.4%	-70.4%

([1]) Abbreviations, see table note at Table 42

Scenario 7 is changing the focus, away from technological changes of individual devices towards user behaviour. The scenario is investigating the influence of the currently observable fact that more and more such devices are sold to the population – i.e. that each person possesses more and more such household appliances. In other terms, the results in this scenario are not showing any reduction, but an increase of the environmental impacts. Based on the found data, especially the area of the Dishwasher, the RAC and the television show a still high potential – visible in the high increase of impacts that these three types of devices show in the end in Table 62, with e.g. more than 3 times the current impacts for the RAC. This results especially for ozone depletion - impact category that is dominated by the RAC – to a huge increase of the overall result (+80%); while for most other impact categories, the overall increase is rather in the order of 35 to 40%.

When focussing on the various life cycle stages (as shown in Table 63), the pictures gets rather unspecific, as an increase of the amount of devices in the end has an impact on all the life cycle stages. Because only the number of devices per person is changing for this scenario, the increase along these life cycle stages does not show in general one life stage more dominant than the other.

8.9 Scenario 8: Increasing remanufacturing and reuse (parts, whole devices) or increasing collection and recycling rates

Description and aim: another issue under the umbrella of "user behaviour" is the topic of reusability in a broad sense, i.e. in form of the actual reuse of entire devices or of parts of such devices, or then in a higher collection and/or recycling rate (in order to achieve a higher degree of such a "reusability" at least on the material level). These two issues are investigated here separately, respectively in scenarios 8a and 8b.

8.9.1 Scenario 8a: Increasing remanufacturing and reuse (whole devices)

Area of intervention: An important aspect in this context is the "psychology" of the user; i.e. why does a user want to replace a household appliance that is in use? Actually, the question in the context of this study is rather, what factor(s) can make a user using the existing household appliance for a longer time (and with longer time, we mean here longer than the average life time assumed for the baseline scenario)?

A study of the German UBA (Umweltbundesamt) about "obsolescence" (the exact title of this study in German is "Einfluss der Nutzungsdauer von Produkten auf ihre Umweltwirkung: Schaffung einer Informationsgrundlage und Entwicklung von Strategien gegen Obsoleszenz") shows that reasons for replacing household appliances are very diverse (Prakash et al., 2016), having their origin in the materials, in the functionality, in the economy but sometimes also in the psychology of the users. According to this German study, the average life time evolved as following in the past 10 years in Germany for the category of "white goods" (i.e. big household appliances such as washing machines):

- first-use duration declined from 14.1 years (2004) to 13.0 years (2013/14);
- main reasons (data for 2012/13) for replacing are to 55.6% due to a defect of device, and to 30.5% the wish for a better device (while old one still works fine);
- average age of washing machines in the recycling system declined from 16 years (in 2004) to 13.7 years (2013); with more than 10% having 5 years and less as age.

The German study contains also similar analysis results for further categories (e.g. for TV devices and notebooks); all of them showing a rather similar situation. In our society, a relevant part of household appliances is changed despite the fact that the device still works perfectly well. The issue here is thus to investigate what would be the effects if one part of these still working (wasted) devices gets a "second chance" and is re-used by a second user.

Policy relevance: Ecodesign Directive (EC, 2009a), Energy Efficiency Directive (EU, 2012b), Roadmap to a Resource Efficient Europe (EC, 2011b), WEEE Directive, (EU, 2012a), and the Circular Economy Package (EC, 2015)

Rationale for building the scenario: In principle, there are several options and ways how such a "re-use" or prolongation of the lifetime could be modelled; here the most straight-forward way is chosen, which means that simply the average life time of the various product groups for which such a re-use is taken into consideration have been adjusted in order to investigate the potential that such prolonged lifetimes would bring in comparison to the baseline scenario. Such a procedure does not take into account the fact that e.g. the energy efficiency is increasing over time and the "re-use" replaces often a more efficient, new device. In the same time, such a prolongation of the lifetime allows also to spread the initial production (together with the EoL-treatment) over more years; making the impact of production (and EoL) lower for such this longer used device. Expressing this latter issue is quite easily possible within the scope of this analysis; while the inclusion of those improvements of future devices requires a more general re-modelling of the complete scenario; and the change of a new, more efficient device is not avoided, but just shifted to a later stage (stage where probably even more efficient devices are available).

Hence, for this above described, straight-forward modelling, the following assumptions are used as starting point for an improved re-use scenario:

- for the product groups "lighting", "TV screen" and "Computer" we do not assume such an extension of the lifetime in Scenario 8 – while lighting bulbs usually are changed when they are broken, the two other product groups show a continuous development, and thus their re-use is less probable (and for the television, such an increase of the lifetime was already examined as part of Scenario 4);
- for all other product groups, an extension of the lifetime is assumed – however, only the high-quality models within each of this product groups would be suitable for such a "second-life" – expressed in the %-values of "devices for 2nd life" in the table below;
- for each device with an extension of the lifetime, we assume that an additional repair amount is required in order to allow for such a "second-life" – due to a lack of respective information, the original repair amount is simply multiplied by a factor of 2 (i.e. we assume 100% more maintenance and repair efforts);
- all the cornerstones and the resulting values for the modelling of this scenario are summarized in the following Table 64.

Table 64. Key figures for the Scenario 8a – investigating a higher reuse of devices/parts. DW=dishwasher, WM=washing machine, TD=tumble dryer, RE=refrigerator, EO= electric oven

Factor	DW	WM	TD	RE	EO	Remarks
1st life (years)	12.5	12.5	13.0	15.0	19.0	Data from baseline scenario
Devices for 2nd life (in %)	15%	10%	20%	10%	10%	Assumptions by author (taking the number of machines in the population as indication – more machines, less % re-use)
2nd life (years)	4	4	4.5	5	6	Assumptions by the author (taking about 1/3 of average first lifetime of a machine)
Average life (years)	13.1	12.9	13.9	15.5	19.6	Calculated, out of values in lines above
Repair	X2	X2	X2	X2	X2	in comparison to the baseline assumption

Parameters modified in the model: Table 65 summarizes the modifications that have been made in baseline model, for each product affected by Scenario 8a.

Table 65. Summary of the new datasets necessary for the modelling of Scenario 8a "increasing remanufacturing and reuse (parts, whole devices)".

Life Cycle Stage	**Made modifications to** **Dishwasher 10ps, Dishwasher 13ps, electric oven, washing machine, tumble dryer, and refrigerator respectively.**
Manufacturing of components	In calculation formula for the five here concerned product groups the average lifetime has been replaced by the here calculated, longer lifetime listed in Table 64.
Manufacturing of the product	
Packaging	
Distribution and retail	
Use phase	
Maintenance and repair	In calculation formula for the five here concerned product groups the average lifetime has been replaced by the here calculated, longer lifetime listed in Table 63; and a factor of 2 has been added in order to take into account the higher repair efforts (see text above).
EoL of the product	In calculation formula for the five here concerned product groups the average lifetime has been replaced by the here calculated, longer lifetime listed in Table 63.

Results: In Figure 31 and Figure 32 the results of Scenario 8a are compared with the respective results from the baseline scenario. In Figure 31 they are split into the contributions from the different product groups, in Figure 32 they are split into the shares of the different life cycle stages distinguished here. Each of the two figures is going along with a table, showing the relative changes (in %) in the different product groups and the different life cycle stages, respectively (Table 66 and Table 67).

Figure 31. Scenario 8a in comparison with the baseline scenario (with total from the baseline set as 100%) – split into the contributions of the various product groups. (For the abbreviations see table note of Table 42)

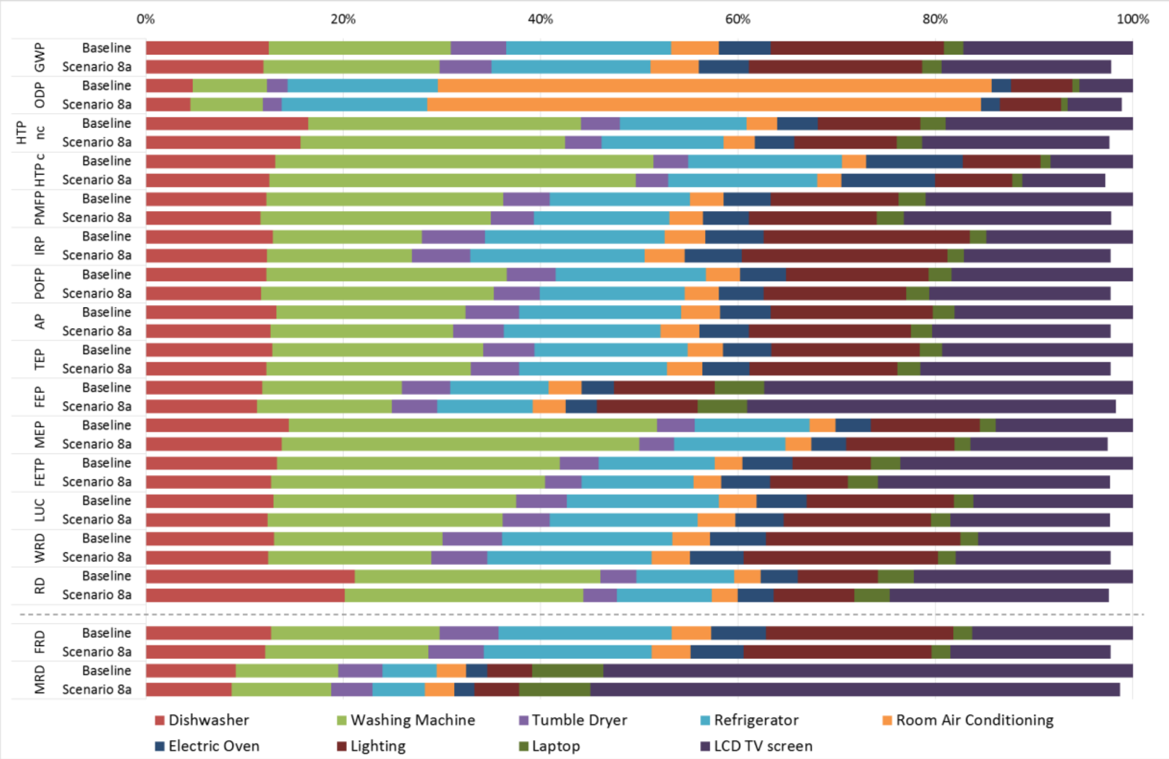


Figure 32. Scenario 8a in comparison with the baseline scenario (with the total impacts of the baseline set as 100%) – split into the contributions of the various life stages. (For the abbreviations see table note of Table 42)

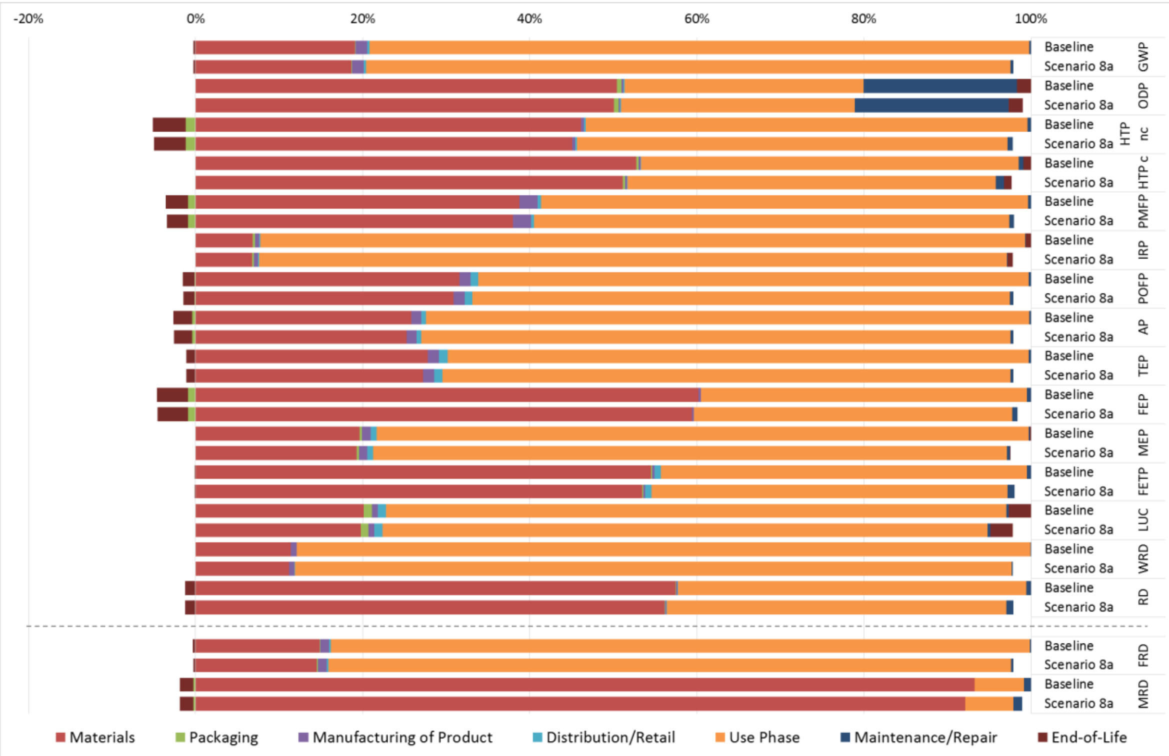


Table 66. Relative changes of the various product groups when comparing Scenario 8a with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	Total	Dish-washer	Washing Machine	Tumble Dryer	Refrige-rator	Room Air Cond.	Electric Oven	Lighting	Laptops	LCD TV Screen
GWP	-2.2%	-4.6%	-3.1%	-6.5%	-3.2%	-	-3.1%	-	-	-
ODP	-1.1%	-4.6%	-3.1%	-6.5%	-3.2%	-	-3.1%	-	-	-
HTP nc	-2.4%	-4.6%	-3.1%	-6.5%	-3.2%	-	-3.1%	-	-	-
HTP c	-2.8%	-4.6%	-3.1%	-6.5%	-3.2%	-	-3.1%	-	-	-
PMFP	-2.2%	-4.6%	-3.1%	-6.5%	-3.2%	-	-3.1%	-	-	-
IRP	-2.2%	-4.6%	-3.1%	-6.5%	-3.2%	-	-3.1%	-	-	-
POFP	-2.3%	-4.6%	-3.1%	-6.5%	-3.2%	-	-3.1%	-	-	-
AP	-2.2%	-4.6%	-3.1%	-6.5%	-3.2%	-	-3.1%	-	-	-
TEP	-2.2%	-4.6%	-3.1%	-6.5%	-3.2%	-	-3.1%	-	-	-
FEP	-1.7%	-4.6%	-3.1%	-6.5%	-3.2%	-	-3.1%	-	-	-
MEP	-2.6%	-4.6%	-3.1%	-6.5%	-3.2%	-	-3.1%	-	-	-
FETP	-2.3%	-4.6%	-3.1%	-6.5%	-3.2%	-	-3.1%	-	-	-
LUC	-2.3%	-4.6%	-3.1%	-6.5%	-3.2%	-	-3.1%	-	-	-
WRD	-2.2%	-4.6%	-3.1%	-6.5%	-3.2%	-	-3.1%	-	-	-
RD	-2.4%	-4.6%	-3.1%	-6.5%	-3.2%	-	-3.1%	-	-	-
FRD	-2.2%	-4.6%	-3.1%	-6.5%	-3.2%	-	-3.1%	-	-	-
MRD	-1.3%	-4.6%	-3.1%	-6.5%	-3.2%	-	-3.1%	-	-	-

([1]) Abbreviations, see table note at Table 42

Table 67. Relative changes of the various life stages when comparing Scenario 8a with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	Total	Materials	Packaging	Production	Distribu-tion	Use	Main-tenance	End-of-Life
GWP	-2.1%	-2.0%	-0.6%	-1.0%	-2.6%	-2.3%	42.8%	3.3%
ODP	-1.0%	-0.8%	-3.0%	-1.9%	-2.6%	-2.3%	0.7%	-2.5%
HTP nc	-2.2%	-2.2%	3.2%	-1.3%	-2.8%	-2.6%	53.5%	3.1%
HTP c	-2.4%	-3.1%	-2.8%	-1.5%	-2.6%	-2.6%	82.8%	-2.7%
PMFP	-2.0%	-2.1%	2.9%	-0.8%	-2.4%	-2.4%	53.7%	2.7%
IRP	-2.2%	-2.0%	-2.9%	-2.0%	-2.6%	-2.3%	55.0%	-2.6%
POFP	-2.1%	-2.2%	4.8%	-0.9%	-2.3%	-2.4%	57.7%	3.0%
AP	-2.1%	-2.1%	3.5%	-1.0%	-2.2%	-2.3%	52.4%	2.5%
TEP	-2.1%	-2.0%	7.9%	-0.8%	-2.3%	-2.4%	51.0%	2.9%
FEP	-1.5%	-1.3%	3.1%	-1.7%	-2.5%	-2.4%	30.8%	2.7%
MEP	-2.4%	-2.0%	-2.3%	-0.9%	-2.3%	-2.7%	52.5%	-2.1%
FETP	-2.0%	-2.0%	-1.5%	-1.6%	-2.9%	-2.7%	52.1%	8.5%
LUC	-2.2%	-2.0%	-3.2%	-1.2%	-2.7%	-2.4%	55.0%	-2.5%
WRD	-2.2%	-2.0%	-0.6%	-1.6%	-2.4%	-2.3%	54.3%	0.4%
RD	-2.1%	-2.3%	2.0%	-2.1%	-2.8%	-2.6%	52.3%	2.3%
FRD	-2.2%	-2.1%	-1.8%	-1.2%	-2.6%	-2.3%	55.4%	3.7%
MRD	-1.0%	-1.2%	3.3%	-1.9%	-2.8%	-2.5%	29.6%	2.3%

([1]) Abbreviations, see table note at Table 42

This first part of Scenario 8 shows that user behaviour can also result in a – moderate – reduction of the environmental impacts related to household appliances; when using such machines longer than this is the case currently.

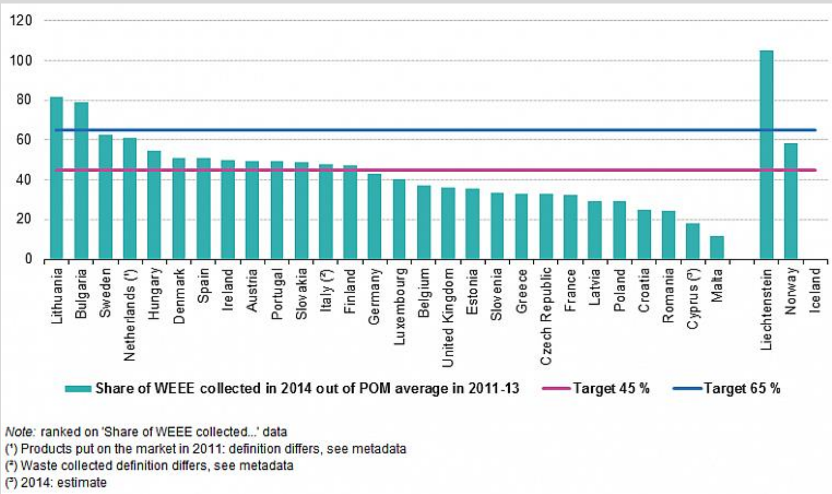
Overall, a reduction of the impacts in the order of 1 to 2.5% could be achieved if a small part (i.e. 10 to 20% according to the product group) of the here covered "big" household appliances are used about one third of time longer. Obviously, the higher maintenance efforts assumed here (i.e. doubling this effect) result in a clear increase of the impacts for the specific life cycle stage (around 55% for most impact categories), but that life stage is of a very minor influence on the total. Due to the chosen generic values, the reduction on the level of the various product groups covered is more or less similar (see Table 66).

8.9.2 Scenario 8b: increasing the collection rates

Area of intervention: For Scenario 8b, the psychological aspects on the user side are a-priori put aside, i.e. the scenario is concentrating on the EoL treatment of such household appliances, more exactly on an increasing collection rate of all these devices. According to the current WEEE directive (i.e. Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment), the collection rate shall be 45% in 2016 and reach 65% by 2019 "of the average weight of EEE placed on the market in the three preceding years". Current statistics show that in 2014, 13 of the EU countries reached the 45% - but only two (i.e. Lithuania and Belgium) had already reached the 2019 level of 65% (details see Box 10).

Box 10. Total collection rate for WEEE in 2014 as a percentage of the average weight of EEE put on the market in the three preceding years (2011-13)

The following figure – taken from http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Total_collection_rate_for_WEEE_in_2014_as_a_percentage_of_the_average_weight_of_EEE_put_on_the_market_in_the_three_preceding_years_(2011-13),_%25.png – shows the collection rates for WEEE in 2014 (in %) for the EU-28 countries, plus Liechtenstein, Norway and Iceland.



For the baseline, collection rates between 0 and 70% have been applied to the various product groups. In view of the above strategy within the WEEE legislation to increase successively the collection rate, a further increase of the WEEE collection rate for the various product groups is assumed for Scenario 8b.

Policy relevance: Ecodesign Directive (EC, 2009a), Communication on Critical Raw Materials (EC, 2011a), Roadmap to a Resource Efficient Europe (EC, 2011b), WEEE Directive, (EU, 2012a) and the Circular Economy Package (EC, 2015).

Rationale for building the scenario: Due to a lack of reliable studies on this subject, the assumption of a uniform 90% collection rate for all product groups others than halogen and incandescent lamps (assumed both as being phased-out in 2030; the reference year for the various investigated scenarios) is used for Scenario 8b. These 90% are supposed to represent the upper limit of what could be expected to come back from such devices in an optimal situation.

Parameters modified in the model: Table 68 summarizes the modifications that have been made in baseline model, for each product affected by Scenario 8b.

Table 68. Summary of the new datasets necessary for the modelling of scenario 8b "increasing the collection rate".

Life Cycle Stage	**Made modifications to: dishwasher 10ps, dishwasher 13ps, electric oven, washing machine, tumble dryer, room air condition-ner (RAC), refrigerator, compact fluorescent lamp*, LED*, laptop computer* and LCD television** **(devices with * do not have adapted maintenance datasets)**
Manufacturing of components	No modification
Manufacturing of the product	No modification
Packaging	No modification
Distribution and retail	No modification
Use phase	No modification
Maintenance and repair	No direct modification – but for the EoL treatment, the modified datasets (see row below) are used.
EoL of the product	Collection rate of 90% towards a proper WEEE treatment (instead of e.g. 70% in the default scenario of the Dishwasher 10 ps), and remaining 10% towards the treatment as domestic waste

Results: In Figure 33 and Figure 34 the results of this scenario are compared with the respective results from the baseline scenario. In Figure 33 they are split into the contributions from the different product groups, in Figure 34 they are split into the shares of the different life cycle stages. Each of the two figures is going along with a table, showing the relative changes (in %) in the different product groups and the different life cycle stages, respectively (Table 69 and Table 70).

Figure 33. Scenario 8b in comparison with the baseline scenario (with total from the baseline set as 100%) – split into the contributions of the various product groups.

Figure 34. Scenario 8b in comparison with the baseline scenario (with the total impacts of the baseline set as 100%) – split into the contributions of the various life stages. (For the abbreviations see table note of Table 42)

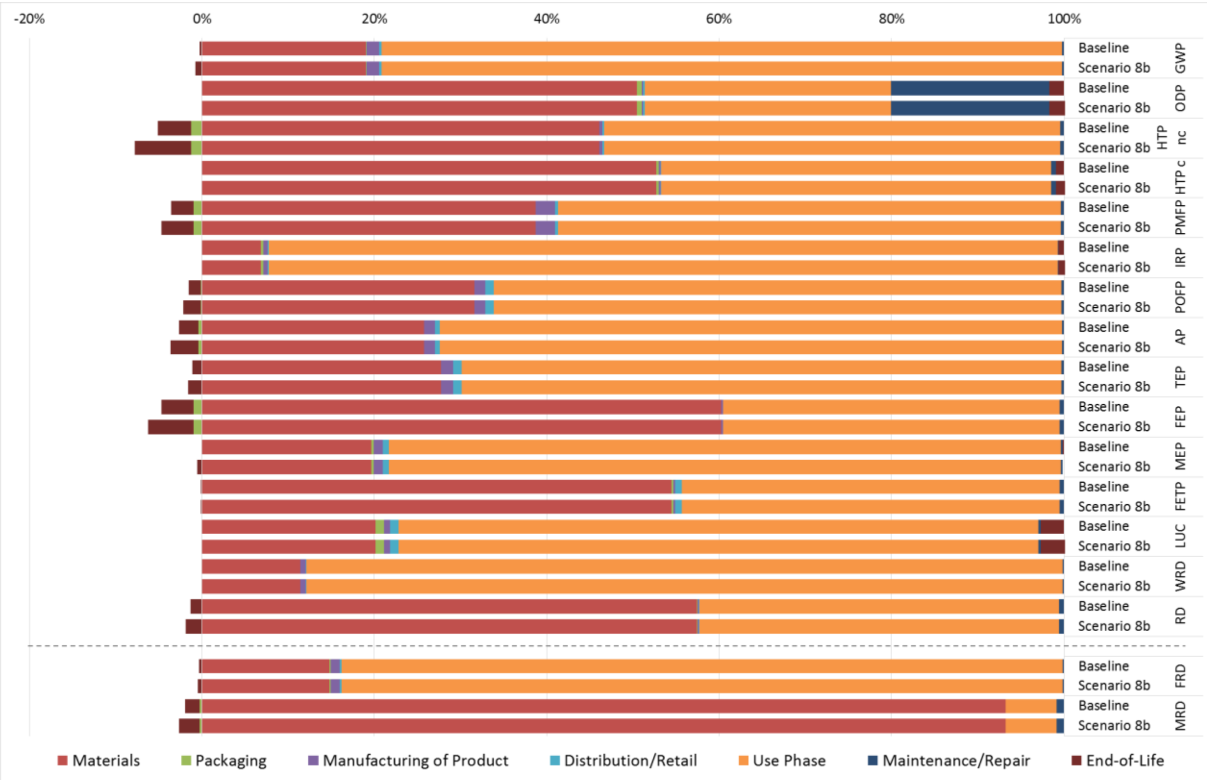


Table 69. Relative changes of the various product groups when comparing Scenario 8b with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	**Total**	**Dish-washer**	**Washing Machine**	**Tumble Dryer**	**Refrige-rator**	**Room Air Cond.**	**Electric Oven**	**Lighting**	**Laptops**	**LCD TV Screen**
GWP	-0.44%	-0.22%	-0.72%	-0.33%	-0.87%	0.23%	-0.33%	-0.01%	-0.56%	-0.58%
ODP	0.74%	0.65%	1.95%	1.15%	1.35%	0.21%	1.37%	-0.00%	4.63%	2.83%
HTP nc	-2.84%	-0.74%	-1.52%	-1.11%	-5.12%	-11.50%	-2.61%	-6.95%	-1.82%	-1.91%
HTP c	0.23%	0.20%	0.07%	0.40%	0.69%	3.96%	0.32%	-0.57%	-1.61%	-0.14%
PMFP	-1.16%	-0.52%	-1.18%	-0.71%	-2.56%	-1.83%	-0.91%	-0.01%	-1.63%	-1.26%
IRP	0.24%	0.09%	0.32%	0.12%	0.43%	1.10%	0.16%	0.00%	0.37%	0.23%
POFP	-0.67%	-0.42%	-0.64%	-0.50%	-1.52%	-0.25%	-0.57%	-0.00%	-0.70%	-0.81%
AP	-1.01%	-0.41%	-1.04%	-0.41%	-1.80%	-2.53%	-0.77%	-0.00%	-1.79%	-1.43%
TEP	-0.48%	-0.28%	-0.53%	-0.33%	-1.04%	-0.14%	-0.35%	-0.00%	-0.72%	-0.60%
FEP	-1.64%	-1.04%	-2.10%	-1.36%	-4.84%	-8.40%	-2.49%	-0.01%	-0.64%	-0.74%
MEP	-0.70%	-0.40%	-0.50%	-0.67%	-2.06%	-0.20%	-0.75%	-0.00%	-1.03%	-1.03%
FETP	0.02%	-0.12%	-0.19%	-0.07%	-0.61%	-1.68%	-0.25%	1.73%	-0.23%	0.40%
LUC	1.05%	0.31%	0.87%	0.58%	2.08%	5.85%	0.82%	-0.00%	1.60%	0.91%
WRD	-0.01%	0.03%	-0.08%	0.02%	0.01%	0.17%	0.04%	0.00%	-0.27%	-0.07%
RD	-0.60%	-0.26%	-0.29%	-0.35%	-1.27%	-3.17%	-0.60%	-0.01%	-0.76%	-0.91%
FRD	-0.14%	-0.12%	-0.18%	-0.15%	-0.41%	0.86%	0.03%	-0.00%	-0.04%	-0.30%
MRD	-0.76%	-0.79%	-0.90%	-0.49%	-2.80%	-3.20%	-1.28%	-0.03%	-0.52%	-0.48%

([1]) Abbreviations, see table note at Table 42

Table 70. Relative changes of the various life stages when comparing Scenario 8b with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	Total	Materials	Packaging	Production	Distribu-tion	Use	Main-tenance	End-of-Life
GWP	-0.44%	-	-	-	-	-	-1.77%	-156.6%
ODP	0.74%	-	-	-	-	-	0.04%	42.3%
HTP nc	-2.84%	-	-	-	-	-	-4.68%	-68.2%
HTP c	0.23%	-	-	-	-	-	0.53%	24.6%
PMFP	-1.16%	-	-	-	-	-	-2.90%	-42.0%
IRP	0.24%	-	-	-	-	-	3.16%	39.2%
POFP	-0.67%	-	-	-	-	-	-2.09%	-46.5%
AP	-1.01%	-	-	-	-	-	-3.84%	-43.8%
TEP	-0.48%	-	-	-	-	-	-1.71%	-44.0%
FEP	-1.64%	-	-	-	-	-	-2.87%	-41.6%
MEP	-0.70%	-	-	-	-	-	-3.44%	-556.0%
FETP	0.02%	-	-	-	-	-	-0.21%	19.8%
LUC	1.05%	-	-	-	-	-	4.43%	38.3%
WRD	-0.01%	-	-	-	-	-	-0.08%	-61.2%
RD	-0.60%	-	-	-	-	-	-0.98%	-45.9%
FRD	-0.14%	-	-	-	-	-	-0.95%	-45.0%
MRD	-0.76%	-	-	-	-	-	-0.84%	-45.0%

([1]) Abbreviations, see table note at Table 42

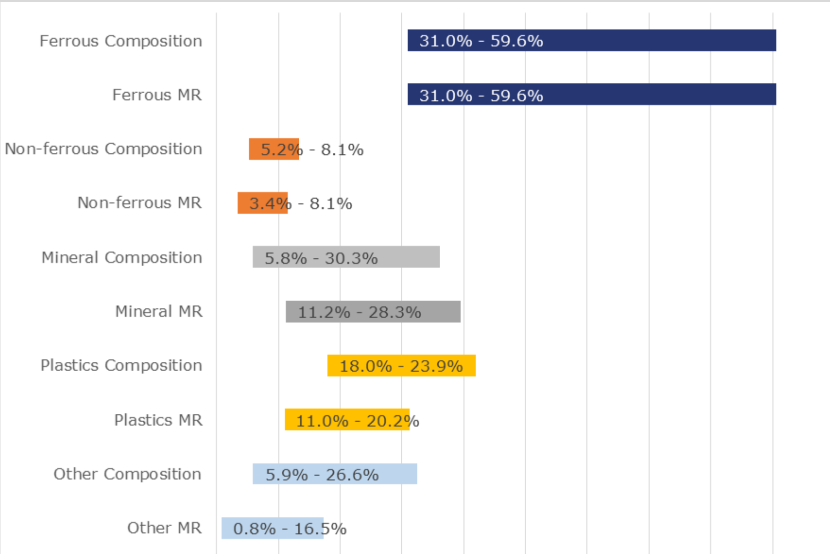
The second part of this scenario – assuming an increase in the collection of such devices for a proper WEEE treatment – shows only a very small reduction of the environmental impacts.

The reduction of the impacts is less than 1% for almost all impact categories; with a slight increase even for a few categories. Life cycle stages with a change are the maintenance (due to the modelling of this step) and obviously the end-of-life stage. Due to the chosen, generic value of 90% for the collection rate, the reduction on the level of the various product groups covered is higher for all those groups that have currently a lower collection rate; while for groups with an already high collection rate, very small changes get visible only (see Table 69).

8.9.3 Scenario 8c: increasing recycling rates of various fractions

Area of intervention: Last but not least, within Scenario 8c, improved End-of-Life treatment processes are put in the centre. In a collaborative effort, Seyring and co-workers evaluated the current EU WEEE targets on the recovery and the re-use of metals and other materials (Seyring et al., 2015). According to this analysis (see Box 11 below) metals and other mineral elements could be recovered on a material basis up to almost 100%, while plastics even in an optimum case do not go beyond about 85% and further fractions are recovered on an even lower level.

Box 11. Average composition of all WEEE versus "material recovered" (MR) amounts with 100% treatment input as reference



This figure (i.e. Figure 18 from Seyring et al., 2015) shows a graphical overview of the materials recovered from the various main fractions that average WEEE is composed of. It shows that for metallic (i.e. ferrous and non-ferrous) and mineral fractions a material recovery of up to 100% is already possible; while in the area of plastics a maximum of 85% gets achieved. For all further fractions, the material recovery fells even below (here, the figure shows that a maximum of about 60% could be expected).

Within the baseline calculations, fraction-specific recycling rates ranging from 0 to 95% have been applied to the various fractions distinguished within this study. Similar as for most other scenarios, the objective is the evaluation of the potential that lays within the specific issue here (i.e. increased recycling rates) and therefore most optimistic recycling rates are used for Scenario 8c.

Policy relevance: Ecodesign Directive (EC, 2009a), Communication on Critical Raw Materials (EC, 2011a), Roadmap to a Resource Efficient Europe (EC, 2011b), WEEE Directive, (EU, 2012a) and the Circular Economy Package (EC, 2015).

Rationale for building the scenario: Within the timeframe of this study, no in-depth review of existing studies dealing with (best/future) recycling technologies could be established. Hence, in order to evaluate the potential of a more efficient recycling process, the values reported in Seyring et al. (2015), and shown in the box above, are used as starting point for the setting of "optimistic" recycling rates for the various fractions that are distinguished within the baseline scenario. In details, the following assumptions were used as starting point for such an optimized material recovery scenario:

- for the plastics fraction we assume that the "high-value" plastics (ABS, PP, PS) will be recovered at a maximum level (assumed to be 5% above the highest value that plastics recycling currently shows, according to Seyring et al. (2015)) – while for the other plastics fraction a low recycling rate (one third compared to ABS & Co) is assumed. For the remaining parts, energy recovery is assumed to be the main option, while landfilling is assumed to be of minor relevance only;
- for both metal fractions, an almost complete material recovery is assumed (based on the fact that Seyring et al. (2015) report a potential for a complete recovery of 100%);
- the printed circuit boards (PCB) are assumed to be separated in a more complete way from the respective devices; resulting in higher amount going for a specific printed wiring board (PWB) recycling; while the remaining parts are assumed to go into energy recovery only;
- for all the further fractions (glass, concrete, miscellaneous) we assume that the first two will mainly go for material recovery, while the last one is accentuated towards energy recovery – allowing in all three cases to reduce the landfill amount;
- all these cornerstones and the resulting values for the modelling of this scenario are summarized in Table 71.

Table 71. Key figures for Scenario 8c (and their corresponding values in the baseline scenario) – investigating increased recycling rates for the various material fractions.

Fraction	**originating from …**	**Baseline**			**Scenario 8c**		
		MR(1)	**ER**	**LF**	**MR**	**ER**	**LF**
ABS/PP/PS	All devices	80	10	10	90	10	-
Other plastics	All devices	-	50	50	30(2)	60	10
Ferrous metals	All devices	95	-	5	98	-	2
Non-ferrous metals	All devices	85	-	15	98	-	2
Printed Circuit Boards (entry rate)	Laptop, TV	80	10	10	95	5	-
	other devices	51	24.5	24.5	90	10	-
Glass	All devices	65	17.5	17.5	90	-	10
Concrete	All devices	65	17.5	17.5	90	-	10
Miscellaneous	All devices	-	50	50	-	75	25

(1) MR = material recovery (i.e. recycling) / ER = energy recovery / LF = landfilling
(2) The types of plastics contained in the each product group are considered

Parameters modified in the model: Table 72 summarizes the modifications that have been made in baseline model, for each product affected by Scenario 8c.

Table 72. Summary of the new datasets necessary for the modelling of Scenario 8c "increasing recycling rates of various fractions"

Life Cycle Stage	**Made modifications to: dishwasher 10ps, dishwasher 13ps, electric oven, washing machine, tumble dryer, room air conditioner (RAC), refrigerator, compact fluorescent lamp*, LED*, laptop computer* and LCD television** **(devices with * do not have adapted maintenance datasets)**
Manufacturing of components	No modification
Manufacturing of the product	No modification
Packaging	No modification
Distribution and retail	No modification
Use phase	No modification
Maintenance and repair	No direct modification – but for the EoL treatment, the modified datasets (see row below) are used.
EoL of the product	Correction of EoL treatment (for proper WEEE treatment and the general EoL treatment processes) of the various fractions, by using the in Table 76 listed new split between the various EoL options, e.g. for ABS from 80% material recovery, 10% energy recovery and 10% landfill to 90% material recovery and 10% energy recovery.

Results: In Figure 35 and Figure 36 the results of Scenrio 8c are compared with the respective results from the baseline scenario. In Figure 35 they are split into the contributions from the different product groups, in Figure 36 they are split into the shares of the different life cycle stages distinguished here. Each of the two figures is going along with a table, showing the relative changes (in %) in the different product groups and the different life cycle stages, respectively (Table 73 and Table 74).

Figure 35. Scenario 8c in comparison with the baseline scenario (with total from the baseline set as 100%) – split into the contributions of the various product groups. (For the abbreviations see table note of Table 42)

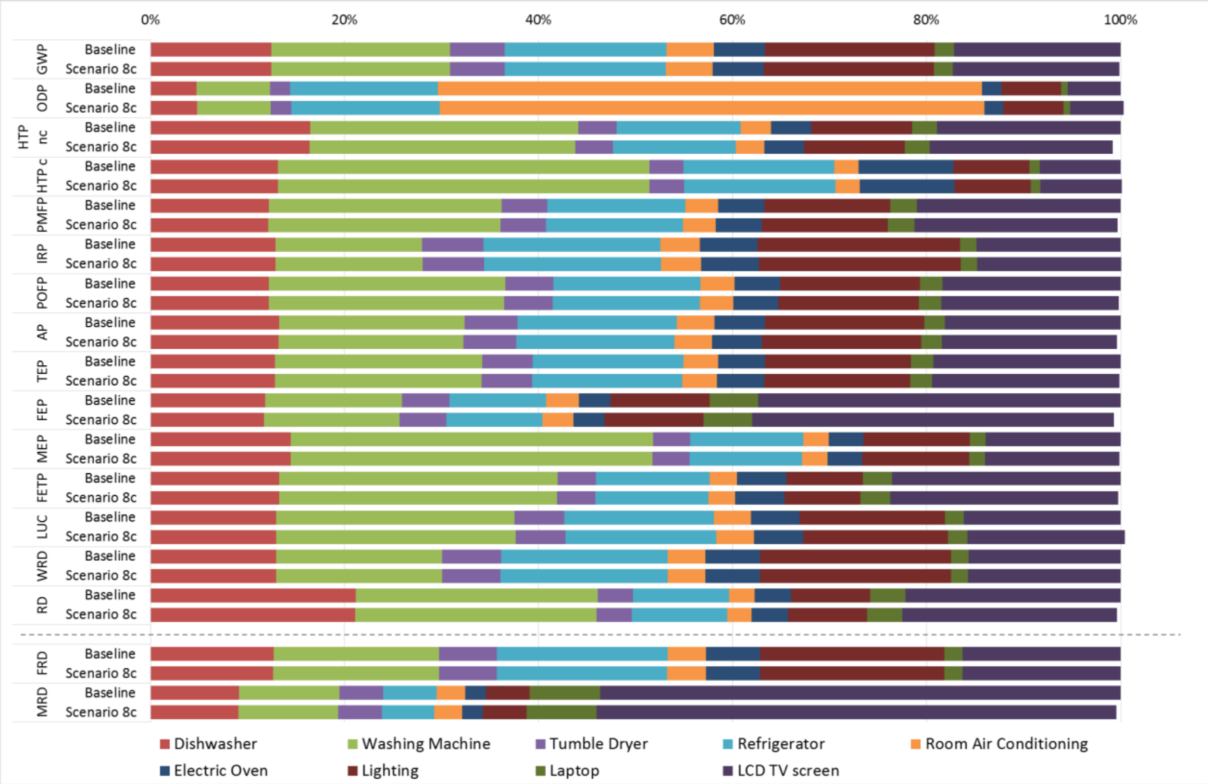


Figure 36. Scenario 8c in comparison with the baseline scenario (with the total impacts of the baseline set as 100%) – split into the contributions of the various life stages. (For the abbreviations see table note of Table 42)

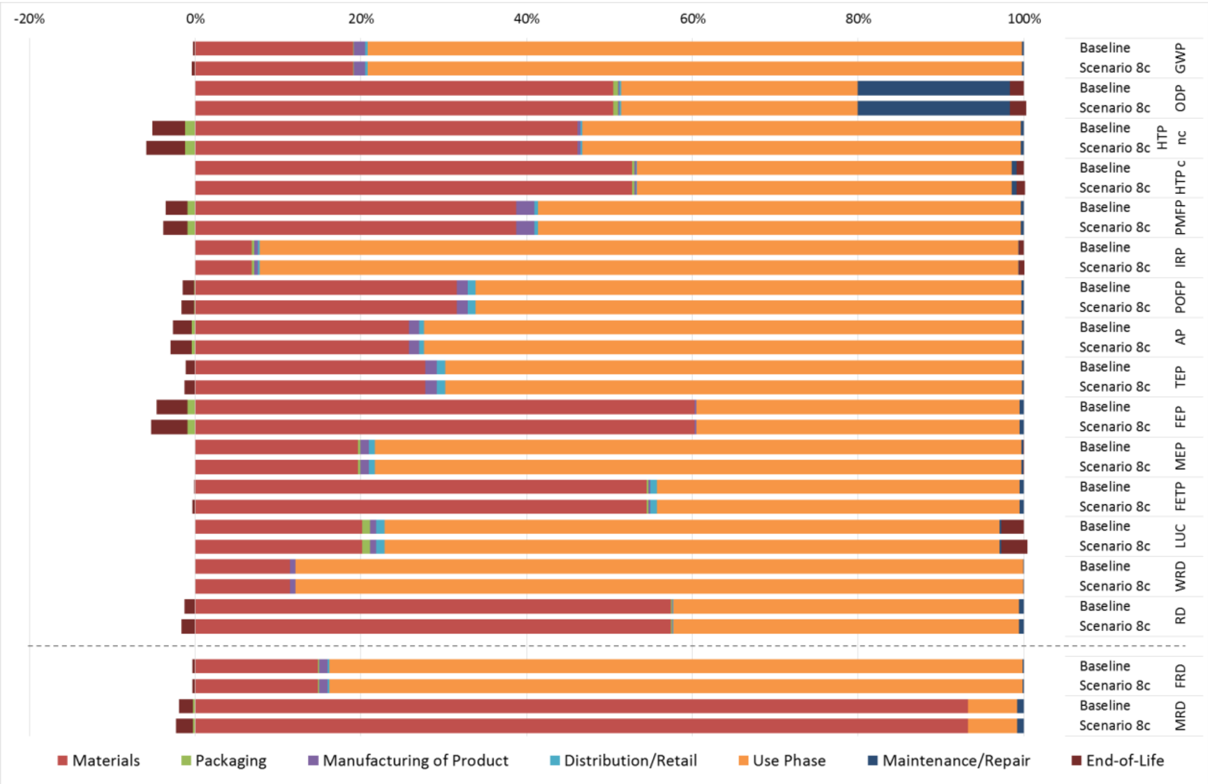


Table 73. Relative changes of the various product groups when comparing Scenario 8c with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	Total	Dish-washer	Washing Machine	Tumble Dryer	Refrige-rator	Room Air Cond.	Electric Oven	Lighting	Laptops	LCD TV Screen
GWP	-0.11%	0.04%	-0.13%	-0.01%	-0.40%	0.12%	-0.01%	-0.00%	-0.14%	-0.13%
ODP	0.29%	0.48%	1.15%	0.82%	0.43%	0.07%	0.79%	-0.00%	0.79%	0.75%
HTP nc	-0.82%	-0.46%	-0.82%	-0.78%	-1.60%	-3.73%	-1.52%	-0.01%	-0.42%	-0.50%
HTP c	0.10%	0.11%	0.04%	0.25%	0.18%	1.19%	0.15%	-0.00%	-0.38%	-0.08%
PMFP	-0.33%	-0.19%	-0.45%	-0.26%	-0.57%	-0.57%	-0.33%	-0.00%	-0.38%	-0.27%
IRP	0.09%	0.05%	0.18%	0.07%	0.11%	0.32%	0.08%	-0.00%	0.05%	0.06%
POFP	-0.16%	-0.15%	-0.21%	-0.14%	-0.28%	-0.16%	-0.17%	-0.00%	-0.18%	-0.15%
AP	-0.36%	-0.26%	-0.52%	-0.28%	-0.51%	-0.88%	-0.42%	-0.00%	-0.40%	-0.36%
TEP	-0.14%	-0.11%	-0.19%	-0.11%	-0.24%	-0.20%	-0.16%	-0.00%	-0.19%	-0.13%
FEP	-0.67%	-0.65%	-1.18%	-0.89%	-1.51%	-3.09%	-1.38%	-0.00%	-0.15%	-0.20%
MEP	-0.10%	-0.07%	-0.12%	-0.06%	-0.19%	0.00%	-0.09%	-0.00%	-0.16%	-0.10%
FETP	-0.27%	-0.12%	-0.13%	-0.21%	-0.67%	-0.58%	-0.31%	-0.72%	-0.11%	-0.15%
LUC	0.41%	0.21%	0.52%	0.38%	0.65%	1.76%	0.46%	-0.00%	0.24%	0.24%
WRD	-0.01%	0.01%	-0.04%	0.01%	-0.01%	0.03%	0.00%	-0.00%	-0.07%	-0.01%
FRD	-0.36%	-0.22%	-0.24%	-0.49%	-0.51%	-3.92%	-0.50%	-0.00%	-0.17%	-0.27%
MRD	-0.02%	-0.05%	-0.05%	-0.01%	-0.05%	0.26%	0.06%	-0.00%	-0.04%	-0.04%

([1]) Abbreviations, see table note at Table 42

Table 74. Relative changes of the various life stages when comparing Scenario 8c with the baseline scenario (relative to the result in the baseline scenario)

Impact Category(1)	Total	Materials	Packaging	Production	Distribu-tion	Use	Main-tenance	End-of-Life
GWP	-0.11%	-	-	-	-	-	-0.43%	-37.6%
ODP	0.29%	-	-	-	-	-	0.02%	16.7%
HTP nc	-0.82%	-	-	-	-	-	-1.84%	-19.7%
HTP c	0.10%	-	-	-	-	-	0.19%	10.7%
PMFP	-0.33%	-	-	-	-	-	-0.83%	-11.9%
IRP	0.09%	-	-	-	-	-	1.13%	13.8%
POFP	-0.16%	-	-	-	-	-	-0.51%	-11.4%
AP	-0.36%	-	-	-	-	-	-1.41%	-15.8%
TEP	-0.14%	-	-	-	-	-	-0.51%	-13.0%
FEP	-0.67%	-	-	-	-	-	-1.18%	-16.9%
MEP	-0.10%	-	-	-	-	-	-0.49%	-79.6%
FETP	-0.27%	-	-	-	-	-	-0.39%	-257.7%
LUC	0.41%	-	-	-	-	-	1.76%	14.9%
WRD	-0.01%	-	-	-	-	-	-0.07%	-39.2%
FRD	-0.36%	-	-	-	-	-	-0.61%	-27.7%
MRD	-0.02%	-	-	-	-	-	-0.12%	-6.1%

(1) Abbreviations, see table note at Table 42

Finally, the third part of this scenario – assuming an increase in the recycling rates of the various metallic/plastic flows during the WEEE treatment – shows hardly any reduction of the environmental impacts.

The changes of the impacts in all examined impact categories are less than 1%. Due to data uncertainty, it is not possible to consider it an actual variation. In the step of the end-of-life treatment, changes in the order of 10 to 15% (with some categories going up to 80 or 250%) can be observed due to the increasing recycling rates (and the reducing rates going into incineration and/or landfills); however, the end-of-life step is in all cases of minor relevance; and thus these changes do not get visible anymore on the level of the complete life cycle.

8.10 Scenario 9: Increased use of LED lighting

Description and aim: Scenario 9 is intended to represent effects of increased use of high energy efficient lightings.

Area of intervention:

- Hotspot: impacts from electricity consumption
- Only one product (lighting)
- Life cycle stage: use stage

Policy relevance: Ecodesign Directive (EC, 2009a), Energy Efficiency Directive (EU, 2012b), and Roadmap to a Resource Efficient Europe (EC, 2011b).

Rationale for building the scenario: Scenario 9 reflects changes on the market induced by the Ecodesign regulations 244/2009 (non-directional household lamps, EC, 2009b) and 1194/2012 (directional lamps, EC, 2012) as well as expectations in the long term (2030) about lamp types used in the residential sector (VHK, 2016b). In 2030, 70% of lamps in dwellings is expected to be LED (VHK, 2016b). The remaining share has been assumed to be CFL as, due to the effects of Ecodesign regulations, there will be a gradual phase-out of most GLS-types (2009-2014) and Halogen lamps (2014-2018) (VHK, 2016b).

Parameters modified in the model: The total stock of lamps is the same of 2010 (considering the same number of dwellings that has been considered for the BoP housing (Baldassarri et al., 2017). The number of dwellings at 2015 in from BoP housing should have been used, however, the baseline 2015 for the housing was not available at the moment in which this report was written. Changes in the lamp technologies (e.g. bill of material, efficiency) are not taken into account. The shares of stock associated to each lamp type for this scenario (Table 75) refer to 2030 and are consistent with information reported in VHK (2016b) for the this year.

Table 75. Share of stock for each lamp type, on the total stock at 2030

Lamp type	% of stock	Stock
Compact fluorescent lamp	30	1,506,864,535
LED	70	3,516,017,248

For the definition of electricity consumption for lighting, a top-down approach has been applied, as it was done for the baseline. The electricity consumption for lighting, by each dwelling, at 2015 is based on data reported in VHK (2016a). In particular, the reduction of electricity consumption for lighting by dwelling at 2015 compared to that one of 2010 (85%) has been considered to update the average electricity consumption for lighting by a single dwelling (Table 76).

Table 76. Electricity consumption for lighting in in the baseline and in Scenario 9 "Increased use of LED"

	Electricity consumption
by single dwelling (kWh/year) in the baseline	404
by single dwelling (kWh/year) in scenario "Increased use of LED"	60.55

In order to revise the electricity consumption of each lamp type and make it consistent with the overall consumption per dwelling, the following steps were followed.

Firstly, an annual consumption by each lamp type has been calculated considering the average annual operating hours (VITO, 2015a), the average kW (VITO, 2015a), and the number of lamps expected to be installed in each dwelling in 2030 (VHK, 2016b). Secondly, the share of consumption by each lamp type has been considered, in order to allocate the overall electricity consumption for lighting by one dwelling in 2030 (VHK, 2016) among the different lamp types. Thirdly, the total electricity consumption by the dwelling stock has been calculated for each lamp type, multiplying the consumption in each dwelling by the total number of dwellings. The average electricity consumption to be used in the BoP appliances for each single lamp type has been calculated by dividing the overall electricity consumption for each lamp type in the dwelling stock, by the stock of each lamp type.

Table 77. Average energy consumption by single lamp type in Scenario 9 "Increased use of LED"

Lamp type	**Average energy consumption in the BoP (kWh/year)**
Compact fluorescent lamp	2.03
LED	2.64

Results: In Figure 37 and Figure 38 the results of Scenario 9 are compared with the results from the baseline scenario. In Figure 37 they are split into the contributions from the different product groups, in Figure 38 they are split into the shares of the different life cycle stages. Each of the two figures is going along with a table (Table 78 and Table 79), showing the relative changes (in %) in the different product groups and the different life cycle stages, respectively.

Figure 37. Scenario 9 in comparison with the baseline scenario (with total from the baseline set as 100%) – split into the contributions of the various product groups. (For the abbreviations see table note of Table 42)

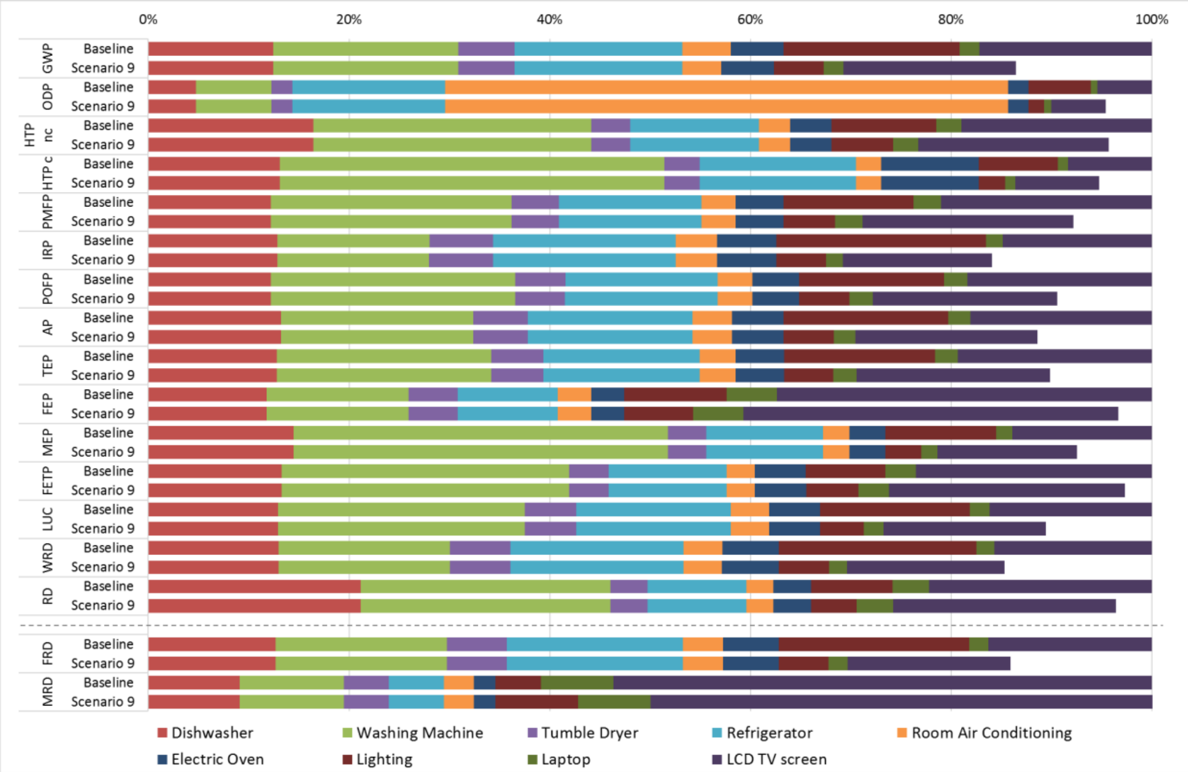


Figure 38. Scenario 9 in comparison with the baseline scenario (with the total impacts of the baseline set as 100%) – split into the contributions of the various life cycle stages. (For the abbreviations see table note of Table 42)

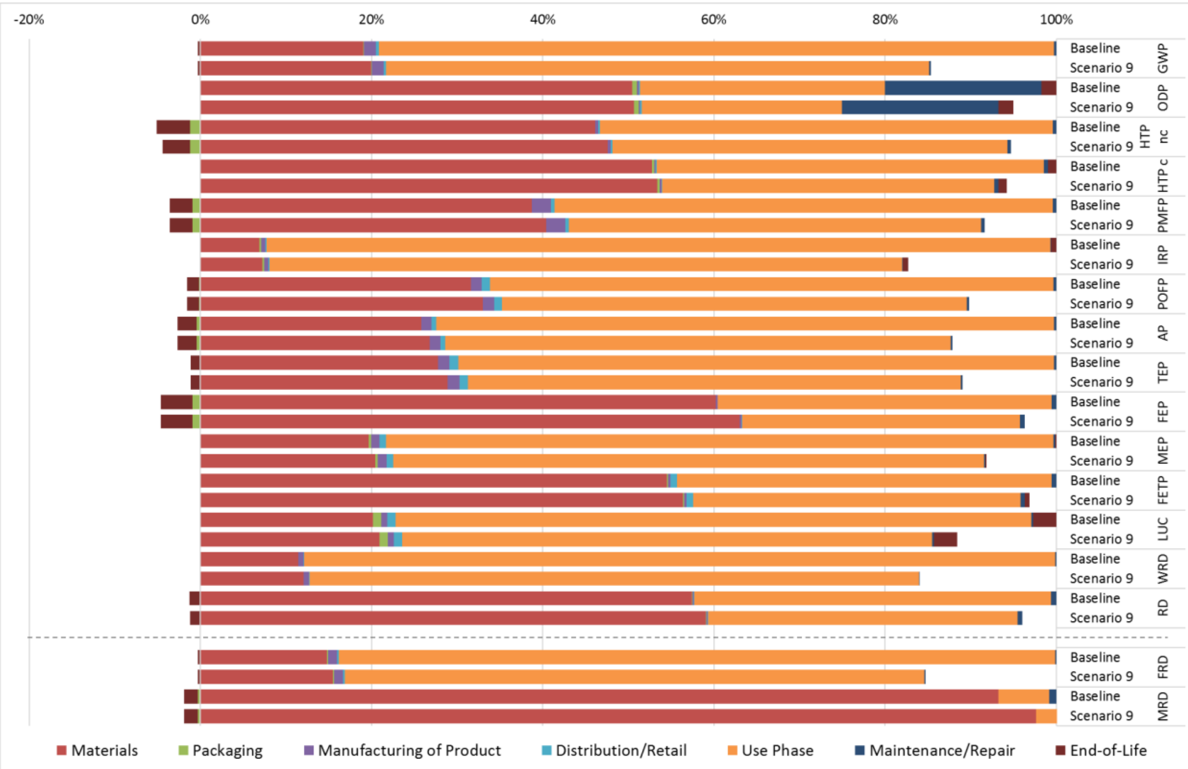


Table 78. Relative changes of the various product groups when comparing Scenario 9 with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	**Total**	**Dish-washer**	**Washing Machine**	**Tumble Dryer**	**Refrige-rator**	**Room Air Cond.**	**Electric Oven**	**Lighting**	**Laptops**	**LCD TV Screen**
GWP	-12.7%	-	-	-	-	-	-	-71.9%	-	-
ODP	-4.6%	-	-	-	-	-	-	-74.2%	-	-
HTP nc	-4.3%	-	-	-	-	-	-	-41.3%	-	-
HTP c	-5.3%	-	-	-	-	-	-	-66.9%	-	-
PMFP	-7.8%	-	-	-	-	-	-	-60.3%	-	-
IRP	-15.9%	-	-	-	-	-	-	-76.4%	-	-
POFP	-9.4%	-	-	-	-	-	-	-65.3%	-	-
AP	-11.4%	-	-	-	-	-	-	-69.6%	-	-
TEP	-10.1%	-	-	-	-	-	-	-67.3%	-	-
FEP	-3.4%	-	-	-	-	-	-	-32.8%	-	-
MEP	-7.5%	-	-	-	-	-	-	-67.9%	-	-
FETP	-2.7%	-	-	-	-	-	-	-33.7%	-	-
LU	-10.6%	-	-	-	-	-	-	-70.8%	-	-
WRD	-14.7%	-	-	-	-	-	-	-74.5%	-	-
RD	-3.6%	-	-	-	-	-	-	-44.0%	-	-
FRD	-14.1%	-	-	-	-	-	-	-74.0%	-	-
MRD	3.7%	-	-	-	-	-	-	82.3%	-	-

([1]) Abbreviations, see table note at Table 42

Table 79. Relative changes of the various life stages when comparing Scenario 9 with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	**Total**	**Materials**	**Packaging**	**Production**	**Distribu-tion**	**Use**	**Main-tenance**	**End-of-Life**
GWP	-12.7%	4.6%	4.4%	0.2%	-1.4%	-18.7%	-0.0%	2.7%
ODP	-4.6%	0.4%	0.1%	-3.2%	-1.5%	-18.2%	0.0%	0.0%
HTP nc	-4.3%	3.2%	0.3%	-0.8%	-1.5%	-12.8%	0.0%	17.7%
HTP c	-5.3%	1.2%	0.6%	-1.2%	-1.5%	-14.2%	-0.0%	4.9%
PMFP	-7.8%	4.3%	-0.4%	1.2%	-1.4%	-17.3%	-0.0%	0.0%
IRP	-15.9%	5.1%	0.4%	-4.1%	-1.4%	-19.3%	0.0%	0.0%
POFP	-9.4%	4.5%	3.0%	0.5%	-1.4%	-17.5%	-0.0%	0.1%
AP	-11.4%	4.0%	0.8%	0.3%	-1.4%	-18.2%	0.0%	0.0%
TEP	-10.1%	4.1%	8.7%	0.6%	-1.4%	-17.3%	0.0%	0.1%
FEP	-3.4%	4.7%	0.1%	-2.3%	-1.4%	-16.7%	-0.0%	0.0%
MEP	-7.5%	4.1%	1.6%	0.6%	-1.4%	-11.5%	-0.0%	0.8%
FETP	-2.7%	3.5%	2.9%	-1.4%	-1.5%	-12.6%	0.0%	595.7%
LU	-10.6%	3.9%	-0.1%	-0.6%	-1.5%	-16.6%	-0.0%	0.1%
WRD	-14.7%	5.7%	5.0%	-2.2%	-1.4%	-18.9%	0.0%	1.9%
RD	-3.6%	2.8%	9.7%	-4.1%	-1.5%	-13.2%	0.0%	3.7%
FRD	-14.1%	4.5%	2.2%	-0.7%	-1.5%	-19.0%	0.3%	-0.7%
MRD	3.7%	4.7%	0.4%	-3.2%	-1.5%	-13.9%	0.0%	0.2%

([1]) Abbreviations, see table note at Table 42

Even if the scenario acts only on one product group (i.e. lighting), the expected reduction of impact is not irrelevant for the whole basket. The highest reduction is obtained for ionising radiation (-15.9%), water depletion (-14.7%), and climate change (-12.7%). This improvement is due to the reduced amount of electricity needed in the use phase.This is confirmed also by the reduction of impacts coming from the use stage, which are generally larger (11%-18%) than the ones of the other life cycle stages. The increase of impact from the EoL for the impact category freshwater ecotoxicity can be explained by the higher impact of LED lights compared to the ones that are substituted in the scenario, as shown in Table 80.

Table 80. Impact of the EoL stage on freshwater ecotoxicity, in the baseline and in Scenario 9.

	CFLi	GLSX	HLLVR	HMLVE	LED	Other products	Total EoL
Impact in EoL of baseline scenario (CTUe)	0.192	0.0031	0.0018	0.0038	-	-0.453	-0.252
Impact in in EoL of Scenario 9 (CTUe)	0.195	-	-	-	1.51	-0.453	1.25

CFLi= compact fluorescent lamp, hot cathode, GLSX=Incandescent lamp, HLLVR= halogen lamp, low voltage, HMLVE=halogen lamp, mains voltage, LED= Light Emitting Diode

However, the absolute increase of freshwater ecotoxicity impact at the EoL is small compared to the improvements achieved in the other life cycle stages. This is confirmed also by the overall results of the lighting product group, which has a general reduction of impact in all the categories considered, ranging from 33% in freshwater ecotoxicity and freshwater eutrophication, to 76% in ionizing radiation impact.

8.11 Scenario 10: Devices-related (overall) saving potential

Description and aim: In the preceding scenarios, the influence of various aspects of the devices covering the here examined product groups on the resulting environmental impacts has been investigated – in Scenario 10, these effects are summed up in order to investigate the "overall" saving potential that lays within the actual devices.

Rationale for building the scenario: This analysis is split into three parts – i.e. Scenario 10a to 10c – taking into account the aspects listed in Table 81.

Table 81. Summary of the content/coverage of the scenarios 10a to 10c

Scenario	Covered aspects	Remarks
Scenario 10a	• More efficient dishwasher and washing machines	modelled as in Scenario 2
	• More efficient refrigerants, containing also a less harmful refrigerant substance	Combination of Scenario 3 and Scenario 6 (part for refrigerant)
	• More efficient television devices	Modelled as in Scenario 4
	• More efficient lighting installation in household	Modelled as in Scenario 9
	• Room air conditioners with lower leakage rate, containing a less harmful refrigerant substance	Combination of Scenario 5 and Scenario 6 (part for air conditioner)
Scenario 10b	• More efficient devices according to Scenario 10a	-
	• Increasing lifetime of big household appliances and television devices	Combining Scenario 8a and the investigation in Box of Scenario 4
	• Higher collection rate for WEEE treatment	Modelled as in Scenario 8b
	• Increased material recovery rates in the various WEEE recycling processes	Modelled as in Scenario 8c
Scenario 10c	• More efficient devices, used longer and treated in an optimized WEEE system as in Scenario 10b	-
	• Increasing amount of devices per household	Modelled as in Scenario 7

Results: In Figure 39 and Figure 40 the results of these three scenario are compared with the results from the baseline scenario. In Figure 39 they are split into the contributions from the different product groups, in Figure 40 they are split into the shares of the different life cycle stages. Each of the two figures is going along with three tables, showing the relative changes of each scenario (in %) in the different product groups and the different life cycle stages, respectively (Table 82 to Table 87).

Figure 39. Scenario 10a to 10c in comparison with the baseline scenario (with total impacts of the baseline as 100%) – split into the contributions of the various product groups. (For the abbreviations see table note of Table 42)

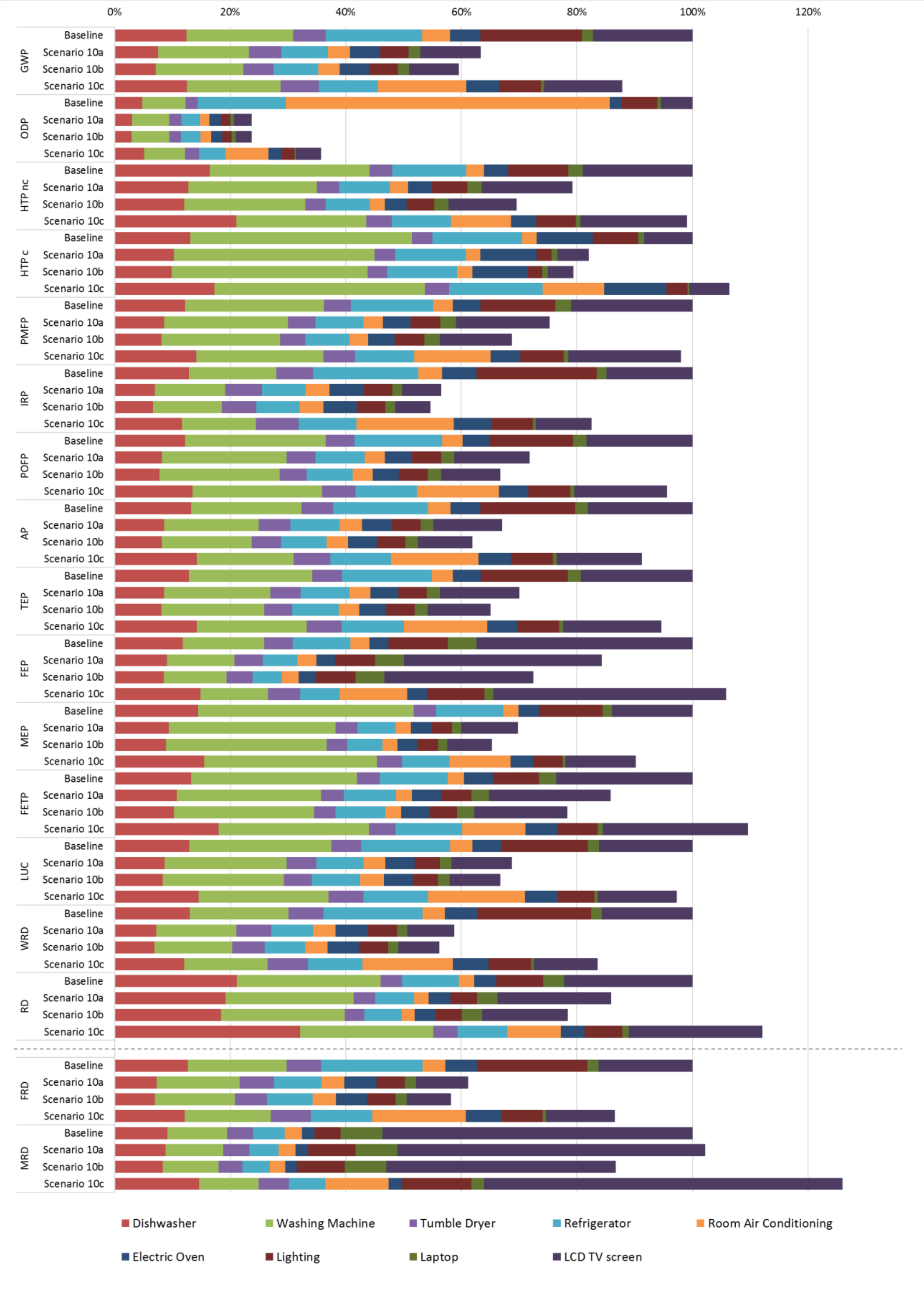


Figure 40. Scenario 10a to 10c in comparison with the baseline scenario (with total impacts of the baseline as 100%) – split into the contributions of the various life stages. (For the abbreviations see table note of Table 42)

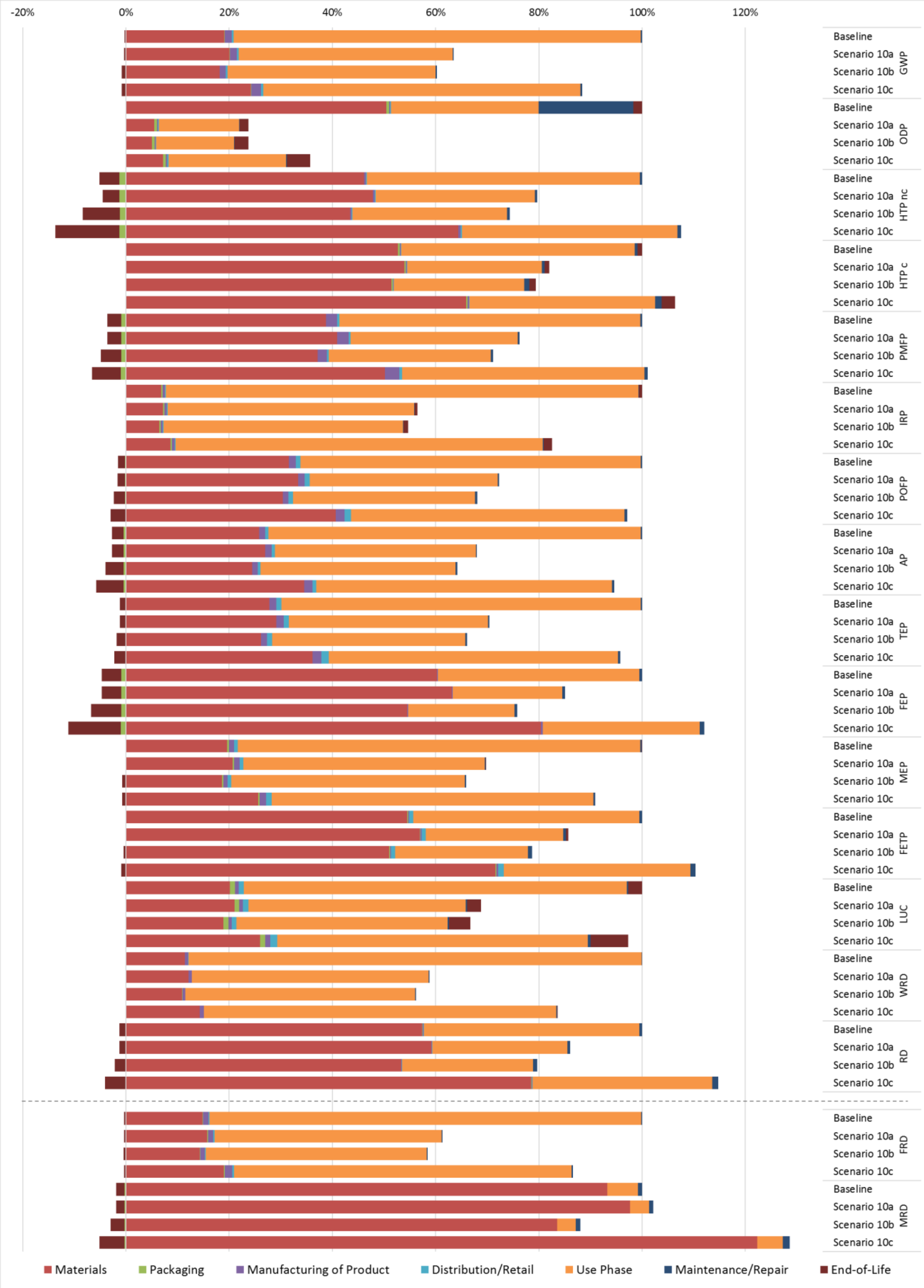


Table 82. Relative changes of the various product groups when comparing Scenario 10a with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	Total	Dish-washer	Washing Machine	Tumble Dryer	Refrige-rator	Room Air Cond.	Electric Oven	Lighting	Laptops	LCD TV Screen
GWP	-36.6%	-39.7%	-14.7%	-	-51.3%	-23.1%	-	-71.9%	-	-38.8%
ODP	-76.3%	-36.9%	-13.8%	-	-79.1%	-97.0%	-	-74.2%	-	-43.6%
HTP nc	-20.7%	-22.3%	-19.7%	-	-31.5%	-0.6%	-	-41.3%	-	-17.1%
HTP c	-17.9%	-21.8%	-9.3%	-	-21.2%	-0.7%	-	-66.9%	-	-35.2%
PMFP	-24.7%	-29.9%	-10.6%	-	-41.0%	-1.2%	-	-60.3%	-	-22.8%
IRP	-43.5%	-46.0%	-19.2%	-	-58.3%	-0.1%	-	-76.4%	-	-54.3%
POFP	-28.2%	-33.1%	-11.1%	-	-43.9%	0.4%	-	-65.3%	-	-29.2%
AP	-32.9%	-34.9%	-14.5%	-	-48.1%	-0.7%	-	-69.6%	-	-34.1%
TEP	-29.9%	-33.2%	-13.9%	-	-45.1%	-0.7%	-	-67.3%	-	-28.8%
FEP	-15.7%	-23.1%	-17.3%	-	-40.5%	-0.1%	-	-32.8%	-	-8.3%
MEP	-30.2%	-35.2%	-22.7%	-	-43.3%	-0.6%	-	-67.9%	-	-29.4%
FETP	-14.2%	-19.1%	-12.8%	-	-23.5%	-0.6%	-	-33.7%	-	-10.7%
LUC	-31.2%	-33.3%	-13.8%	-	-47.3%	-0.3%	-	-70.8%	-	-34.9%
WRD	-41.2%	-44.5%	-18.9%	-	-57.9%	-0.2%	-	-74.5%	-	-48.3%
RD	-14.0%	-9.1%	-11.0%	-	-31.5%	-4.6%	-	-44.0%	-	-11.5%
FRD	-38.8%	-42.4%	-16.2%	-	-53.0%	-0.2%	-	-74.0%	-	-44.7%
MRD	2.2%	-3.1%	-3.5%	-	-8.5%	-0.2%	-	82.3%	-	-0.7%

([1]) Abbreviations, see table note at Table 42

Table 83. Relative changes of the various life stages when comparing Scenario 10a with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	**Total**	**Materials**	**Packaging**	**Production**	**Distribu-tion**	**Use**	**Main-tenance**	**End-of-Life**
GWP	-36.6%	5.4%	-21.4%	0.1%	3.2%	-47.4%	-23.2%	-11.4%
ODP	-76.3%	-89.1%	-0.8%	-3.2%	3.1%	-45.8%	-99.6%	0.5%
HTP nc	-20.7%	3.7%	-1.9%	-0.8%	2.9%	-41.6%	-0.9%	17.4%
HTP c	-17.9%	2.4%	-3.3%	-1.2%	3.1%	-42.5%	0.3%	2.6%
PMFP	-24.7%	5.6%	3.7%	1.1%	3.4%	-44.5%	-2.5%	-1.9%
IRP	-43.5%	5.4%	-2.6%	-4.1%	3.2%	-47.9%	-1.6%	0.8%
POFP	-28.2%	5.6%	-14.3%	0.5%	3.5%	-44.8%	-1.8%	-2.5%
AP	-32.9%	4.8%	-4.6%	0.2%	3.7%	-46.1%	-3.0%	-1.1%
TEP	-29.9%	5.1%	-50.8%	0.6%	3.5%	-44.5%	-2.1%	-2.5%
FEP	-15.7%	4.8%	-0.4%	-2.3%	3.2%	-45.7%	-0.1%	0.0%
MEP	-30.2%	5.4%	-9.6%	0.6%	3.5%	-40.1%	-1.6%	10.1%
FETP	-14.2%	4.4%	-18.2%	-1.4%	2.8%	-39.1%	0.0%	583.2%
LUC	-31.2%	4.3%	1.3%	-0.6%	3.0%	-43.3%	-1.4%	0.5%
WRD	-41.2%	6.2%	-23.3%	-2.2%	3.4%	-47.7%	-1.5%	-12.7%
RD	-14.0%	3.0%	-72.5%	-4.1%	2.8%	-37.2%	-6.6%	4.1%
FRD	-38.8%	6.5%	-9.2%	-0.7%	3.1%	-47.4%	-0.9%	-9.1%
MRD	2.2%	4.8%	-2.9%	-3.2%	2.8%	-38.3%	-0.2%	0.3%

([1]) Abbreviations, see table note at Table 42

Table 84. Relative changes of the various product groups when comparing Scenario 10b with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	Total	Dish-washer	Washing Machine	Tumble Dryer	Refrige-rator	Room Air Cond.	Electric Oven	Lighting	Laptops	LCD TV Screen
GWP	-40.4%	-42.6%	-17.9%	-6.7%	-53.9%	-22.7%	-3.3%	-71.9%	-1.0%	-49.7%
ODP	-76.2%	-38.4%	-12.8%	-4.3%	-77.7%	-96.7%	-0.6%	-74.2%	6.7%	-49.1%
HTP nc	-30.4%	-26.6%	-24.4%	-8.1%	-40.7%	-17.7%	-7.1%	-54.3%	-2.8%	-37.7%
HTP c	-20.6%	-24.6%	-11.4%	-5.4%	-22.2%	5.0%	-1.8%	-68.0%	-2.8%	-47.1%
PMFP	-31.2%	-33.6%	-14.6%	-7.3%	-46.2%	-3.9%	-4.1%	-60.3%	-2.7%	-40.4%
IRP	-45.3%	-48.3%	-21.0%	-6.2%	-59.0%	1.5%	-2.8%	-76.5%	0.5%	-58.5%
POFP	-33.2%	-36.6%	-14.3%	-7.0%	-47.5%	-0.1%	-3.7%	-65.3%	-1.2%	-44.0%
AP	-38.1%	-38.5%	-18.4%	-7.1%	-52.2%	-4.6%	-4.2%	-69.6%	-2.8%	-47.7%
TEP	-34.9%	-36.5%	-16.9%	-6.8%	-48.1%	-1.1%	-3.4%	-67.3%	-1.2%	-43.5%
FEP	-27.5%	-28.0%	-23.0%	-8.4%	-49.1%	-13.2%	-6.9%	-32.9%	-1.0%	-31.0%
MEP	-34.7%	-38.5%	-25.6%	-7.0%	-47.5%	-0.8%	-3.8%	-67.9%	-1.5%	-44.2%
FETP	-21.6%	-22.6%	-15.4%	-6.3%	-26.5%	-3.2%	-3.1%	-40.2%	-0.5%	-31.6%
LUC	-33.3%	-35.6%	-14.7%	-5.3%	-45.8%	8.2%	-1.5%	-70.9%	2.3%	-45.7%
WRD	-43.8%	-47.0%	-21.3%	-6.4%	-59.2%	0.1%	-3.0%	-74.5%	-0.5%	-55.1%
RD	-21.5%	-13.1%	-13.9%	-7.0%	-35.3%	-13.6%	-3.8%	-44.7%	-1.1%	-33.2%
FRD	-41.8%	-45.2%	-18.8%	-6.6%	-55.0%	1.0%	-2.9%	-74.0%	-0.2%	-53.1%
MRD	-13.3%	-8.3%	-7.4%	-6.8%	-14.8%	-8.6%	-4.6%	82.0%	-0.7%	-26.0%

([1]) Abbreviations, see table note at Table 42

Table 85. Relative changes of the various life stages when comparing Scenario 10b with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	Total	Materials	Packaging	Production	Distribu-tion	Use	Main-tenance	End-of-Life
GWP	-40.4%	-4.7%	-31.9%	-16.2%	-3.9%	-48.9%	10.5%	-185.0%
ODP	-76.2%	-90.0%	-4.0%	-12.4%	-3.8%	-47.4%	-99.3%	56.5%
HTP nc	-30.4%	-5.8%	0.9%	-15.8%	-3.3%	-43.4%	33.8%	-82.8%
HTP c	-20.6%	-2.5%	-7.2%	-14.7%	-3.8%	-44.2%	83.7%	32.8%
PMFP	-31.2%	-4.2%	7.0%	-17.3%	-4.4%	-46.2%	37.7%	-51.5%
IRP	-45.3%	-5.2%	-6.3%	-15.4%	-3.9%	-49.4%	53.2%	52.0%
POFP	-33.2%	-3.8%	-16.4%	-17.2%	-4.6%	-46.4%	44.8%	-55.6%
AP	-38.1%	-5.0%	-2.7%	-16.9%	-5.0%	-47.6%	33.4%	-56.2%
TEP	-34.9%	-5.6%	-59.8%	-17.6%	-4.7%	-46.2%	36.9%	-55.0%
FEP	-27.5%	-9.5%	2.6%	-15.3%	-4.1%	-47.3%	9.1%	-56.2%
MEP	-34.7%	-5.2%	-14.7%	-17.2%	-4.7%	-42.0%	36.5%	-637.1%
FETP	-21.6%	-6.4%	-24.8%	-13.5%	-3.1%	-41.1%	42.8%	-294.6%
LUC	-33.3%	-6.1%	-1.8%	-15.8%	-3.5%	-45.0%	57.3%	51.9%
WRD	-43.8%	-4.3%	-33.8%	-16.2%	-4.4%	-49.2%	44.4%	-116.3%
RD	-21.5%	-7.2%	-83.9%	-14.3%	-3.2%	-39.2%	35.7%	-70.3%
FRD	-41.8%	-3.5%	-16.7%	-15.4%	-3.9%	-48.9%	46.2%	-52.8%
MRD	-13.3%	-10.4%	-0.1%	-14.5%	-3.2%	-40.2%	11.8%	-65.0%

([1]) Abbreviations, see table note at Table 42

Table 86. Relative changes of the various product groups when comparing Scenario 10c with the baseline scenario (relative to the result in the baseline scenario)

Impact Category(1)	Total	Dish-washer	Washing Machine	Tumble Dryer	Refrige-rator	Room Air Cond.	Electric Oven	Lighting	Laptops	LCD TV Screen
GWP	-12.1%	0.4%	-11.9%	16.4%	-38.3%	213.7%	9.2%	-59.2%	-69.8%	-21.5%
ODP	-64.3%	7.7%	-6.5%	19.4%	-70.2%	-86.7%	12.3%	-62.5%	-67.4%	-20.5%
HTP nc	-1.0%	28.2%	-18.9%	14.6%	-20.6%	234.0%	4.9%	-33.5%	-70.3%	-2.7%
HTP c	6.4%	31.7%	-4.9%	18.0%	4.1%	326.3%	10.9%	-53.5%	-70.3%	-17.4%
PMFP	-2.0%	16.0%	-8.4%	15.7%	-28.0%	290.0%	8.3%	-42.3%	-70.3%	-7.0%
IRP	-17.5%	-9.7%	-15.2%	17.0%	-45.2%	311.9%	9.8%	-65.8%	-69.3%	-35.3%
POFP	-4.4%	10.7%	-8.0%	16.1%	-29.8%	305.6%	8.8%	-49.5%	-69.8%	-12.5%
AP	-8.8%	7.5%	-12.4%	15.9%	-36.1%	287.4%	8.2%	-55.8%	-70.3%	-18.3%
TEP	-5.4%	10.9%	-10.9%	16.3%	-30.6%	301.4%	9.1%	-52.5%	-69.8%	-11.8%
FEP	5.8%	25.9%	-17.4%	14.3%	-31.9%	252.4%	5.1%	-2.4%	-69.8%	7.8%
MEP	-9.8%	7.4%	-20.1%	16.0%	-29.8%	302.4%	8.7%	-53.3%	-69.9%	-12.8%
FETP	9.6%	35.2%	-9.2%	16.9%	-1.7%	292.8%	9.4%	-13.1%	-69.6%	6.9%
LUC	-2.7%	12.5%	-8.5%	18.1%	-27.5%	339.2%	11.3%	-57.7%	-68.8%	-15.2%
WRD	-16.4%	-7.4%	-15.6%	16.8%	-45.5%	306.1%	9.6%	-62.9%	-69.6%	-29.9%
RD	12.1%	51.9%	-7.6%	16.1%	-13.4%	250.7%	8.7%	-19.6%	-69.8%	4.4%
FRD	-13.4%	-4.2%	-12.8%	16.6%	-39.8%	309.9%	9.7%	-62.2%	-69.5%	-26.8%
MRD	26.0%	60.3%	-0.7%	16.3%	14.0%	271.1%	7.8%	164.7%	-69.7%	15.6%

(1) Abbreviations, see table note at Table 42

Table 87. Relative changes of the various life stages when comparing Scenario 9c with the baseline scenario (relative to the result in the baseline scenario)

Impact Category(1)	Total	Materials	Packaging	Production	Distribu-tion	Use	Main-tenance	End-of-Life
GWP	-12.1%	27.0%	64.6%	33.9%	35.7%	-22.1%	43.3%	-190.5%
ODP	-64.3%	-85.8%	5.3%	52.7%	35.4%	-20.6%	-99.0%	163.6%
HTP nc	-1.0%	39.6%	-3.2%	24.4%	33.4%	-21.1%	86.1%	-216.1%
HTP c	6.4%	25.0%	10.4%	32.6%	35.3%	-20.5%	131.5%	178.1%
PMFP	-2.0%	29.6%	-1.1%	23.6%	37.4%	-19.4%	78.6%	-113.2%
IRP	-17.5%	25.3%	8.0%	16.3%	35.7%	-22.3%	101.1%	162.9%
POFP	-4.4%	28.8%	38.9%	26.8%	38.1%	-19.6%	87.1%	-106.7%
AP	-8.8%	34.1%	4.4%	26.1%	39.4%	-20.6%	76.6%	-142.5%
TEP	-5.4%	30.3%	78.6%	23.4%	38.3%	-19.5%	82.7%	-105.4%
FEP	5.8%	33.6%	-3.4%	19.2%	36.3%	-22.0%	58.4%	-172.3%
MEP	-9.8%	30.4%	15.9%	23.6%	38.3%	-20.1%	82.0%	-699.5%
FETP	9.6%	31.3%	25.5%	40.1%	32.8%	-17.3%	93.8%	-742.3%
LUC	-2.7%	29.0%	5.8%	34.0%	34.3%	-18.9%	116.1%	170.0%
WRD	-16.4%	25.3%	71.6%	18.4%	37.3%	-22.3%	82.7%	211.1%
RD	12.1%	36.7%	20.6%	23.7%	33.2%	-16.7%	99.8%	-213.5%
FRD	-13.4%	28.4%	43.3%	36.0%	35.6%	-21.8%	91.0%	-5.3%
MRD	26.0%	31.2%	-3.5%	27.3%	33.3%	-16.8%	65.9%	-192.5%

(1) Abbreviations, see table note at Table 42

Most of the examined impact categories show the highest reduction potential in more efficient devices (covered by Scenario 10a), while all the changes on the end-of-life level (summarized in Scenario 10b) hardly further reduce the resulting impacts of the here examined household appliances.

Combining – in Scenario 10c – all these reduction potentials with the future increase of the amount of household appliances per household (and thus per person) analysed in Scenario 7, results for 4 impact categories (HTP cancer, FEP, FETP, MRD) in such a high increase, that the final result is even higher than the result of the baseline. The only category that remains on the very low level is ODP, as here the main impact is related to the change of the refrigerant in the room air conditioners (RAC). Actually, across all the other impact categories, RAC is responsible for the highest increase in the Scenario 9c (see Table 86); due to the expectation such devices will be spread in a much higher number by 2030 (for details, see Scenario 7).

8.12 Scenario 11: Overall potential of sector of household appliances

Description and aim: In order to get an overall picture about the "potential" that lays within the area of household appliances, this scenario is combining the outcomes from Scenario 1 (representing the potential in the area of the energy supply) and the above Scenario 10c (representing the overall potential that lays within household devices and the way they are getting used in our society).

Rationale for building the scenario: In accordance with Scenario 1, showing the potential in the area of the energy supply, all the datasets of the use phase from Scenario 10c (e.g. "RefrigeratorCOMBI_E_Use Phase_Scenario10c") have been copied and their link for the electricity mix has been replaced by the newly created, in Scenario 1 described, more sustainable future European electricity mix (i.e. by "market for electricity 2030, low voltage/EU-28"). These new datasets are named as '_Scenario11' in order to distinguish them from the other scenarios (e.g. "RefrigeratorCOMBI_E_UsePhase_Scenario11"). In a second step, these new datasets for the use phase have been combined with the datasets from Scenario 10c for all the other life stages (before/after use) in a new dataset for the whole life cycle (e.g. "RefrigeratorCOMBI_TOTAL LIFE CYCLE_Scenario11") in order to calculate the results for this scenario.

Results: In Figure 41 and Figure 42 the results of this scenario are compared with the results from the baseline scenario. In Figure 41 they are split into the contributions from the different product groups, in Figure 42 they are split into the shares of the different life cycle stages. Each of the two figures is going along with a table, showing the relative changes (in %) in the different product groups and the different life cycle stages, respectively (Table 88 and Table 89).

Figure 41. Scenario 11 in comparison with the baseline scenario (with total from the baseline set as 100%) – split into the contributions of the various product groups. (For the abbreviations see table note of Table 42)

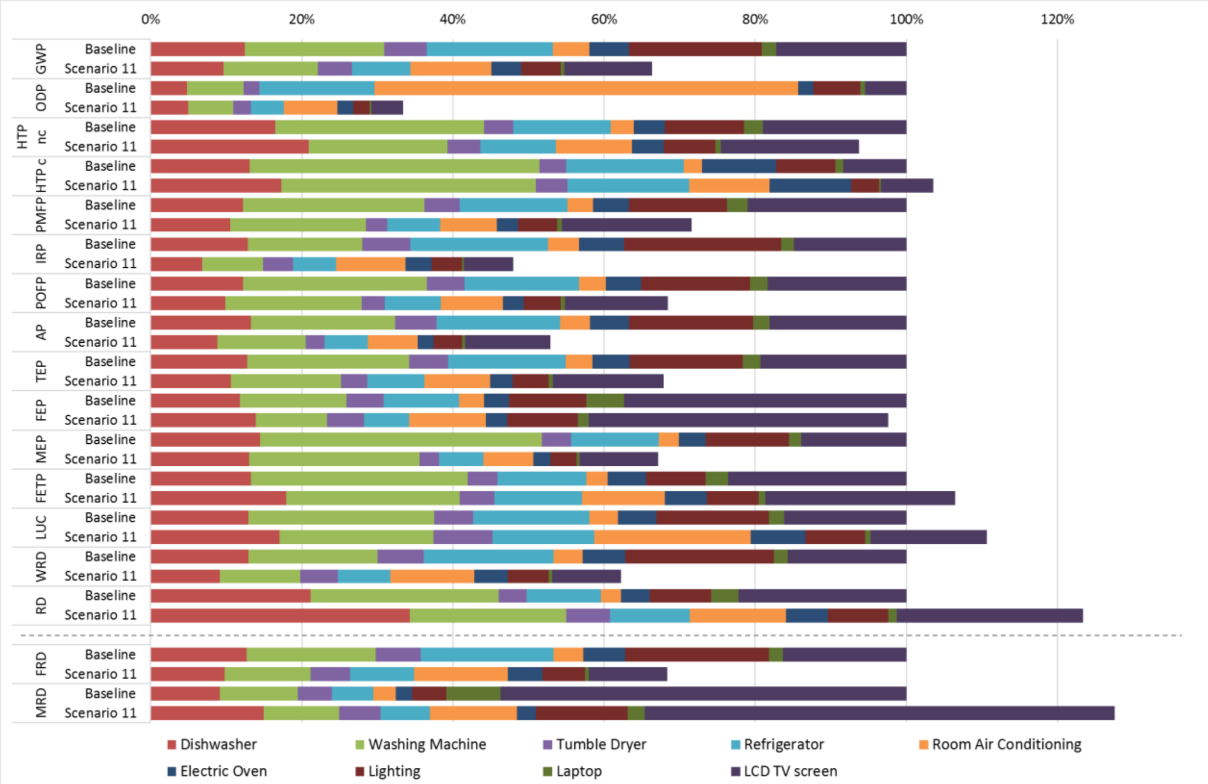


Figure 42. Scenario 11 in comparison with the baseline scenario (with the total impacts of the baseline set as 100%) – split into the contributions of the various life cycle stages. (For the abbreviations see table note of Table 42)

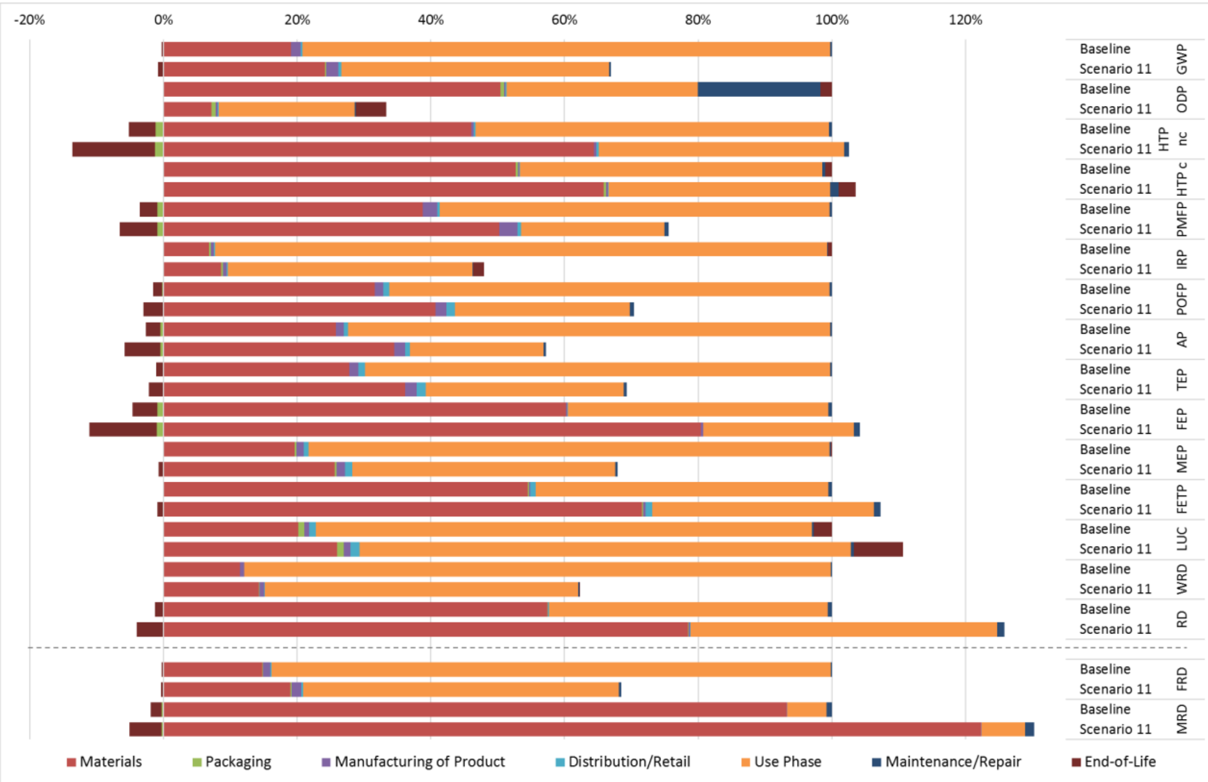


Table 88. Relative changes of the various product groups when comparing Scenario 11 with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	Total	Dish-washer	Washing Machine	Tumble Dryer	Refrige-rator	Room Air Cond.	Electric Oven	Lighting	Laptops	LCD TV Screen
GWP	-33.6%	-22.6%	-32.1%	-20.5%	-53.5%	119.8%	-25.7%	-69.9%	-75.8%	-32.4%
ODP	-66.6%	3.4%	-20.7%	12.3%	-71.4%	-87.3%	5.7%	-64.6%	-68.7%	-23.0%
HTP nc	-6.3%	26.9%	-33.4%	10.8%	-22.0%	223.5%	1.7%	-34.8%	-70.7%	-3.4%
HTP c	3.6%	31.7%	-12.1%	17.7%	4.0%	325.6%	10.8%	-53.6%	-70.4%	-17.5%
PMFP	-28.4%	-13.5%	-25.5%	-39.7%	-50.5%	120.6%	-39.9%	-60.4%	-75.7%	-18.2%
IRP	-52.0%	-47.0%	-46.9%	-37.8%	-68.5%	124.8%	-41.9%	-80.8%	-81.2%	-56.4%
POFP	-31.5%	-19.5%	-25.8%	-37.3%	-51.3%	136.8%	-41.7%	-66.2%	-76.4%	-25.6%
AP	-47.1%	-33.1%	-39.0%	-55.2%	-65.1%	68.5%	-58.2%	-77.3%	-80.6%	-37.8%
TEP	-32.1%	-17.2%	-31.7%	-33.8%	-51.1%	141.5%	-38.2%	-68.2%	-76.4%	-24.0%
FEP	-2.4%	17.6%	-33.0%	-0.1%	-40.5%	205.8%	-13.9%	-8.6%	-70.6%	6.1%
MEP	-32.8%	-10.2%	-39.5%	-32.3%	-49.1%	148.6%	-36.7%	-68.4%	-76.4%	-24.8%
FETP	6.5%	35.1%	-19.9%	16.7%	-1.7%	292.4%	9.4%	-13.1%	-69.6%	6.9%
LUC	10.6%	31.8%	-17.1%	53.3%	-13.2%	443.3%	42.9%	-46.7%	-63.5%	-5.1%
WRD	-37.7%	-29.2%	-37.9%	-17.0%	-60.0%	189.2%	-22.5%	-72.3%	-76.2%	-41.7%
RD	23.4%	62.3%	-17.1%	59.6%	6.2%	383.2%	45.9%	-1.9%	-67.3%	10.9%
FRD	-31.7%	-23.0%	-33.3%	-12.2%	-51.7%	214.2%	-17.7%	-70.4%	-74.7%	-36.3%
MRD	27.6%	63.7%	-3.5%	21.4%	19.0%	287.9%	17.2%	169.3%	-69.5%	16.0%

([1]) Abbreviations, see table note at Table 42

Table 89. Relative changes of the various life stages when comparing Scenario 11 with the baseline scenario (relative to the result in the baseline scenario)

Impact Category(1)	**Total**	**Materials**	**Packaging**	**Production**	**Distribu-tion**	**Use**	**Main-tenance**	**End-of-Life**
GWP	-33.6%	27.0%	64.6%	33.9%	35.7%	-49.3%	43.3%	-190.5%
ODP	-66.6%	-85.8%	5.3%	52.7%	35.4%	-28.7%	-99.0%	163.6%
HTP nc	-6.3%	39.6%	-3.2%	24.4%	33.4%	-30.6%	86.1%	-216.1%
HTP c	3.6%	25.0%	10.4%	32.6%	35.3%	-26.7%	131.5%	178.1%
PMFP	-28.4%	29.6%	-1.1%	23.6%	37.4%	-63.1%	78.6%	-113.2%
IRP	-52.0%	25.3%	8.0%	16.3%	35.7%	-60.1%	101.1%	162.9%
POFP	-31.5%	28.8%	38.9%	26.8%	38.1%	-60.3%	87.1%	-106.7%
AP	-47.1%	34.1%	4.4%	26.1%	39.4%	-72.4%	76.6%	-142.5%
TEP	-32.1%	30.3%	78.6%	23.4%	38.3%	-57.5%	82.7%	-105.4%
FEP	-2.4%	33.6%	-3.4%	19.2%	36.3%	-42.1%	58.4%	-172.3%
MEP	-32.8%	30.4%	15.9%	23.6%	38.3%	-49.5%	82.0%	-699.5%
FETP	6.5%	31.3%	25.5%	40.1%	32.8%	-24.4%	93.8%	-742.3%
LUC	10.6%	29.0%	5.8%	34.0%	34.3%	-0.9%	116.1%	170.0%
WRD	-37.7%	25.3%	71.6%	18.4%	37.3%	-46.6%	82.7%	211.1%
RD	23.4%	36.7%	20.6%	23.7%	33.2%	10.0%	99.8%	-213.5%
FRD	-31.7%	28.4%	43.3%	36.0%	35.6%	-43.5%	91.0%	-5.3%
MRD	27.6%	31.2%	-3.5%	27.3%	33.3%	10.7%	65.9%	-192.5%

(1) Abbreviations, see table note at Table 42

Here, the effects from Scenario 10c and 1 are combined – resulting in comparison to the baseline thus (again) in a picture that shows for most of the categories a reduction of the overall impacts; more important for categories like e.g. GWP (with one third less) and IRP (less than half compared to the baseline), while in categories like HTP, FEP, FETP or LUC changes below 10% can be observed (reduction/increase). It is still the impact category ODP that shows the highest reduction, relative to the baseline, with a reduction of about two third of this impact. On the level of fossil resources (FRD), the higher amount of RAC devices still results in such a high increase (a factor of 4 for the FRD impacts) of the overall energy consumption that despite the use of a more renewable electricity mix, is increasing by more than 20%.

8.13 Scenario 12: Domotics – a first estimate of its potential

Description and aim: "Domotics" stands for systems that automate buildings and improve energy performance while increasing comfort and security (Fundación San Valero, 2014b). User-related applications, like lighting or heating and climatisation, are the primary focus of domotics – but also further devices and appliances could be concerned when a smarter building automatization is planned and/or installed. According to Fundación San Valero (2014b), the investigations during the four-year-LIFE-project DOMOTIC[12] at three different (public) buildings in Spain has shown an annual improvement of the energy efficiency in the order of 64% and, combined with a higher use of renewable energy sources, to a reduction of the CO_2 emissions by 680 tons per year. A recent study from Singapore comes to a less optimistic and positive result. Bhati and colleagues examined the influence of "smart homes in a smart city" (i.e. Singapore) on the energy (electricity) consumption (Bhati et al., 2017) and they conclude that the behaviour patterns of the user could lead to the opposite of energy savings, as current "smart" technology is not in all aspects really 'smart' and may not always lead the user to a more sustainable behaviour.

In the framework of the BoP appliances, Scenario 12 is thought to be a kind of an outlook towards possible consequences of more fundamental changes in the way how different types of these household appliances may be used in the future.

Area of intervention: Lighting and room air conditioner are at the core of Scenario 11, as these two devices have the use phase closely modulated with the actual occupancy of a room, i.e. usually if there is nobody in a room, you do not need to illuminate the room. All the other devices do not depend only on the presence of a person in a room / in a building, but also on its actual behaviour (e.g. a person that prefers to eat salads will use much less the electric oven than a person that is keen on soups, etc.). For the Scenario 11, it is assumed that all these further appliances are in a first step only in the following sense part of such a smart home solution: modern, energy-efficient devices will be installed/used.

Policy relevance: Ecodesign Directive (EC, 2009a), Energy Efficiency Directive (EU, 2012b), Roadmap to a Resource Efficient Europe (EC, 2011b).

Rationale for building the scenario: Starting points for this scenario are the various scenarios from the LIFE-project DOMOTIC that are described in details (i.e. including their saving potential within the context of the public buildings examined in this project) in the "best practices" report of the project (i.e. in Fundación San Valero, 2014a), the study from Fraunhofer in the US about the technical (saving) potential behind home automation systems (Urban et al., 2016) and the ECO scenarios in the 2015 preparatory study for lighting (VITO, 2015b). Hence, in order to evaluate the potential that may be in such an "intelligent" house automatization, the following key assumptions are used as starting point for Scenario 11:

- lighting: starting point is the baseline 2015 (Scenario 13, described below);

[12] LIFE project "DOMOTIC" (2010-2014) – Coordination by Fundación San Valero (ES) – funded by the European Commission to 50% under the project reference LIFE+ 09 ENV/ES/000493

- all lighting is based on LED technology, no use of CFLi anymore by 2030;
- the active "burning" time of the lighting is assumed to be reduced by 30% due to the automatic system installed (assumption by author – equal to the highest reduction in the scenarios of the 2015 preparatory study, i.e. scenario "ECO120+LBL" reported in VITO 2015b for the year 2030 – and confirmed by the developed "lighting" scenario in the study from Fraunhofer USA, i.e. in Urban et al., 2016);
- the installed capacity (in kW) is reduced by 40% (based on the same scenario from VITO, 2015b that reports an overall reduction of the installed capacity – in residential sector as well as the non-residential of 67% assuming that the reduction in the latter one will be more important) – assuming both technologies in the 2015 scenario (CFLi, LED) having the same W/lighting source, this equals to a reduction of 10% of the 2015 LED amount;
- the saving potential by various automatisation systems for climatisation lays in the order of 10-15% (Urban et al., 2016) – here the upper value of 15% is assumed (in relation to the annual consumption of the baseline scenario);
- the RAC are assumed to have the lower leakage rate (reported in Scenario 5) and being filled with the alternative refrigerant (reported in Scenario 6);
- no changes in the number of RAC installations per household or person are taken into account here – the calculation is made with the number of devices according to the baseline scenario;
- no other devices are changed – i.e. the remaining product groups are integrated as in the baseline scenario modelled.

<u>Parameters modified in the model</u>: Table 90 summarizes the modifications that have been made in baseline model, for each product affected by this scenario.

Table 90. Summary of the new datasets necessary for the modelling of Scenario 12 "domotics – a first estimation of its potential"

Life Cycle Stage	Made modifications to		
	LED	**Room Air Conditioner (RAC)**	**BoP Household Appliances** [13]
Manufacturing of components	No modification	Replacing the amount of "Refrigerant R134a" by the same amount of "Alternative Refrigerant R600a" (isobutane)	All the other lighting technologies than LED are set to 0. For LED the number is reduced by 10% (equal to 60% of the total number from the scenario for 2015). For the LED Lamp as well as the Room Air Conditioner (RAC) the modification (see left columns) have been included into these calculations of all BoP Household Appliances here.
Manufacturing of the product	No modification	No modification	
Packaging	No modification	No modification	
Distribution and retail	No modification	No modification	
Use phase	Correction of amount of electricity consumed to 62.9kWh (i.e. 30% less than in the preceding scenarios including LED lamps) over the entire lifetime.	Replacing the amount of "Ethane, 1,1,1,2-tetrafluoro-, HFC-134a emitted to air" by the same amount of "isobutane emitted to air" and correction of the amount from 0.60 kg to 0.18 kg	
Maintenance and repair	No modification	Replacement of the amount of "Refrigerant R134a" by the same amount of "Alternative Refrigerant R600a" for filling and correction of amount from 0.49*1.2 kg to 0.14*1.2 kg (representing decrease of losses from 50% to 15%); For the input of the replaced parts, the modified dataset for the manufacturing of components (see row above) is used.	
EoL of the product	No modification	Replacement of the amount of "treatment of used R134a" by the same amount of "treatment of spent solvent mixture, hazardous waste incineration" (used here as a proxy for the treatment of R600a)	

Results: In Figure 43 and Figure 44 the results of Scenario 12 are compared with the respective results from the baseline scenario. In Figure 43 they are split into the contributions from the different product groups, in Figure 44 they are split into the shares of the different life cycle stages distinguished here. Each of the two figures is going along with a table, showing the relative changes (in %) in the different product groups and the different life cycle stages, respectively (Table 91 and Table 92).

[13] (i.e. to datasets covering total of all examined devices)

Figure 43. Scenario 12 in comparison with the baseline scenario (with total from the baseline set as 100%) – split into the contributions of the various product groups. (For the abbreviations see table note of Table 42)

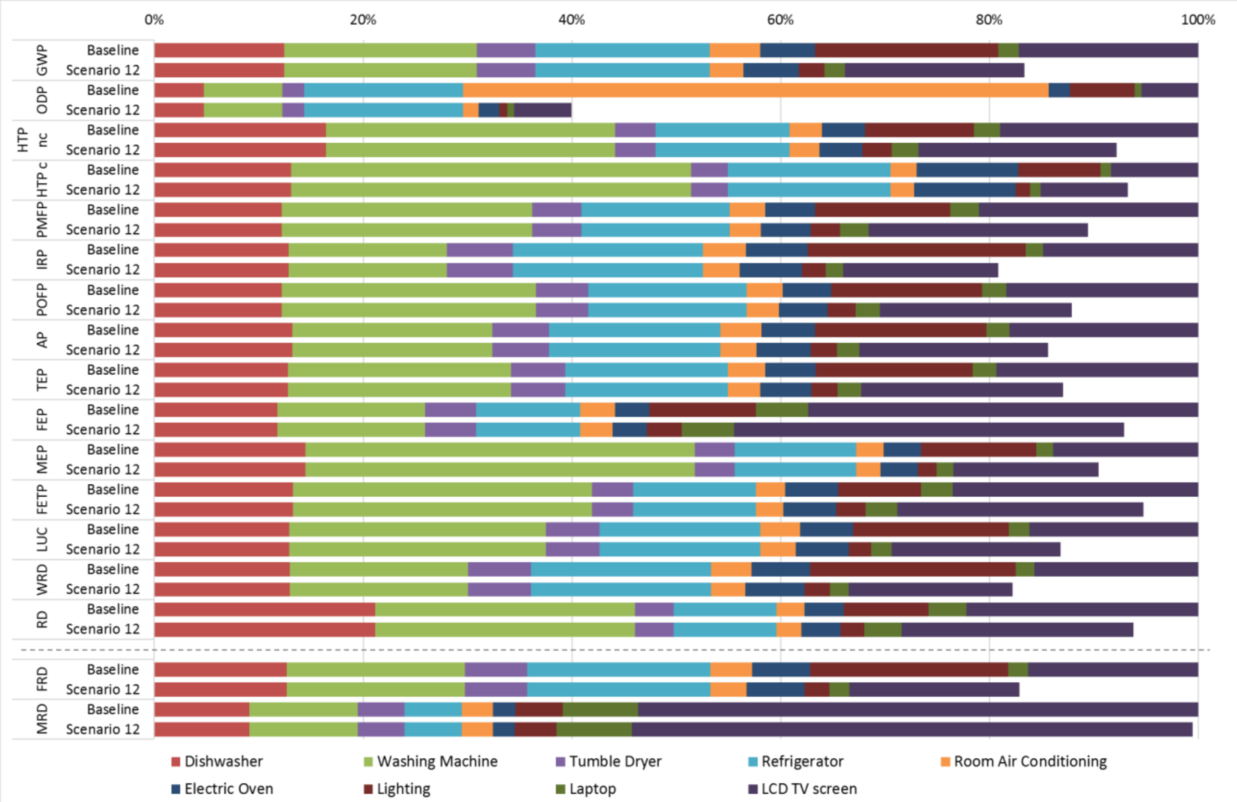


Figure 44. Scenario 12 in comparison with the baseline scenario (with the total impacts of the baseline set as 100%) – split into the contributions of the various life cycle stages. (For the abbreviations see table note of Table 42)

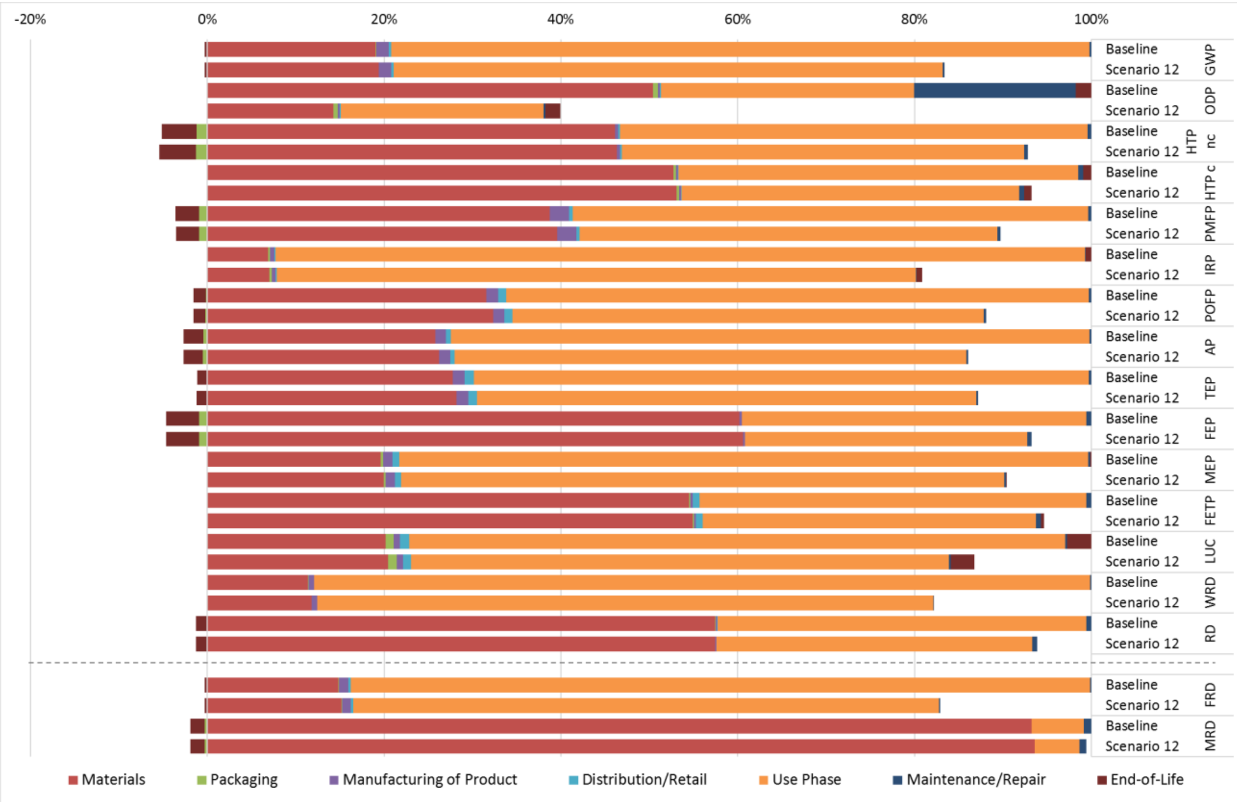


Table 91. Relative changes of the various product groups when comparing Scenario 12 with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	Total	Dish-washer	Washing Machine	Tumble Dryer	Refrige-rator	Room Air Cond.	Electric Oven	Lighting	Laptops	LCD TV Screen
GWP	-16.7%	-	-	-	-	-32.9%	-	-85.9%	-	-
ODP	-60.1%	-	-	-	-	-97.3%	-	-87.6%	-	-
HTP nc	-7.8%	-	-	-	-	-8.1%	-	-72.9%	-	-
HTP c	-6.7%	-	-	-	-	-9.1%	-	-82.6%	-	-
PMFP	-10.6%	-	-	-	-	-11.3%	-	-78.4%	-	-
IRP	-19.1%	-	-	-	-	-14.2%	-	-88.9%	-	-
POFP	-12.1%	-	-	-	-	-10.6%	-	-81.5%	-	-
AP	-14.4%	-	-	-	-	-12.0%	-	-84.6%	-	-
TEP	-13.0%	-	-	-	-	-11.8%	-	-83.5%	-	-
FEP	-7.1%	-	-	-	-	-6.8%	-	-67.0%	-	-
MEP	-9.5%	-	-	-	-	-11.8%	-	-83.8%	-	-
FETP	-5.3%	-	-	-	-	-7.1%	-	-64.3%	-	-
LUC	-13.2%	-	-	-	-	-10.8%	-	-85.6%	-	-
WRD	-17.8%	-	-	-	-	-14.3%	-	-87.6%	-	-
RD	-6.2%	-	-	-	-	-11.5%	-	-72.4%	-	-
FRD	-17.1%	-	-	-	-	-13.4%	-	-87.3%	-	-
MRD	-0.6%	-	-	-	-	-1.1%	-	-11.5%	-	-

([1]) Abbreviations, see table note at Table 42

Table 92. Relative changes of the various life stages when comparing Scenario 12 with the baseline scenario (relative to the result in the baseline scenario)

Impact Category(1)	Total	Materials	Packaging	Production	Distribu-tion	Use	Main-tenance	End-of-Life
GWP	-16.7%	1.8%	-51.8%	-1.9%	-2.5%	-21.3%	-24.1%	-0.01%
ODP	-60.1%	-71.8%	-1.5%	-3.8%	-2.4%	-19.8%	-99.1%	-0.01%
HTP nc	-7.8%	0.5%	-3.1%	-2.5%	-2.2%	-13.9%	-1.5%	-5.62%
HTP c	-6.7%	0.7%	-6.8%	-2.6%	-2.4%	-15.6%	-0.8%	-1.93%
PMFP	-10.6%	2.1%	4.5%	-1.4%	-2.6%	-18.9%	-3.8%	-0.04%
IRP	-19.1%	2.6%	-5.2%	-4.8%	-2.4%	-21.0%	-1.9%	-0.01%
POFP	-12.1%	2.3%	-35.3%	-1.8%	-2.7%	-19.1%	-2.8%	-0.03%
AP	-14.4%	1.8%	-9.6%	-1.9%	-2.9%	-19.9%	-3.8%	-0.01%
TEP	-13.0%	1.6%	-102.1%	-1.8%	-2.7%	-18.9%	-3.0%	-0.02%
FEP	-7.1%	0.6%	-0.8%	-3.5%	-2.5%	-18.2%	-0.3%	0.01%
MEP	-9.5%	1.6%	-18.1%	-1.8%	-2.7%	-12.5%	-3.0%	-0.13%
FETP	-5.3%	0.8%	-34.0%	-2.6%	-2.1%	-13.8%	-0.9%	431.8%
LUC	-13.2%	1.4%	1.3%	-2.4%	-2.3%	-18.1%	-1.7%	0.01%
WRD	-17.8%	3.2%	-57.5%	-3.7%	-2.6%	-20.6%	-2.0%	0.47%
RD	-6.2%	0.0%	-111.4%	-4.7%	-2.2%	-14.5%	-7.0%	3.08%
FRD	-17.1%	2.3%	-26.7%	-2.4%	-2.4%	-20.7%	-2.8%	-0.09%
MRD	-0.6%	0.4%	-4.4%	-4.1%	-2.2%	-15.1%	-0.3%	0.20%

(1) Abbreviations, see table note at Table 42

This simplified scenario – giving a first hint towards the potential that lays in a more automated control of household appliances in dwellings – shows already a saving potential in the order to 10 to 20% across almost all impact categories. Due to assumption for the RAC, the impact on ODP shows even a potential of 60% reduction (based however on issues that are already described in earlier scenarios and that are not directly linked to this scenario). Compared to the baseline scenario, such a 100% LED-based lighting scenario could reduce the impacts on the environment by 70 to 85%.

A more detailed investigation of the issue of domotics would make sense in a future study – taking into account also that for such a controlling necessary infrastructure (sensors, control unit, etc.) and related energy consumption; as well as further issues (e.g. heating) that could be integrated into such a system.

8.14 Scenario 13 – Baseline 2015

The aim of Scenario 13 is to update the baseline to the closest year for which data are available, to have an updated overview of the impacts coming from the consumption of appliances in EU households.

The stock of each representative product in the BoP has been updated to the selected year (2015). Consistently, the number of EU citizens has been updated. Technologies are supposed to be the same of the baseline 2010. In case of lighting, the average annual consumption by the single lamp types have been modified, as explained below.

Table 93 summarizes the inputs to Scenario 13. The amount of appliances "consumed" per person is also reported, considering that the number of citizens grew from 502,489,100 to 508,401,408, according to Eurostat.

Table 93. Quantities of products in the BoP appliances – Scenario Baseline 2015

Representative Product	**Total stock of the product group – 2010 (unit)**	**Total stock of the product group – 2015 (unit)**	**Amount per citizen –2015 (unit/p*y^{-1})**	**Per citizen variation (%)**
Dishwasher 10 ps	12,419,850	14,825,400	0.0292	18%
Dishwasher 13 ps	70,379,150	84,010,600	0.1652	18%
Washing Machine	185,828,000	197,805,000	0.3891	5%
Tumble dryer	63,037,000	68,358,000	0.0795	6%
Combined refrigerators-freezers	299,289,000	304,716,000	0.3356	1%
Air conditioner, single split	28,077,000	46,453,000	0.0914	64%
Electric oven (built-in)	216,000,000	221,403,298	0.2044	5%
Compact fluorescent lamp	148,593,6824	1,707,779,806	3.3591	14%
Halogen lamp, low voltage	902,902,229	853,889,903	1.6796	-7%
Halogen lamp, mains voltage	1,058,346,935	853,889,903	1.6796	-20%
Incandescent lamp	716,225,361	1,506,864,535	2.9639	108%
LED	0	100,457,636	0.1976	100%
Notebook	178,630,000	230,520,000	0.1814	28%
LCD TV screen	332,254,364	408,241,161	0.4256	21%

Stock data for 2015 have been taken from Ecodesign Impact Accounting (VHK, 2016a, 2016b) for all products in the BoP, with the exception of:

- electric oven (built in) and notebook, for which data sources are the preparatory studies for Ecodesign (BIO Intelligence Service, 2011 and VITO, 2017, respectively)
- LCD TV screen for which the tendency of the increase from 1 to 2 TV per household (Bertoldi and Atanasiu, 2009) has been assumed;
- lighting, for which the total stock of lamps is the same of 2010 (considering the same number of dwellings used in the BoP Housing). The number of dwellings at 2015 in from BoP housing should be used, however the baseline 2015 for the BoP housing was not available when this study was carried out. The assumptions done for the share of stock associated to each lamp type are consistent with information reported in VHK (2016) and are reported in the Table 94.

Table 94. Share of stock for each lamp type, on the total stock in 2015

Lamp type	% of stock
Compact fluorescent lamp	34
Halogen lamp, low voltage	17
Halogen lamp, mains voltage	17
Incandescent lamp	30
LED	2

For the definition of electricity consumption for lighting, as done for the baseline, a top-down approach has been applied. The electricity consumption for lighting, by each dwelling, at 2015 is based on data reported in VHK, 2016 and is 338 kWh/year. In order to revise the electricity consumption of each lamp type and make it consistent with the overall consumption per dwelling and by total stock at 2015, the following steps were done.

Firstly, an annual consumption by each lamp type has been calculated considering the average annual operating hours (VITO, 2015a), the average power lamp (VITO, 2015a), and number of lamps installed in each dwelling at 2015 (VHK, 2016). Secondly, the share of consumption by each lamp type on the total consumption so calculated has been considered to distribute among the lamp types the overall electricity consumption for lighting by a dwelling (VHK, 2016). Thirdly, the total electricity consumption by the dwelling stock has been calculated for each lamp type, by multiplying the consumption in each dwelling for the total number of dwellings. The average electricity consumption to be used in the BoP for each single lamp type has been calculated by dividing the overall electricity consumption for each lamp type by the dwelling stock, by the stock of each lamp type (based on Table 94) and is reported in Table 95.

Table 95. Average energy consumption by single lamp type at 2015

Lamp type	**Average energy consumption in the BoP (kWh/year)**
Compact fluorescent lamp	5.19
Halogen lamp, low voltage	14.52
Halogen lamp, mains voltage	15.56
Incandescent lamp	22.41
LED	6.74

It has been assumed that washing machine and dishwashers cover the 100% of the stock as well as air conditioner. For the tumble dryer the coverage is taken from the preparatory study (Ecobilan - PricewaterhouseCoopers, 2009) and relates to 2014 as it is the closest year to 2015. For the refrigerator the coverage is taken from VHK (2016a). For the electric oven coverage data by the representative product have been retrieved in the Ecodesign preparatory study (BIO Intelligence Service, 2011). For the notebook the same coverage % applied in baseline 2010 is considered as well as for the LCD TV screen.

Results: In Figure 45 and Figure 46 the results of Scenario 13 are compared with the respective results from the baseline scenario. In the first figure they are split into the contributions from the different product groups, in the second figure they are split into the shares of the different life cycle stages. Each of the two figures is going along with a table (Table 96 and Table 97), showing the relative changes (in %) in the different product groups and the different life cycle stages.

Figure 45. Scenario 13 in comparison with the baseline scenario (with total from the baseline set as 100%) – split into the contributions of the various product groups. (For the abbreviations see table note of Table 42)

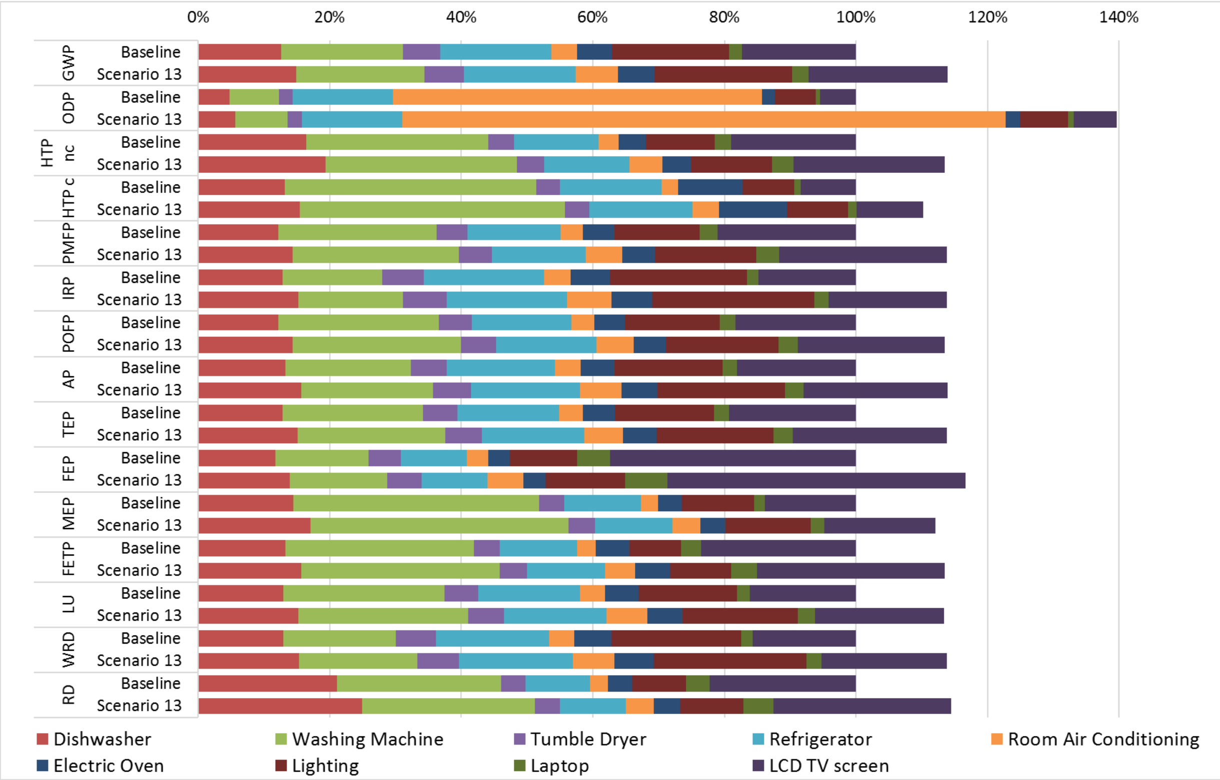
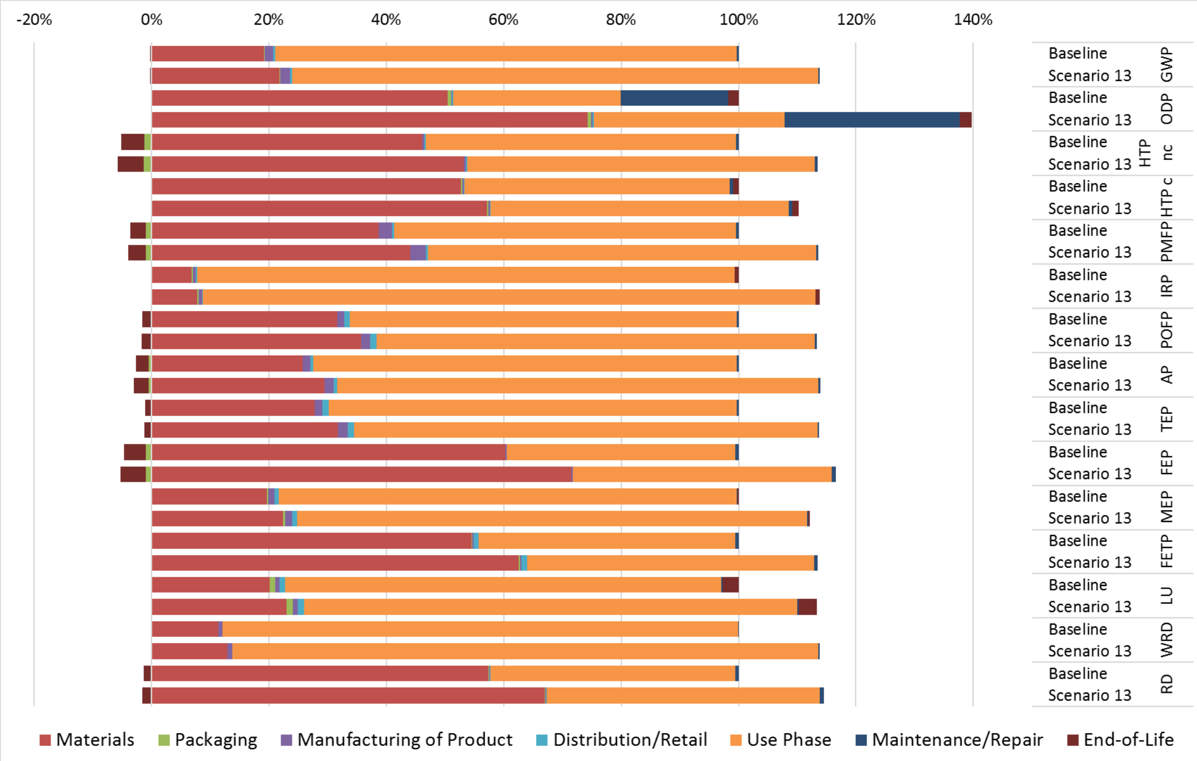


Figure 46. Scenario 13 in comparison with the baseline scenario (with the total impacts of the baseline set as 100%) – split into the contributions of the various life stages. (For the abbreviations see table note of Table 42)



As expected, the increase in the number of products per household leads to higher overall impact per person. Ozone depletion impact has the largest increase (+40%), due to the larger number of air conditioner units installed in EU houses in 2015 compared to 2010. For the rest of the impact categories considered, the impact is between 10% and 17% larger than in 2010. In general, the increase of impact for product groups is proportional to the increase of the number of appliance units for that group (Table 96).

Regarding the change of impact from each life cycle stage, the largest increase is on the contribution of the maintenance and repair stage to human toxicity non-cancer (+63%). This is mainly due to the printed wiring board in the LCD TV. The increased need of producing the materials used in the appliances has a relevant effect on ozone depletion (+47.4% in the baseline 2015 scenario compared to baseline 2010), due to the increased use of refrigerants in air conditioners.

Finally, the impact from packaging production and treatment at the end of life is 54% larger in 2015 than in 2010 with regards to resource depletion and 46% for terrestrial eutrophication. This increase is of course related to the larger number of items sold in 2015 compared to 2010. However, it has a small effect to the overall impact of the BoP, due to the limited contribution of packaging compared to the other life cycle stages.

Table 96. Relative changes of the various product groups when comparing Scenario 13 with the baseline scenario (relative to the result in the baseline scenario)

Impact Category(1)	**Total**	**Dish-washer**	**Washing Machine**	**Tumble Dryer**	**Refrige-rator**	**Room Air Cond.**	**Electric Oven**	**Lighting**	**Laptops**	**LCD TV Screen**
GWP	13.9%	18.0%	5.2%	5.4%	0.6%	63.5%	5.1%	18.1%	27.5%	21.4%
ODP	39.7%	18.0%	5.2%	5.4%	0.6%	63.5%	5.1%	18.0%	27.5%	21.4%
HTP nc	13.5%	18.0%	5.2%	5.4%	0.6%	63.5%	5.1%	17.9%	27.5%	21.4%
HTP c	10.2%	18.0%	5.2%	5.4%	0.6%	63.5%	5.1%	18.1%	27.5%	21.4%
PMFP	13.8%	18.0%	5.2%	5.4%	0.6%	63.5%	5.1%	18.2%	27.5%	21.4%
IRP	13.9%	18.0%	5.2%	5.4%	0.6%	63.5%	5.1%	18.0%	27.5%	21.4%
POFP	13.5%	18.0%	5.2%	5.4%	0.6%	63.5%	5.1%	18.2%	27.5%	21.4%
AP	14.0%	18.0%	5.2%	5.4%	0.6%	63.5%	5.1%	18.1%	27.5%	21.4%
TEP	13.8%	18.0%	5.2%	5.4%	0.6%	63.5%	5.1%	18.2%	27.5%	21.4%
FEP	16.7%	18.0%	5.2%	5.4%	0.6%	63.5%	5.1%	17.9%	27.5%	21.4%
MEP	12.1%	18.0%	5.2%	5.4%	0.6%	63.5%	5.1%	18.2%	27.5%	21.4%
FETP	13.5%	18.0%	5.2%	5.4%	0.6%	63.5%	5.1%	18.4%	27.5%	21.4%
LU	13.4%	18.0%	5.2%	5.4%	0.6%	63.5%	5.1%	18.0%	27.5%	21.4%
WRD	13.8%	18.0%	5.2%	5.4%	0.6%	63.5%	5.1%	18.0%	27.5%	21.4%
RD	14.5%	18.0%	5.2%	5.4%	0.6%	63.5%	5.1%	18.4%	27.5%	21.4%
FRD	13.9%	18.0%	5.2%	5.4%	0.6%	63.5%	5.1%	18.4%	27.5%	21.4%
MRD	18.6%	18.0%	5.2%	5.4%	0.6%	63.5%	5.1%	18.4%	27.5%	21.4%

(1) Abbreviations, see table note at Table 42

Table 97. Relative changes of the various life stages when comparing scenario 13 with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	**Total**	**Materials**	**Packaging**	**Production**	**Distribu-tion**	**Use**	**Main-tenance**	**End-of-Life**
GWP	13.9%	13.6%	32.8%	19.5%	11.1%	13.8%	25.8%	1.5%
ODP	39.7%	47.4%	6.0%	19.1%	11.0%	13.6%	63.0%	15.6%
HTP nc	13.5%	15.4%	-3.8%	16.4%	10.1%	11.8%	16.3%	-15.3%
HTP c	10.2%	8.3%	8.6%	17.1%	10.9%	12.3%	9.2%	18.2%
PMFP	13.8%	13.8%	-6.9%	18.4%	11.9%	13.4%	15.8%	-10.5%
IRP	13.9%	13.7%	7.7%	13.5%	11.1%	13.9%	14.6%	15.3%
POFP	13.5%	13.1%	13.8%	18.8%	12.2%	13.4%	14.6%	-8.4%
AP	14.0%	14.4%	-0.4%	18.4%	12.8%	13.6%	16.6%	-13.3%
TEP	13.8%	14.5%	45.9%	18.5%	12.3%	13.4%	16.0%	-8.6%
FEP	16.7%	18.8%	-4.8%	14.4%	11.4%	13.1%	18.9%	-15.7%
MEP	12.1%	14.3%	14.1%	18.0%	12.3%	11.4%	15.6%	25.0%
FETP	13.5%	14.8%	21.5%	17.7%	9.8%	11.9%	15.4%	-4.7%
LU	13.4%	14.3%	4.8%	18.9%	10.5%	13.1%	15.5%	16.4%
WRD	13.8%	13.5%	34.9%	15.2%	11.9%	13.8%	14.3%	15.7%
RD	14.5%	16.6%	54.8%	14.2%	10.0%	11.6%	19.4%	-17.6%
FRD	13.9%	13.2%	20.2%	19.0%	11.1%	13.8%	15.2%	-2.7%
MRD	18.6%	19.1%	3.3%	15.5%	10.0%	11.9%	18.9%	17.2%

([1]) Abbreviations, see table note at Table 42

8.15 Scenario 14 - Relevance of electricity mix for group of Member States

Scenario 14 is intended as a sensitivity analysis on the electricity mix used in the use phase of products. In particular, the aim is to understand main changes in the overall impacts from the BoP Appliances by using electricity mixes representative of the three climatic zone of BoP housing (warm zone, moderate zone, and cold zone).

Scenario 14 addresses the impact from electricity consumption in use by room air conditioner as well as its relevance in the overall environmental profile of the BoP. The scenario focus on the room air conditioner as the electricity consumption from this appliance is strongly climate-related. Based on data from Odyssee (IEE Project ODYSSEE database) for the reference year 2010, the overall consumption by cooling is 80% in the warm area and 20% in the moderate area. The electricity consumption from cooling in cold area accounts for less than 0.5%.

To model the scenario, the electricity mixes by zone, as built and described in BoP Housing (Baldassarri et al., 2017 - Annex 2, Table 78), have been considered. The contribution of each country to the electricity mix of the zone is based on the number of dwellers. Thus, the electricity consumption by the room air conditioner has been represented as indicated in Table 98Table 147.

Table 98. Electricity mixes used in Scenario 14 "relevance of electricity mix for group of Member States.

Electricity mixes to represent the consumption by room air conditioner	**Contribution**
Electricity mix - warm area	80%
Electricity mix - moderate	20%
Electricity mix - cold area	0%

<u>Results:</u> In Figure 47 and Figure 48 the results of Scenario 14 are compared with the respective results from the baseline scenario. In the first figure they are split into the contributions from the different product groups, in the second figure they are split into the shares of the different life cycle stages. Each of the two figures is going along with a table (Table 99 and Table 100), showing the relative changes (in %) in the different product groups and the different life cycle stages.

Figure 47. Scenario 14 in comparison with the baseline scenario (with total from the baseline set as 100%) – split into the contributions of the various product groups. (For the abbreviations see table note of Table 42)

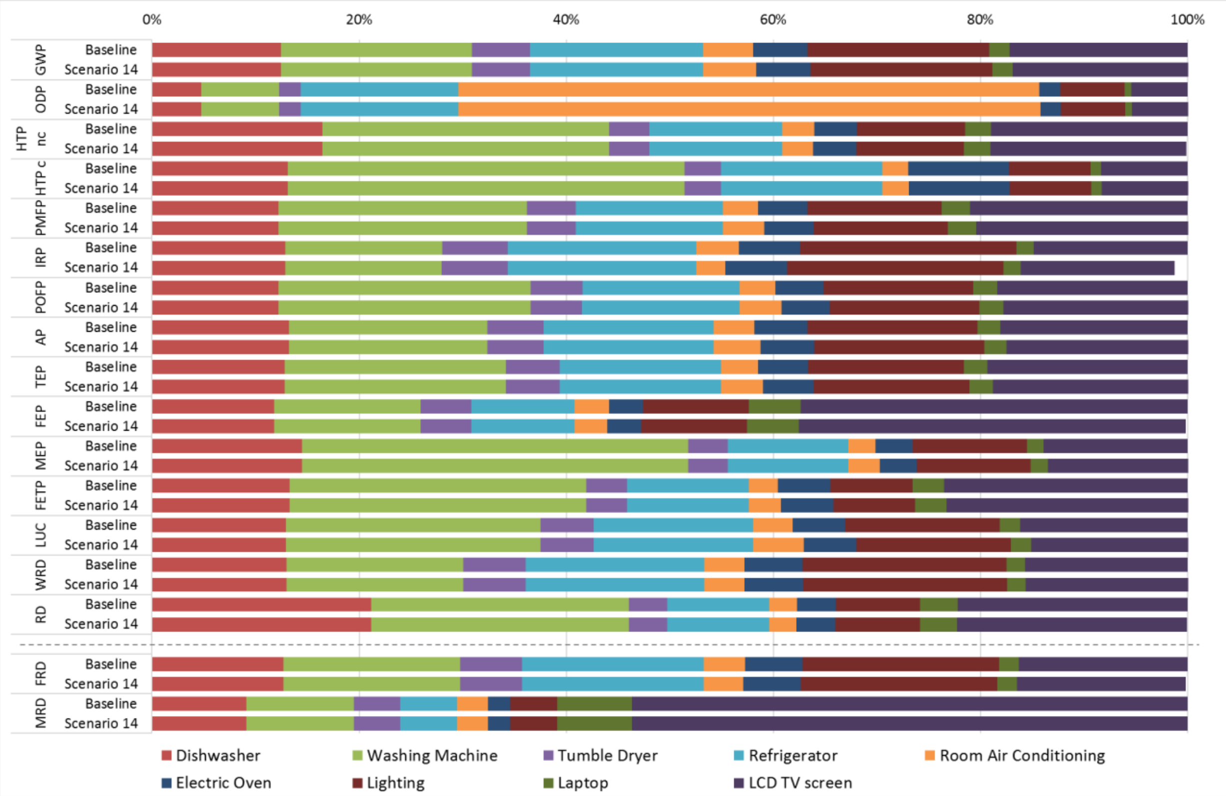


Figure 48. Scenario 14 in comparison with the baseline scenario (with the total impacts of the baseline set as 100%) – split into the contributions of the various life stages. (For the abbreviations see table note of Table 42)

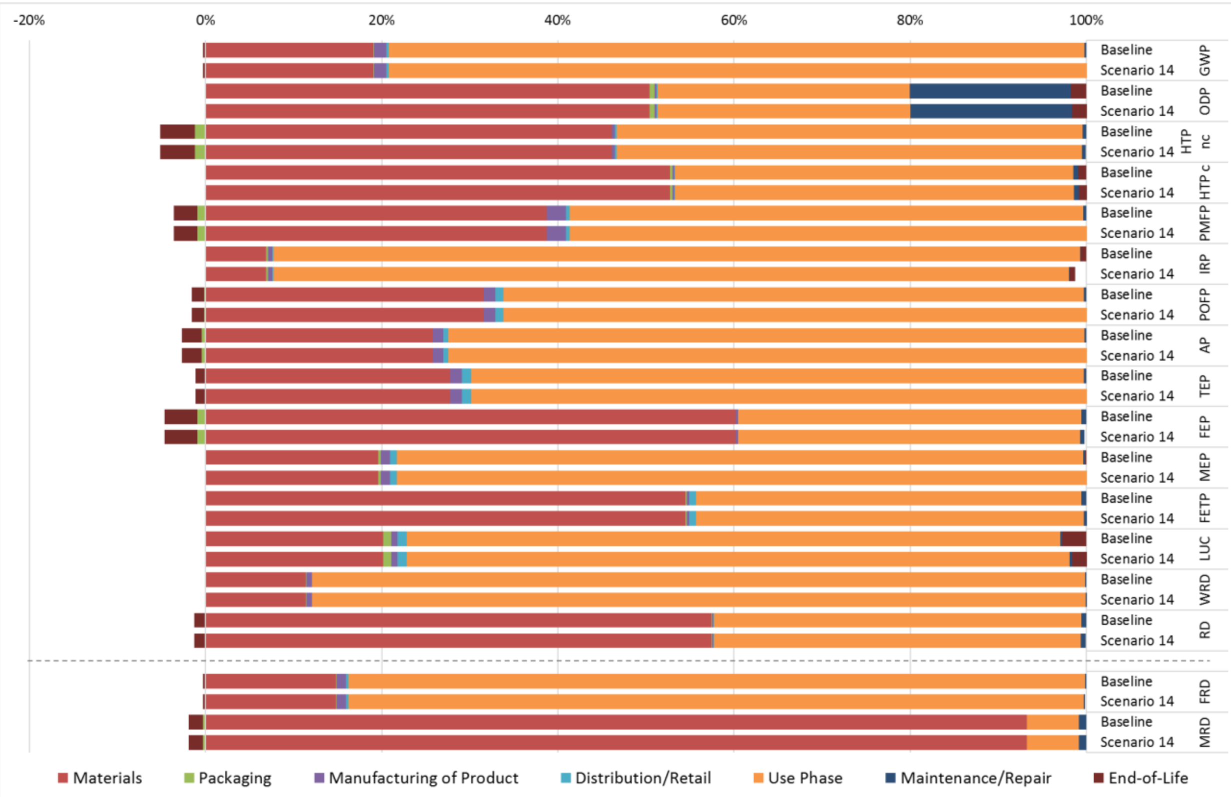


Table 99. Relative changes of the various product groups when comparing Scenario 14 with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	Total	Dish-washer	Washing Machine	Tumble Dryer	Refrige-rator	Room Air Cond.	Electric Oven	Lighting	Laptops	LCD TV Screen
GWP	0.3%	-	-	-	-	5.9%	-	-	-	-
ODP	0.1%	-	-	-	-	0.2%	-	-	-	-
HTP nc	-0.1%	-	-	-	-	-3.0%	-	-	-	-
HTP c	0.1%	-	-	-	-	2.2%	-	-	-	-
PMFP	0.6%	-	-	-	-	17.7%	-	-	-	-
IRP	-1.3%	-	-	-	-	-30.9%	-	-	-	-
POFP	0.6%	-	-	-	-	16.9%	-	-	-	-
AP	0.6%	-	-	-	-	15.5%	-	-	-	-
TEP	0.5%	-	-	-	-	-5.5%	-	-	-	-
FEP	-0.2%	-	-	-	-	-5.5%	-	-	-	-
MEP	0.4%	-	-	-	-	14.7%	-	-	-	-
FETP	0.3%	-	-	-	-	9.7%	-	-	-	-
LU	1.1%	-	-	-	-	27.8%	-	-	-	-
WRD	0.0%	-	-	-	-	1.2%	-	-	-	-
RD	-0.0%	-	-	-	-	-1.7%	-	-	-	-
FRD	-0.2%					-4.3%				
MRD	0.0%					0.1%				

([1]) Abbreviations, see table note at Table 42

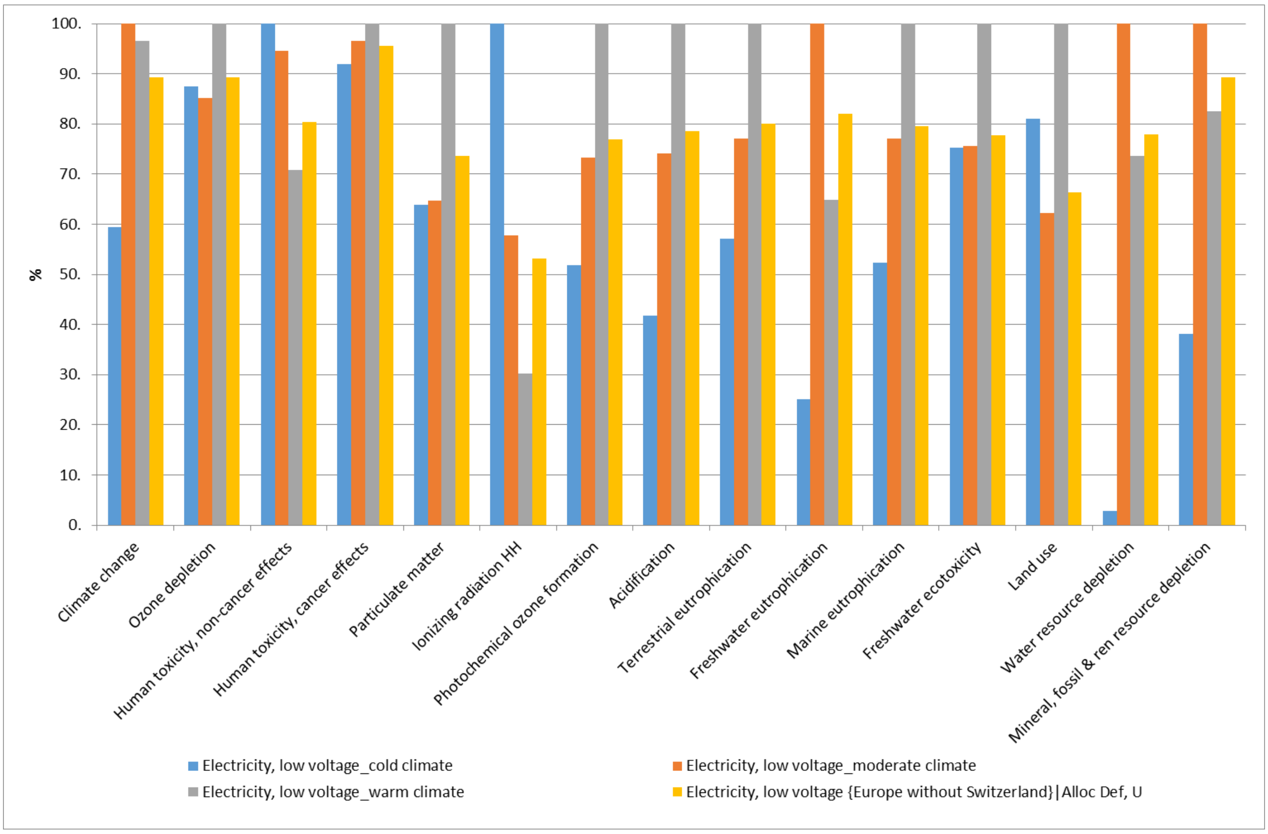
Table 100. Relative changes of the various life stages when comparing Scenario 14 with the baseline scenario (relative to the result in the baseline scenario)

Impact Category([1])	Total	Materials	Packaging	Production	Distribu-tion	Use	Main-tenance	End-of-Life
GWP	0.3%	-	-	-	-	0.4%	-	-
ODP	0.1%	-	-	-	-	0.3%	-	-
HTP nc	-0.1%	-	-	-	-	-0.2%	-	-
HTP c	0.1%	-	-	-	-	0.1%	-	-
PMFP	0.6%	-	-	-	-	1.0%	-	-
IRP	-1.3%	-	-	-	-	-1.4%	-	-
POFP	0.6%	-	-	-	-	0.9%	-	-
AP	0.6%	-	-	-	-	0.8%	-	-
TEP	0.5%	-	-	-	-	0.7%	-	-
FEP	-0.2%	-	-	-	-	-0.4%	-	-
MEP	0.4%	-	-	-	-	0.5%	-	-
FETP	0.3%	-	-	-	-	0.6%	-	-
LU	1.1%	-	-	-	-	1.4%	-	-
WRD	0.0%	-	-	-	-	0.1%	-	-
RD	-0.0%	-	-	-	-	-0.1%	-	-
FRD	-0.2%					-0.2%		
MRD	0.0%					0.1%		

([1]) Abbreviations, see table note at Table 42

The use of electricity mix representative for the three climatic zones leads to small changes of the impact of the BoP on some impact categories. For most of the impact categories considered there is a slight increase (from 0.1% to 1.1%), whereas a slight decrease is registered for ionising radiation (-1.3%), human toxicity, non-cancer effects (-0.1%) and freshwater eutrophication (-0.2%). In addition to this, a reduction of 4% on the impact from fossil resource depletion is obtained according to the method EF 3.0. Figure 49 gives an overview of the differences between the impacts of 1 kWh produced with the EU electricity mix used in the baseline scenario and with the three mixes used in this scenario, for the room air conditioner (characterized with ILCD method).

Figure 49. Comparison between impacts from electricity from EU mix (Electricity, low voltage {Europe without Switzerland} |market group for | Alloc Def, U – ecoinvent 3.2) and electricity from warm, moderate and cold mix.



8.16 Scenario 15 – Installation of PV systems for self-consumption

Description and aim: Scenario 15 analyses the effect of an increase in installation of PV systems on the roof of private houses, as a contribution to their supply of electricity. The scenario makes use of the model of the PV system described before, implemented on the housing stock modelled in the BoP on Housing, composed by Single-family Houses (SFH) and Multi-family Houses (MFH) in three climatic zones of EU (warm, moderate, and cold) (Baldassarri et al., 2017).

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 (EU, 2012b), and Roadmap to a Resource Efficient Europe (EC, 2011b).

Rationale for building the scenario: around 20% of the installed PV capacity in the EU 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 the EU.

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 EU 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 modules. The results of the study indicate that for each m^2 of roof in the building stock, 0.4 m^2 can be considered suitable for the installation of PV modules. 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 9 m^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 9 m^2 per citizen. Since there are no data on the roof area that is currently used in the EU 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 EU building stock modelled in the BoP Housing.

Figure 50 summarises 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 50. Calculation flow and related assumptions used to model the PV scenario

	PV_MIN	PV_MAX
a) Solar architecturally suitable roof area per person (average of EU conditions), calculated by Nowak at al (2002).	$9 m^2/p$	
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

Parameters modified in the model:

Scenario 15 has been modelled consistently with what was done for the scenario on the installation of solar collectors in the BoP Housing, 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 (in the BoP Housing) to model this scenario:

- production phase: the PV system (production of raw materials, manufacture, and packaging) is added to the inventory (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 101 and Table 102, based on the number of persons living in each type of dwelling. Following this approach, the total PV surface installed in Europe is 8.91E+08 m^2 for option "PV_MIN" and 2.67E+09 m^2 for the option "PV_MAX".

Table 101. Size of PV system (m²/dwelling) – option "PV_MIN" (1.8 m^2/person) according to climatic zones*. SFH = single-family house, MFH = multi-family house

		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 102. Size of PV system (m²/dwelling) – option "PV_MAX" (5.4 m^2/person) according to climatic zones*. SFH = single-family house, MFH = multi-family house

		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

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

The PV system produces electricity, resulting in a reduced need of electricity from the grid. The PV system produces 145 kWh/m^2 installed, if considering the average EU conditions of solar irradiation. To better differentiate the electricity production potential in the three climatic zones considered in the BoP Housing, an average value for each of the three zones was applied in the model. The values derive from the PVGIS system (Šùri et al., 2008), which estimates the potential of solar electricity generation in the EU starting from spatialized solar radiation data. The values used for each zone are: 183 kWh/m^2 for the warm zone, 140 kWh/m^2 for the moderate zone and 110 kWh/m^2 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 103 for option PV_MIN and in Table 104 for option PV_MAX.

Table 103. Annual electricity production by PV system in each dwelling type, for the option "PV_MIN" (kWh/dwelling*year^{-1}). SFH = single-family house, MFH = multi-family house

		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 104. Annual electricity production by PV system in each dwelling type, for the option "PV_MAX" (kWh/dwelling*year^{-1}). SFH = single-family house, MFH = multi-family house

		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 105 and Table 106 summarise 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 105. Remaining annual electricity demand to be covered by the conventional system, for the option "PV_MIN" (kWh/dwelling*year^{-1}). SFH = single-family house, MFH = multi-family house

	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 106. Remaining annual electricity demand to be covered by the conventional system, for the option "PV_MAX" (kWh/dwelling*year^{-1}). SFH = single-family house, MFH = multi-family house

	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 107). 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 108). 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.

Table 107. Reduction (as %) for electricity taken from the grid, when the PV system is installed according to option "PV_MIN". SFH = single-family house, MFH = multi-family house

	SFH				MFH			
	<1945	1945-1969	1970-1989	1990-2008	<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 108. Reduction (as %) for electricity taken from the grid, when the PV system is installed according to option "PV_MAX". SFH = single-family house, MFH = multi-family house

	SFH				MFH			
	<1945	1945-1969	1970-1989	1990-2008	<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%

Results:

The two options tested allow for a reduction in all impact categories except freshwater ecotoxicity and resource depletion (Figure 51 and Table 109). 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 module 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 EF 3.0 method. This method applies the abiotic depletion (ADP) concept, as it is in 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 the EF 3.0 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 modules of the PV system, which is a hotspot of the PV life cycle, as mentioned before.

Figure 51. Relative results of the scenarios PV_MIN and PV_MAX compared to the baseline, taken as 100%. (For the abbreviations see table note of Table 42)

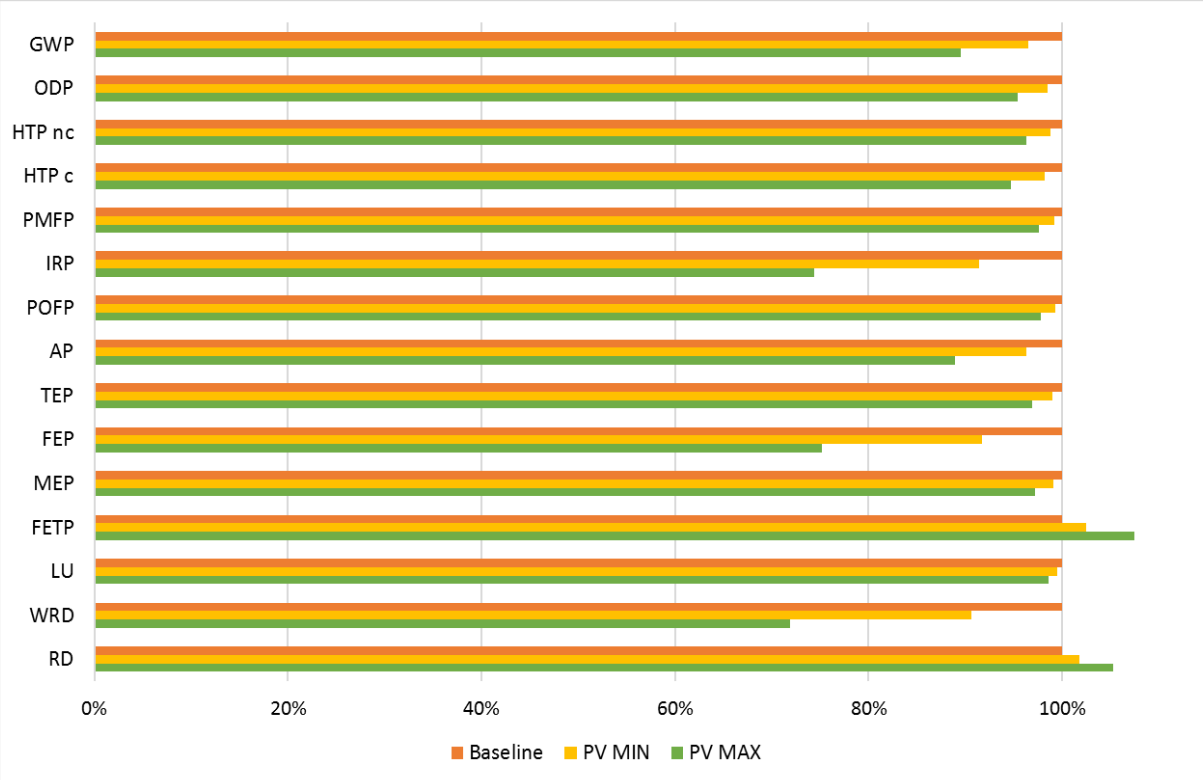


Table 109. Results of the scenarios PV_MIN and PV_MAX compared to the baseline

Impact Category[1]	**Unit**	**Baseline**	**PV_MIN**		**PV_MAX**	
GWP	kg CO_2 eq	2.62E+03	2.53E+03	*-3.5%*	2.35E+03	*-10.5%*
ODP	kg CFC-11 eq	3.33E-04	3.28E-04	*-1.5%*	3.17E-04	*-4.6%*
HTP nc	CTUh	2.70E-04	2.67E-04	*-1.2%*	2.60E-04	*-3.7%*
HTP c	CTUh	3.48E-05	3.41E-05	*-1.8%*	3.29E-05	*-5.3%*
PMFP	kg $PM_{2.5}$ eq	2.90E+00	2.88E+00	*-0.8%*	2.83E+00	*-2.4%*
IRP	kBq U^{235} eq	2.05E+02	1.87E+02	*-8.5%*	1.52E+02	*-25.6%*
POFP	kg NMVOC eq	6.11E+00	6.07E+00	*-0.7%*	5.98E+00	*-2.2%*
AP	molc H+ eq	1.34E+01	1.29E+01	*-3.7%*	1.19E+01	*-11.1%*
TEP	molc N eq	1.84E+01	1.83E+01	*-1.0%*	1.79E+01	*-3.1%*
FEP	kg P eq	1.48E-01	1.36E-01	*-8.3%*	1.12E-01	*-24.8%*
MEP	kg N eq	1.68E+00	1.66E+00	*-0.9%*	1.63E+00	*-2.8%*
FETP	CTUe	1.14E+03	1.17E+03	*2.5%*	1.22E+03	*7.4%*
LU	kg C deficit	4.84E+03	4.82E+03	*-0.5%*	4.78E+03	*-1.4%*
WRD	m^3 water eq	1.51E+02	1.37E+02	*-9.4%*	1.08E+02	*-28.1%*
RD	kg Sb eq	1.18E-01	1.20E-01	*1.7%*	1.24E-01	*5.2%*
FRD	MJ	4.84E+04	4.61E+04	*-4.9%*	4.14E+04	*-14.6%*
MRD	kg Sb eq	5.13E-03	5.61E-03	*9.4%*	6.57E-03	*28.2%*

([1]) Abbreviations, see table note at Table 42

8.16.1 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 52 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 52. Calculation flow and related assumptions used to model the PV sensitivity scenario

a) Solar architecturally suitable roof area per building, calculated by estimating the ground floor area for each building type in the BoP Housing and applying the 0.4 factor calculated by Nowak at al (2002).	18-144 m^2	
b) Reduced suitable roof area per building (20% of a) or 60% of a)), to take into account that some roofs may already have PV installed and that not all the potential may be used.	Sens_MIN 3.6-28.8 m^2	Sens_MAX 10.8-86.4 m^2
c) Available area per dwelling, calculated considering the number of dwellings (dw) in each building type of the BoP Housing	Sens_MIN 1.2-4.0 m^2/dw	Sens_MAX 3.6-14.4 m^2/dw
d) Annual electricity production by PV system in each dwelling type (considering a different production in the three zones, depending on the climatic conditions)	Sens_MIN 132-732 kWh	Sens_MAX 396-2197 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)	Sens_MIN 2759-11057 kWh	Sens_MAX 2100-10178 kWh

The ground floor area of the two types of buildings, single family house and multi-family house (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 110 and Table 111. 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 112 to Table 119).

Table 110. Summary of features of single-family house 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 111. Summary of features of multi-family house in the BoP Housing and PV surface assumed in the options “Sensitivity_MIN” and “Sensitivity_MAX”

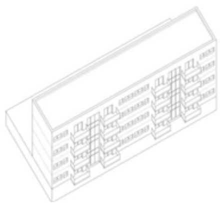
Dwelling type	**Multi-Family House**											
	MFH_warm_<1945	MFH_warm_1945-69	MFH_warm_1970-89	MFH_warm_1990-2010	MFH_moderate_<1945	MFH_moderate_1945-69	MFH_moderate_1970-89	MFH_moderate_1990-2010	MFH_cold_<1945	MFH_cold_1945-69	MFH_cold_1970-89	MFH_cold_1990-2010
Building typology	Low-rise > 10 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 112. 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 113. 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 114. 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 115. 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 116. 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 117. 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 118. 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	1990-2008	<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 119. 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	1990-2008	<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 118). 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 119).

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 120).

Table 120. 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 the impacts compared to the respective two options tested before (Figure 53 and Table 121). 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 closer to reality, especially because there are only few studies conducted at the EU 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 14 m^2/person, with a range of uncertainty of +/-4.5 m^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 EU country. According to their findings, Spain has a larger roof surface available, compared to other EU 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 in the EU. 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 electricity of 461 TWh/y for the PV scenarios (area estimated per person) and 256 TWh/y for the sensitivity scenarios (area calculated per building). When comparing this study to the study by Defaix et al. (2012) it is worth considering that the number provided by Defaix et al. (2012) 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 EU, both for what concerns the estimated available roof surface and the electricity generation potential.

On the contrary, it is worth underlining 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 53. Relative results of the scenarios Sensitivity_MIN, Sensitivity_MAX, PV_MIN and PV_MAX compared to the baseline, taken as 100%. (For the abbreviations see table note of Table 42)

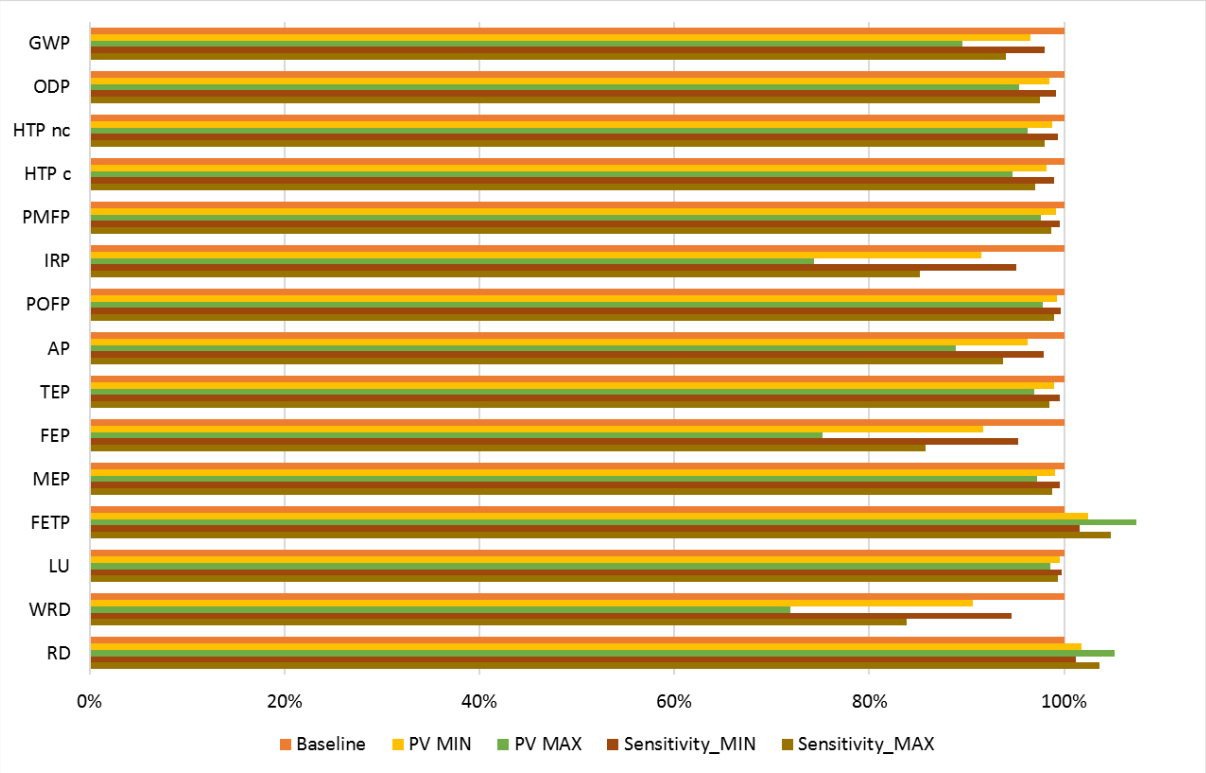


Table 121. Results of the scenarios Sensitivity_MIN and Sensitivity_Max compared to scenarios PV_MIN and PV_MAX and to the baseline

Impact Category[1]	**Unit**	**Baseline**	**PV_MIN**		**PV_MAX**		**Sens_MIN**		**Sens_MAX**	
GWP	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%*
ODP	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%*
HTP nc	CTUh	2.70E-04	2.67E-04	*-1.2%*	2.60E-04	*-3.7%*	2.68E-04	*-0.7%*	2.65E-04	*-2.0%*
HTP c	CTUh	3.48E-05	3.41E-05	*-1.8%*	3.29E-05	*-5.3%*	3.44E-05	*-1.0%*	3.37E-05	*-2.9%*
PMFP	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%*
IRP	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%*
POFP	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%*
AP	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%*
TEP	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%*
FEP	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%*
MEP	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%*
FETP	CTUe	1.14E+03	1.17E+03	*2.5%*	1.22E+03	*7.4%*	1.16E+03	*1.6%*	1.19E+03	*4.8%*
LU	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%*
WRD	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%*
RD	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%*
FRD	MJ	4.84E+04	4.61E+04	*-4.9%*	4.14E+04	*-14.6%*	4.71E+04	*-2.8%*	4.44E+04	*-8.4%*
MRD	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%*

(1) Abbreviations, see table note at Table 42

8.17 Summary of results from scenario analysis

Table 122 represents a summary of the results of the scenarios assessed for the BoP appliances, 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 122. Summary of results of the scenarios analyzed. Results are expressed as variation (%) compared to the baseline

	GWP	ODP	HTP nc	HTP c	PMFP	IRP	POFP	AP	TEP	FEP	MEP	FETP	LU	WRD	RD	FRD	MRD
Baseline 2015	13.9%	39.7%	13.5%	10.2%	13.8%	13.9%	13.5%	14.0%	13.8%	16.7%	12.1%	13.5%	13.4%	13.8%	14.5%	13.9%	18.6%
SC.1: More renewable European Electricity Mix	-24.4%	-1.7%	-1.7%	-0.1%	-30.6%	-40.9%	-31.4%	-45.8%	-30.6%	-8.3%	-21.6%	-0.1%	21.3%	-24.1%	18.7%	-20.2%	2.7%
SC.2: Improved efficiency dishwasher and washing machine	-7.7%	-2.8%	-9.1%	-6.4%	-6.2%	-8.8%	-6.8%	-7.4%	-7.2%	-5.2%	-13.6%	-6.2%	-7.7%	-9.0%	-4.7%	-8.2%	-0.7%
SC.3: Improved efficiency of the refrigerator-freezer	-8.5%	-3.1%	-4.0%	-3.3%	-5.8%	-10.6%	-6.7%	-7.9%	-7.0%	-4.0%	-5.1%	-2.8%	-7.3%	-10.0%	-3.1%	-9.3%	-0.5%
SC.4: Improved efficiency television device	-6.7%	-2.4%	-3.3%	-2.9%	-4.8%	-8.1%	-5.4%	-6.2%	-5.6%	-3.1%	-4.1%	-2.5%	-5.6%	-7.6%	-2.6%	-7.3%	-0.4%
SC.5: Reduction leakages of air conditioning appliances	-0.7%	-12.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SC.6: Substitution of refrigerants	-1.2%	-63.4%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%
SC.7: Increasing number of devices per household	36.8%	182.5%	42.5%	32.0%	37.1%	31.4%	35.1%	36.0%	35.9%	46.5%	32.9%	41.4%	34.7%	32.0%	45.4%	32.8%	55.1%
SC.8a: Increasing remanufacturing and reuse	-2.2%	-1.1%	-2.4%	-2.8%	-2.2%	-2.2%	-2.3%	-2.2%	-2.2%	-1.7%	-2.6%	-2.3%	-2.3%	-2.2%	-2.4%	-2.2%	-1.3%
SC.8b: Increasing the collection rates	-0.4%	0.7%	-2.8%	0.2%	-1.2%	0.2%	-0.7%	-1.0%	-0.5%	-1.6%	-0.7%	0.0%	1.1%	0.0%	-0.6%	-0.1%	-0.8%
SC.8c: Increasing recycling rates of various fractions	-0.1%	0.3%	-0.8%	0.1%	-0.3%	0.1%	-0.2%	-0.4%	-0.1%	-0.7%	-0.1%	-0.3%	0.4%	0.0%	-0.4	-0.4%	0.0%
SC.9: Increased use of LED lighting	-12.7%	-4.6%	-4.3%	-5.3%	-7.8%	-15.9%	-9.4%	-11.4%	-10.1%	-3.4%	-7.5%	-2.7%	-10.6%	-14.7%	-3.6%	-14.1%	3.7%
SC.10a: Devices-related saving potential	-36.6%	-76.3%	-20.7%	-17.9%	-24.7%	-43.5%	-28.2%	-32.9%	-29.9%	-15.7%	-30.2%	-14.2%	-31.2%	-41.2%	-14.0%	-38.8%	2.2%
SC.10b: Devices-related potential and reusability	-40.4%	-76.2%	-30.4%	-20.6%	-31.2%	-45.3%	-33.2%	-38.1%	-34.9%	-27.5%	-34.7%	-21.6%	-33.3%	-43.8%	-21.5%	-41.8%	-13.3%
SC.10c: Devices overall potential and changing amount	-12.1%	-64.3%	-1.0%	6.4%	-2.0%	-17.5%	-4.4%	-8.8%	-5.4%	5.8%	-9.8%	9.6%	-2.7%	-16.4%	12.1%	-13.4%	26.0%
SC.11: Overall potential of sector of household appliances	-33.6%	-66.6%	-6.3%	3.6%	-28.4%	-52.0%	-31.5%	-47.1%	-32.1%	-2.4%	-32.8%	6.5%	10.6%	-37.7%	23.4%	-31.7%	27.6%
SC.12: Domotics – a first estimate of its potential	-16.7%	-60.1%	-7.8%	-6.7%	-10.6%	-19.1%	-12.1%	-14.4%	-13.0%	-7.1%	-9.5%	-5.3%	-13.2%	-17.8%	-6.2%	-17.1%	-0.6%
SC.14: Relevance of electricity mix for group of MS	0.3%	0.1%	-0.1%	0.1%	0.6%	-1.3%	0.6%	0.6%	0.5%	-0.2%	0.4%	0.3%	1.1%	0.0%	0.0%	-0.2%	0.0%

(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 (Mineral, fossil & renewable resource depletion), FRD (Fossil resource depletion), MRD (Mineral and metal resources depletion)

The described scenarios can be split into two classes: the scenarios 1 to 9 and 12 investigate one specific issue each, while scenarios 10 and 11 have the objective to look on the combined effect and to show the influence of these various aspects when integrated, in an overall approach. The split of the latter issue across four scenarios (i.e. Scenario 10a, 10b, 10c, and 11) is done in order to have transparency that allows identifying the influence of each single issue.

In that sense, very interesting scenarios are Scenario 10b showing the potential that lays within technological developments (based on the situation 2010 concerning the number of devices per person), either on the level of the devices (material, use phase) as well as on the level of the end-of-life treatment (including the prolongation of life-time), and Scenario 11, showing in addition to all this **the influence that the increasing number of devices and the change in the future electricity mix** will have on all the "technical improvements", summarized in the Scenario 10b.

Due to the increase of the number of devices per person, most of the impact categories show a higher potential in Scenario 10b (e.g. for climate change a reduction of about 40% is shown – while the inclusion of the increase of devices and the future, more renewable electricity production reduce actually this potential to about 34% - each time in comparison with the baseline scenario). **More devices per person means that the impacts of the materials, the production of the devices and their distribution is increasing in comparison to the baseline situation**. There are few impact categories where this is not the case; i.e. that have an even higher reduction potential in Scenario 11. Among these impact categories are e.g. ionising radiation (coming mainly from the assumed "phasing out" of nuclear power plants in EU, when calculating the future EU electricity mix) or acidification (in this case, the reduction of the amount of coal-based electricity leads to reduced releases to the atmosphere of those substances contributing to acidification). For few impacts – namely human toxicity – cancer effects, ecotoxicity, land use, and mineral and metals depletion – the results in Scenario 11 present even an increase compared to the baseline. This can mainly be explained by the increase in the amount of materials used for producing a larger number of devices compared to the baseline and to the influence of the use of a more renewable electricity mix. For instance, the increase of the impact on land use is due to a larger use of wood as energy source.

All in all, it could be noted that the "technical" reduction potential is (still) quite high – but that a further increase of the number of devices per household could "eat up" substantial parts of this potential.

A potential additional improvement may come from the auto-production of energy at the household scale, as demonstrated by the scenario on PV. However, it can also be generate trade-offs, such as the increase in resource depletion.

At the same time there are also few limitations to be taken into account and kept in mind when going through all these scenarios and their respective results. The most important ones are the following:

- although all these scenarios have a perspective related to the future (in some cases, such as in scenarios 1, 7, 10 and 11, they represent a projection of a possible situation in 2030) the raw data processed within the LCA models, the LCA datasets for materials, processes and services that are from the current database of ecoinvent (version 3.2) do not really represent the processes that will be used in the future. Moreover, it can be expected that few datasets may be even outdated with representing old technologies. As industry usually strives for more efficiency in production, the unavoidably used "older" data can be considered a conservative approach in view of the overall real potential of improvement e.g. scenario of a future more renewable electricity mix (as modelled in Scenario 1);
- the change of the technology – i.e. a washing machine sold today is not the same as a washing machine sold 5 years ago – is only partly taken into account here; no complete new BoM have been investigated when evaluating the potential of various technologies. Instead approximations for changes of key elements have been taken

into account only (e.g. the increase of the insulation in case of the refrigerator, resulting in a clearly lower electricity consumption, for Scenario 3)[14]. As most of the product groups covered in the BoP appliances have the main impact found in the use phase, such simplifications should not result in a major distortion of results;

- What is not taken into account – and, therefore, a quantification of this missing part is hardly possible – is the fact that sometimes our society replaces one technology with a different technology (e.g. laptop computers are getting more and more replaced by the much smaller and lighter tablet devices – resulting in a decreasing number of laptop devices in the scenario 7, investigating the increasing amount of devices that each of us possesses). This is a clear limitation; published studies (e.g. Hischier et al. 2015) show that the impact of a tablet is clearly lower than the respective impact of a modern laptop computer – however, an inclusion of a further product types, product categories requires quite some changes also on the level of the frame, the goal of the study; changes that have not been possible within the frame (i.e. time, efforts) of this study.

Background data used in this study are based on the LCA database ecoinvent (version 3.2). As ecoinvent allows a transparent analysis and access to its process chains, an adaptation of existing datasets to fit them better into the study setup is easily possible. Using ecoinvent implies also the use of datasets that do not have fix cut-off criteria; but that try rather to be as complete as possible; allowing the application of the whole bunch of different impact categories across the entire study here.

On the level of the foreground data, the main issue is that the various preparatory studies of these different product groups were published in different years, so some of them are more recent(e.g. studies published in 2015) and some of them are less recent (e.g. studies published in 2007). Hence, the representativeness of the data sources used to model the devices is not equal among the different product groups in the BoP. However, it can be considered in all cases as the most appropriate approach possible with available data. As an overall conclusion, it can nevertheless be stipulated that – especially due to the stepwise construction of the scenarios – the big lines of each scenario are given in an adequate way and they allow an easy comparison with other issues (and scenarios) developed here.

Obviously there is another point that can have a quite big influence on the results: the consumer behaviour, especially in view of how long a product is actually used, before it ends-up as waste (more exact as WEEE, waste electric and electronic equipment). But also the way how the product is used (e.g. a washing machine has today a capacity of about 8 kg of dirty clothes that can be washed in one washing cycle; however the actual load often is much lower (see documentation of the baseline scenario), which leads that the potential efficiency of such a machine is not exploited. An evaluation of the influence of all these points is not possible; but it was explored e.g. in the additional investigation within the Scenario 4 (more efficient television) to understand better such changes.

However, for a change towards a more sustainable lifestyle it is not enough to use more (energy) efficient devices. A sustainable lifestyle implies products serve real needs. Today it is questionable if the overall impacts of the BoP appliances can be reduced as the number of devices per person and the time that these devices are in use can increase.

[14] An exception is the area of lighting; for this topic, the used technology got varied between the different scenarios (up to a 100% LED-based lighting in the scenario 12, dealing with the issue of "domotics").

9 Comparison of Life Cycle Assessment results with MEErP results

The Methodology for Ecodesign of Energy related Products (MEErP) was developed to support the preparatory studies according to the Directive 2009/125/EC on Ecodesign of Energy-related Products (EC, 2009a). In this report the reviewed methodology by Kemna (2011) is condered. MEErP makes use of LCA as an assessment tool and it is applied to all the product groups that are covered by the Ecodesign directive. Since the BoP appliances is composed by representative products selected among the ones covered by the Ecodesign directive, it is interesting to compare the results of the two approaches (the Consumer Footprint and the MEErP).

The comparison entails the following steps:

1. Methodological comparison: a) system boundaries, allocation approach, and other assumptions; b) characterisation and impact assessment method used for the environmental assessment (Task 5 of MEErP).
2. Quantitative comparison: a) comparison of characterised results for each product in the BoP for which the results of the analysis with the Ecoreport tool [15]are available; b) comparison of the relevance of processes and life cycle stages for each product in the BoP for which the results of the analysis with the Ecoreport tool are available.

It has to be considered that the study underpinning the calculation of the Consumer Footprint started in 2016 and run in parallel to the Environmental Footprint (EF) pilot phase. Hence, the modelling approach adopted and the life cycle inventory data used are not fully compliant with EF rules and are only intended to illustrate the use of LCA to define the baseline of impacts due to consumption in the EU and to test eco-innovation and policy options against that baseline.

9.1 Methodological comparison

The general aim of the two approaches is quite similar, i.e. to run a base-case life cycle assessment, to identify hotspots, and to evaluate possible improvements. However, the focus of MEErP is on the design of solutions to improve the environmental profile of products, working with one product group at a time. On the contrary, the focus of the Consumer Footprint is on the overall impact generated by the purchase and use of energy-related products by the EU citizens, and on the solutions to reduce this impact.

Both approaches use LCA as assessment method. However, there are some methodological differences, both at the inventory and at the life cycle impact assessment stages. The inventory of the representative products in the BoP appliances is largely based on the description and inventory of the base cases defined in the Ecodesign preparatory studies. The system boundaries are the same in both approaches. However, the two differ for what concerns the end of life of products and materials. The general approach is the same, but the way in which it is applied is different and can lead to different results. MEErP assigns credits for recycling fractions, based on down-cycling or open loop recycling. Recycling credits at the end of life are assigned to plastics, electronics (excluding LCD/CRT screens), miscellaneous materials, refrigerants, mercury and extra materials. Credits for metals are already taken into account at the production phase (recycled content of input materials). The Consumer Footprint assigns credits as well, but they are accounted for entirely at the end of life (see section 4.7 of this report for details). The two approaches differ also for what concerns the method used for the environmental impact assessment. Table 123 provides an overview of the indicators considered in the Consumer Footprint and MEErP 2011. The impact assessment of the Consumer Footprint is currently based on the ILCD method. However, also the EF 3.0 method is considered in the comparison. In EF 3.0 method the recommendation for four impact categories, namely Particulate Matter,

[15] The Ecoreport tool was developed to be used to assess the environmental impacts of products in Ecodesign preparatory studies, following MEErP.

Resource Use, Land Use, and Water Use, has been changed compared to ILCD, and the characterisation factors (CFs) for climate change have been updated from IPCC, 2007 to IPCC, 2013, and the CFs for ozone depletion have been updated from WMO (1999) to WMO (2014).

The main difference between the Consumer Footprint and MEErP is that MEErP includes some pressure indicators (accounting of resources used and emissions from life cycle of products), whereas in the Consumer Footprint potential impacts are assessed. This is fully in line with the goal and scope of the MEErP, which is in support to material and energy efficiency of energy-related products. Other indicators of MEErP that are closely related to the aim of the methodology are the ones referred to the amount of waste as a whole, the amount of hazardous and non-hazardous waste, and the rate of recycling of specific materials. On the contrary, ILCD and EF 3.0 have a broader goal and aim to assess the environmental impacts of single products and larger systems, as well as to identify possible environmental trade-offs. Therefore, the indicators and related characterization models and factors refer to a wider range of environmental issues, such as ionising radiations, ozone depletion, human toxicity, etc. Moreover, the characterisation models used in ILCD and EF 3.0 are generally taken from the scientific literature and aim to reflect the state-of-the art in the scientific domain covered by the indicator. Characterisation in MEErP is instead based on values in EU legislation, because it is assumed that these limits are taking into consideration the latest scientific insights in the field covered by the legislation. This leads also to a larger number of flows (i.e. substances that are characterized or accounted for) considered in ILCD/EF 3.0 compared to those accounted for in MEErP (Table 123). Considering these differences, it is not surprising that only few impact categories (or indicators) correspond in the two approaches, whereas for others only partial overlappings have been identified, as highlighted in Table 123. The impact categories included both in ILCD/EF 3.0 and MEErP are: climate change; particulate matter; ionising radiation; acidification potential; eutrophication potential; water use; mineral and metals resource use; energy resource use.

However, also for these impact categories, the characterisation models, and the related unit of measures in which results are expressed, are different in the two methods. For instance, the impact of PM emissions is expressed in kg $PM_{2.5eq}$ in the case of ILCD, in "disease incidence" in case of EF 3.0, and in kg of PM_{10eq} in the case of MEErP. This difference makes the results of the two method difficult to compare in terms of quantity. The same applies for ionising radiation, acidification, eutrophication, water use, and energy resource use. Even if the two methods include an indicator for the same environmental issues, the background models used to calculate the characterisation factors are different (in the case of water, MEErP does not have CF, but only an inventory of water used) and so quantitative results of the two methods are not directly comparable. The impact on mineral and metal resource use is expressed with the same unit in ILCD, EF 3.0, and MEErP, i.e. kg Sb_{eq}., however the underpinning characterisation methods are different hence the results cannot be compared. The assessment of photochemical ozone formation is similar in the Consumer Footprint (either using ILCD or EF 3.0) and MEErP for what concerns the NMVOCs: the characterisation factor for all NMVOCs in ILCD and EF 3.0 is equal to 1; therefore, it is the same as accounting for the mass of NMVOC only (as it is in MEErP). However, ILCD and EF 3.0 consider also other substances that have a potential for photochemical ozone formation. Regarding toxicity, the approach of the two methods is quite different: ILCD and EF 3.0 refer to the characterisation factors developed according to the USEtox model, to calculate the potential impact on human health in terms of cancer and non-cancer effects and the impact on freshwater ecotoxicity. MEErP applies CFs for dioxins and furans as Persistent Organic Pollutants (POPs), Heavy Metal (HMw) and Polycyclic Aromatic Hydrocarbons (PAHs) emissions to water and Heavy Metals to air (HMa). Hazardous substances (HS), and substances of very high concern (SVHC) are reported only as inventory. The only impact category for which the two methods refer to the same model is climate change (or GWP) and the resulrs are expressed in kg CO_2 eq. The reference model, and related characterisation factors (for ILCD and MEErP) is IPCC (2007), whereas EF 3.0 refers to IPCC (2013).

Table 123. Overview of indicators considered in the Consumer Footprint (ILCD, and EF 3.0 method) and MEErP 2011

ILCD				EF 3.0				MEErP			
Impact category	**Model**	**Unit**	**N° of flows**	**Impact category**	**Model**	**Unit**	**N° of flows**	**Impact category**	**Model/ References for CFs**	**Unit**	**N° of flows**
Climate change	IPCC, 2007	kg CO_2 eq	101 to air	**Climate change**	IPCC, 2013	kg CO_2 eq	207 to air	**Global Warming Potential (GWP-100)**	IPCC, 2007	kg CO_2 eq	52 to air
Ozone depletion[16]	WMO, 1999	kg CFC-11 eq	23 to air	**Ozone depletion**	WMO, 2014	kg CFC-11 eq	24 to air				
Human toxicity, cancer	USEtox (Rosenbaum et al., 2008)	CTUh	605 to air, 605 to soil, 605 to water	**Human toxicity, cancer**	based on USEtox2.1 model (Fantke et al. 2017), adapted as in Saouter et al., 2018	CTUh	621 to air, 621 to soil, 621 to water	**Persistent Organic Pollutants (POP)** **Polycyclic Aromatic Hydrocarbons emissions to air (PAHa)** **Heavy metals emissions to air (HMa)**	Industrial emission Directive (2010/75/EU) Ambient Air Quality Directive(2008/50/EC) Directive relating to arsenic, cadmium, mercury, nickel and PAH in ambient air (2004/107/EC)	ng Teq[17] mg Ni eq mg Ni eq	17 to air 3 to air 10 to air
Human toxicity, non-cancer	USEtox (Rosenbaum et al., 2008)	CTUh	440 to air, 439 to soil, 439 to water	**Human toxicity, non-cancer**	based on USEtox2.1 model (Fantke et al. 2017), adapted as in Saouter et al., 2018	CTUh	3450 to air, 3450 to soil, 3450 to water				
Ecotoxicity freshwater	USEtox (Rosenbaum et al., 2008)	CTUe	2521 to air, 2520 to soil, 2520 to water	**Ecotoxicity freshwater**	based on USEtox2.1 model (Fantke et al. 2017), adapted as in Saouter et al., 2018	CTUe	6011 to air, 6011 to soil, 6011 to water	**Heavy metals and PAH emissions to water (HMw)**	Water Quality Directive (2008/105/EC)	mg Hg/20 eq[18]	5 to water
Particulate matter and respiratory inorganics	Humbert (2009)	kg $PM_{2.5}$ eq	10 to air	**Particulate matter and respiratory inorganics**	UNEP, 2016	disease incidence	9 to air	**Particulate Matter (PM)**	Ambient Air Quality Directive (2008/50/EC)	g PM_{10} eq	3 to air

[16] Ozone depletion was included as impact category in MEErP 2005 but it has been removed in 2011 version because it is considered that ODP-emissions are now practically non-existing, due to the Montreal agreement.However, with cooling system and increasing reliance on cold chains this might become again relevant.

[17] Total concentration equivalent (Teq) of Tetrachlorodibenzodioxin (TCDD). Pesticides are not included because they are expected to have little bearing on energy-related products

[18] The unit is reported in the MEERP (Kemna, 2011) and it is based on the annual average concentration limit values AA-EQS (AnnuaAverage – Environmental Quality Standard) from Directive 2008/150/EC (Water Quality Directive): Hg (0.05 µg/l); PAH (0.05 µg/l); Cd (0.2 µg/l); Pb (7.2 µg/l); Ni (20 µg/l). Characterisation values are calculated from the inverse of these values, using (Hg/20) mass equivalent as the reference accounting unit.

ILCD				EF 3.0				MEErP			
Impact category	**Model**	**Unit**	**N° of flows**	**Impact category**	**Model**	**Unit**	**N° of flows**	**Impact category**	**Model/ References for CFs**	**Unit**	**N° of flows**
Ionising radiation	Frischknecht et al., 2000	kBq U-235 eq	21 to air, 21 to water	**Ionising radiation**	Frischknecht et al., 2000	kBq U-235 eq	21 to air, 21 to water	**Radiation (Radon, UV, medical)**	See note[19]	Bq	n.a.
Photochemical ozone formation	Van Zelm et al., 2008, as applied in ReCiPe, 2008	kg NMVOC eq	133 to air	**Photochemical ozone formation**	Van Zelm et al., 2008, as applied in ReCiPe, 2008	kg NMVOC eq.	136 to air	**Non-methane Volatile Organic Compounds (NMVOC)**	Inventory	kg NMVOC	1 to air
Acidification	Posch et al., 2008	mol H^+ eq	7 to air	**Acidification**	Posch et al., 2008	mol H^+ eq	9 to air	**Acidification Potential (AP)**	UNECE 1999 CLRTAP protocol	g SO_2 eq	16 to air
Terrestrial eutrophication	Posch et al., 2008	mol N eq	7 to air	**Terrestrial eutrophication**	Posch et al., 2008	mol N eq	7 to air				
Freshwater eutrophication	Struijs et al., 2009	kg P eq	4 to water	**Freshwater eutrophication**	Struijs et al., 2009	kg P eq	4 to water	**Eutrophication Potential of emissions to water (EP)**	Urban Waste Water Treatment Directive (91/271/EC) – concentration limit values	g PO_4 eq	11 to water
Marine eutrophication	Struijs et al., 2009	kg N eq	5 to water, 6 to air	**Marine eutrophication**	Struijs et al., 2009	kg N eq	5 to water 7 to air				
Land use	Milà i Canals et al. 2007	kg C	73 occupation, 133 transformation	**Land use**	Soil quality index based on an updated LANCA model (De Laurentiis et al. 2019)	Pt	57 occupation, 114 transformation				

[19] Council Directive 96/29/Euratom of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation
Commission Recommendation of 21 February 1990 on the protection of the public against indoor exposure to radon (90/143/Euratom) laying down reference and design levels for indoor radon.
Radon in drinking water is addressed by a Commission Recommendation on the protection of the public against exposure to radon in drinking water supplies (notified under document number C(2001) 4580, 2001/928/Euratom, 20 December 2001)
Directive 97/43/Euratom provides for a high level of health protection to ionising radiation in medical exposure (dental and other X-ray applications).Relevant technical standards are (a.o.) the IEC (International Electrotechnical Commission) 60601-series
Effects of UV radiation from artificial light is currently under investigation by SCENIHR (Scientific Committee on Emerging and Newly Identified Health Risks).

ILCD				EF 3.0				MEErP			
Impact category	**Model**	**Unit**	**N° of flows**	**Impact category**	**Model**	**Unit**	**N° of flows**	**Impact category**	**Model/ References for CFs**	**Unit**	**N° of flows**
Water depletion	Swiss Ecoscarcity 2006	m^3	24	**Water scarcity**	Boulay et al., 2018; UNEP 2016	m^3 water eq	7	**Water (Process water and cooling water)**	Inventory	m^3	2
Resource depletion	ADP reserve base (van Oers et al., 2002)	kg Sb eq	92	**Resource use (mineral and metals)**	ADP ultimate reserve (van Oers et al., 2002)	kg Sb eq	48	**Critical Raw Materials (CRM)**[20]	Based on Raw Material Communication (COM(2011)25)	kg Sb eq[21]	14
				Resource use (fossils)	ADP fossils (van Oers et al., 2002)	MJ	6	**Energy**[22]	Inventory	MJ	n.a.
								Materials – total mass	*Inventory*	kg	-
								EoL metals and glass	*Inventory*	kg	-
								EoL plastics and Printed Wiring Board (PWB)	*Inventory*	kg	-
								Recycling maximum	-	%	-
								Refrigerants and mercury	*Inventory*	g	-
								Waste (Hazardous and non-hazardous)	*Inventory*	kg	-
								Hazardous substances (HS/SVHC)[23]	*Inventory*	kg	6

Additional impacts considered in MEErP are the following physical impacts during use phase: Noise: sound power level; Vibration: frequency and amplitude; EMF: electro-magnetic field.

[20] Among mineral resources, MEErP considers only critical raw materials CRM, which are specifically relevant for energy-related products
[21] Please note that the three indicators are expressed in the same unit, but the characterisation models behind are different, so results should not be compared quantitatively
[22] MEErP accounts for: Total primary energy (as Gross Energy Requirement – GER); electricity (primary energy); heating energy (fossil fuels, Net Calorific Value)
[23] Hazardous substances (HS) and substances of very high concern (SVHC) considered: Cadmium, Lead, Mercury, Hexavalent Chromium, Polybrominated biphenyls (PBB) and Polybrominated diphenyl ethers (PBDE).

9.2 Comparison of results

The results of life cycle assessment (run with the LCIA method ILCD v. 1.08 and EF 3.0) of the products included in the BoP Appliances have been compared with the results obtained in the Ecodesign preparatory studies (run with MEErP 2011). When comparing the results, it has to be considered that:

- the representative products in the BoP have been modelled according to the assumptions and input data used the Ecodesign preparatory studies, as much as possible. However, there are some differences in the modelling of the EoL and recycling credits (as explained before) and in the datasets used. Therefore, the final LCI in the two cases is not exactly the same.
- the two approaches rely on a different set of indicators, characterization models and, consequently, units of measure. The only indicator for which results of ILCD and MEErP can be directly compared is climate change (GWP), based on IPCC (2007) model and expressed in kg CO_2 eq. The only indicator for which results of EF 3.0 and MEErP can be compared is the Gross Energy Requirement (GER) (calculated as ADP fossil in EF 3.0), expressed in MJ. These results are reported in Table 124 and Table 125.
- even if the results of other indicators are not directly comparable, it is interesting to see if the two approaches converge in identifying the most relevant life cycle phases in the product life cycle analyzed. However, the Consumer Footprint accounts for the benefit of recycling entirely at the EoL, whereas MEErP accounts for the benefit of material recycled content at the production (material) stage and at the EoL. Moreover, MEErP includes the two stages of the Consumer Footprint "Raw material component" and "Production" in one single stage, called "Production".

The following tables report the comparison of results for the representative products included in the BoP appliances. Notebook, LCD TV screens, and PV panels are not included because MEErP results for these two products were not available when the analysis was performed. The unit of analysis is one piece of appliance.

Table 124. Comparison of climate change (GWP) results calculated with ILCD and MEErP

Appliances	GWP (kg CO_2 eq)		
	Consumer footprint (ILCD)	MEErP 2011	Difference
Dishwasher 10 ps	3.14E+03	1.81E+03	-43%
Dishwasher 13 ps	3.18E+03	2.02E+03	-37%
Washing Machine	2.09E+03	1.47E+03	-30%
Electric condenser tumble dryer	3.26E+03	2.16E+03	-34%
Combined refrigerators-freezers	2.52E+03	2.49E+03	-4%
Air conditioner, single split	4.39E+03	3.30E+03	-25%
Electric oven (built-in)	1.72E+03	1.55E+03	-10%
Compact fluorescent lamp	3.79E+01	2.30E+01	-39%
Incandescent lamp	2.69E+01	2.10E+01	-22%
Halogen lamp, low voltage	3.61E+01	2.70E+01	-25%
Halogen lamp, mains voltage	2.72E+01	2.10E+01	-23%
LED	1.58E+01	9.80E+01	521%

Table 125. Comparison of Gross Energy Requirement results with EF 3.0 and MEErP

Appliance	Gross Energy Requirement (MJ)		
	Consumer Footprint (EF 3.0)	MEErP 2011	Difference
Dishwasher 10 ps	6.68E+04	3.98E+04	-40%
Dishwasher 13 ps	6.75E+04	4.44E+04	-34%

Washing Machine	4.04E+04	3.21E+04	-21%
Electric condenser tumble dryer	7.22E+04	4.81E+04	-33%
Combined refrigerators-freezers	5.54E+04	5.47E+04	-2%
Air conditioner, single split	7.44E+04	5.34E+04	-28%
Electric oven (built-in)	3.81E+04	3.45E+04	-9%
Compact fluorescent lamp	8.32E+02	5.29E+02	-36%
Incandescent lamp	6.12E+02	4.88E+02	-20%
Halogen lamp, low voltage	8.21E+02	6.30E+02	-23%
Halogen lamp, mains voltage	6.17E+02	4.89E+02	-21%
LED	2.44E+02	2.28E+03	+834%

The results of GWP and GER for the products compared are quite different for the two methods. Results of the assessment with MEErP are generally smaller (up to 40% less) than the ones with ILCD and EF 3.0, with the exception of LED, for which anomalous results are observed due to much higher results for the use phase when using MEErP. The causes of this difference can be both at the inventory and at the impact assessment. Firstly, the inventory used for the Consumer Footprint is generally more detailed than the one used for the Ecodesign preparatory studies. Secondly, the number of flows characterized by ILCD and EF 3.0 is larger than the ones characterized by MEErP. These differences can be considered valid for a more general comparison of LCA and MEErP studies, as confirmed also by the results of the comparison done between MEErP and LCA (with Eco-indicator 95 method) in the context of the preparatory study for refrigerators (VHK, 2015). Looking at the contribution of life cycle phases to the impacts considered in the two methods, there is a general convergence in identifying the use phase as the most relevant one, followed by the production phase. Even if the ranking of the life cycle phases is generally the same in the results of the two approaches, the relative shares of each phase vary between the two. The most relevant differences are:

- Climate change: the share of production is a bit higher in MEErP than in ILCD (around 20%, instead of 10%) for the dishwasher (10 ps and 13 ps) and the refrigerator. On the contrary, it is lower (around 20% in MEErP, compared to about 40% in ILCD) for the washing machine. The relative importance of the use phase changes accordingly.
- Particulate matter: the most relevant phase for each of the products considered is distribution and retail according to MEErP (with contributions ranging from 30% for the dishwashers up to 80% for the refrigerator), whereas ILCD identifies the use phase, followed by the production phase, as the most relevant ones. A possible explanation for this discrepancy may be the use of more detailed inventories for all the life cycle phases and the use of a larger set of characterization factors (including PM precursors) in the case of ILCD, i.e. the possibility to better consider direct and indirect emissions coming from the production and use phases.
- Acidification: the contribution of the production phase is generally lower in MEErP than in ILCD (with the exception of the refrigerator). The relevance of the use phase changes accordingly. This discrepancy could be due to the different characterization model applied in the two approaches and to the limited number of flows considered in MEErP.
- Eutrophication (freshwater eutrophication in ILCD): the relevance of the production phase is generally higher in MEErP than in ILCD, with the exception of the dishwasher (for which the use phase contributes to more than 70% of the eutrophication potential). EoL is also quite relevant for this impact category in the case of MEErP, whereas its contribution is generally negligible (or negative) in the case of ILCD.
- The EoL phase is generally more relevant (either as a source of impacts or of credits) in MEErP compared to ILCD. This difference might be explained by the focus that MEErP has on waste, which may lead to a more detailed compilation of the inventory for this life cycle phase compared to the Consumer Footprint.

10 Conclusion

The BoP appliances is composed by a selection of products that are considered representative of the European household consumption of energy-related products. The selected representative products cover the most relevant product groups in terms of energy consumption and market share, and it is in line with the list of product groups covered by the Ecodesign Directive (EC, 2009a).

The definition of average product for each product group allows for using a bottom-up approach, and analysing options for improvement at the product level.

The backbone of the LCA, the LCIs of the representative products in the basket, are largely based on the assumptions and bill of materials of the base case products considered in the Ecodesign preparatory studies, complemented with data from the literature when needed. On one hand, this choice ensures consistency among the product groups, on the other hand, this may limit the possibility to have very detailed inventories, as it is, for instance, for studies that investigated specific products and used data of the actual production site.

Differently from what was done for the other BoPs in the Consumer Footprint, which were based on a calculation of apparent consumption, the composition of the functional unit of the BoP, i.e. the amount of appliances allocated to an average EU citizen in the reference year (2010), is based on stock data from the Ecodesign preparatory studies, complemented with other sources of data when needed. Stock data were considered more reliable due to the uncertainty on the real lifetime of this kind of products, and the influence that this may have on the calculation of the annual apparent consumption starting from Eurostat data.

The hotspot analysis done following the recommendations in the guidelines of ILCD and EF 3.0 impact assessment methods confirmed the high relevance of the use phase over the other life cycle phases considered, due to electricity use. Within the use phase, the energy efficiency of products and consumer behaviour (i.e. intensity of use) are the two factors that determine the impact. Large appliances, such as washing machines, refrigerators, TV screens, dishwashers and lighting are the product groups that contribute the most to the overall impact of the BoP appliances. This is partially due to their specific impact per unit and partially to the high number of those appliances owned by an average EU citizen. The environmental profile of the PV system included in the study is dominated by the impacts due to the production of the PV modules.

The impact on resource depletion, and specifically on energy carriers – when this type of resources is assessed separately - is the most relevant one among the impact categories considered in the two methods. Washing machines, LCD TV screens, and dishwashers are the products related to most of the resource impact, irrespectively of the resource impact assessment methods.

Starting from these results, a set of scenarios was developed, acting on energy efficiency of appliances, less harmful refrigerants for the air conditioning units, the use of renewable energy sources, user behaviour and solutions in the field of domotics. Several combinations of these options have been tested, together with the variation of the stock that is expected for the future (e.g. higher number of appliances per household, increased dimension of the average product, etc.).

The scenarios on improved energy efficiency of the representative products (i.e. in line with the requirements of the Ecodesign directive) showed that there is a good savings potential (around 10%-20%) for most of the impact categories. The greatest potential appears to be on the reduction of the ozone depletion from the use of refrigerants in air conditioning units: scenario 6, which assumes the substitution of the current average refrigerant (R134a) with a less impacting one (namely R600a - isobutane), shows a potential reduction of 60% for ozone depletion, compared to the baseline scenario. Scenarios acting at the end of life, assuming increased remanufacturing and reuse of devices and higher collection and recycling rates (as implementation of the WEEE directive), show in general a smaller saving potential (below 10%) compared to the other scenarios. Scenario 1, on the use of a more renewable electricity mix, using a forecast of the EU energy mix in the year 2030, shows a reduction in most of the impact categories, but also an increase of the impact on land use and resource depletion, due to the different mix of resources used as input to the electricity production system.

A similar trade-off is showed in the combined scenarios 10 and 11. Scenario 11 can be considered as an overall summary of the effects of all the measures and changes tested on the BoP appliances, because it includes the improvements in energy efficiency, the change in the composition of the electricity mix, specific improvements for products groups (e.g. less harmful refrigerants for the air conditioning and the increase share of LED for lighting), the change of users' behaviour and the expected change in the composition of the stock (i.e. increased number of appliances per household). The result of all these intervention is a significant reduction of impact for most of the impact categories (up to -65% for ozone depletion and around 34% for climate change). However, the impact on land use, freshwater ecotoxicity, and resource depletion (minerals and metals) is larger than in the baseline.

It should be highlighted that uncertainties and limitations related to the representativeness of the products included in the BoP, the datasets and assumptions used to model the inventory of representative products and robustness of the impact assessment methods used, could play an important role in the calculated results. Those uncertainties are not quantitatively assessed in this report.

It is consider overall that the main conclusions drawn from this analysis on the Basket-of-Product indicator for appliances are reliable as they use the state-of-the-art LCA and are relevant to support several policies, such as the Ecodesign Directive (EC, 2009) and WEEE Directive (EU, 2012a), but also for policies with a broader scope, such as those related to resource efficiency (EC, 2011b), critical raw materials (EC, 2011a), energy efficiency (EU, 2012b) and circular economy (EC, 2015). Moreover, the structure of the Consumer Footprint and the possibility to develop scenarios acting on user behaviour is of particular importance for policies in the area of sustainable consumption and in light of the current increasing interest in behaviour-oriented policies.

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List of abbreviations and definitions

ABS	Acrylonitrile butadiene styrene
ADP	Abiotic Depletion Potential
AP	Acidification (impact category)
BoM	Bill of Materials
BoP	Basket of Product
CdTe	Cadmium-Tellurium
CED	Cumulative energy demand (impact category)
CFL	Compact fluorescent lamps
CF	Characterisation Factor
CFC	Chlorofluorocarbons
CLRTAP	Convention on Long Range Transboundary Air Pollution
COP	Coefficient of Perfomance
CRM	Critical Raw Material
CRT	Cathode-ray Tube
EF	Environmental Footprint
ELCD	European Reference Life Cycle Database
EoL	End of-Life
EPS	Expandable Polystyrene
FU	Functional Unit
FEP	Freshwater eutrophication (impact category)
FETP	Freshwater ecotoxicity (impact category)
FRD	Fossil resource depletion (impact category)
GER	Gross Energy Requirement
GLS	Incandescent lamps
GWP	Climate change (impact category)
HID	High intensity discharge lamps
HL	Halogen lamps
HM	Heavy Metal
HS	Hazardous substances
HTP c	Human toxicity, cancer effects (impact category)
HTP nc	Human toxicity, non-cancer effects (impact category)
IEE	Intelligence Energy Europe
ILCD	International Life Cycle Data System
IPCC	Intergovernmental Panel on Climate Change
IRP	Ionizing radiation effects, human health (impact category)
LCA	Life cycle assessment
LCD	Liquid-crystal display
LCI	Life cycle inventory
LED	Light emitting diodes
LFL	Linear fluorescent lamps
LUC	Land use changes (impact category)
MEErp	Methodology for Ecodesign of Energy related Products
MEP	Marine eutrophication (impact category)
MFH	Multi-Family House
MRD	Mineral resource depletion (impact category)
NFs	Normalisation factors
NMVOC	Non-Methane Volatile Organic Compound
ODP	Ozone depletion (impact category)
PA6	Polycaprolactam (Nylon 6)
PAH	Polycyclic Aromatic Hydrocarbons
PC	Polycarbonate
PCB	Printed Circuit Board
PE	Polyethylene
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category rules
PET	Polyethylene terephthalate
PMMA	Polymethyl methacrylate
PMFP	Particulate matter (impact category)
POFP	Photochemical ozone formation (impact category)
POP	Persistent Organic Pollutant
PP	Polypropylene
ps	place setting

PS	Polystyrene
PUR	Polyurethane
PV	Photovoltaic
PVC	Polyvinyl chloride
PWB	Printed Wiring Board
RD	Combined (mineral, fossil and renewable) resource depletion (impact category)
SFH	Single-Family House
SVHC	Substances of Very High Concern
TEP	Terrestrial eutrophication (impact category)
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
WEEE	Waste Electrical and Electronic Equipment
WMO	World Meteorological Organisation
WRD	Water resource depletion (impact category)

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Annex 1. Additional information for dishwasher

For the product "dishwasher", the BoP includes two models corresponding to the base cases modeled in the last preparatory study for Ecodesign requirements development[24] (hereinafter the preparatory study), namely a dishwasher 10 place setting (ps) and a dishwasher 13 ps.

Assumptions for the production of materials/components

The Bill of Materials components (BoM) is taken from the preparatory study (published on http://susproc.jrc.ec.europa.eu/Dishwashers/index.html in October 2015). However, in the BoP model, the following materials/components are not included:

- Crepe tape
- Double-sided adhesive tape
- Silicon, liquid silicon.

They overall represent an amount lower than 0.03% of the total mass. These materials/components were not included in the assessment conducted in the context of the preparatory study. In the present study these materials/components are excluded because proper datasets to represent them were missing in Ecoinvent.

The electronic part is a controller board. The composition of the controller board is assumed to be:

- Cable (38%)
- PCBs (37%)
- Steel – housing (24%)
- Plastic (1%)

This composition has been derived by mixing the average composition of the "electronic for control units/RER" in Ecoinvent and the average composition of the electronic part for Dishwasher found in literature (Tecchio et al. 2016).

The BoM for both of dishwasher 13 and 10 ps is reported in Table 126 and Table 127.

Table 126. BoM of the dishwasher 13ps, including packaging

Material component	Amount (kg)	Note
Ferrous metals	21.553	Steel, galvanized steel and ferrite
Non ferrous metals	5.831	Copper and copper-zinc (CuZn)

[24] Working document accessed at http://susproc.jrc.ec.europa.eu/Dishwashers/documents.html in March 2017

Plastics	10.862	ABS, PE, PS, PMMA, PA6, PC, PP, PUR, E-glass fiber, PET
Electronic	1.381	Cables, PCB, steel and PVC
Cardboard and paper	2.738	
Bitumen	5.400	
Tot	47.767	
Product Packaging	**Amount (kg)**	**Note**
Cardboard and paper	0.407	
Plastics	0.926	EPS and PE
Tot	1.33	

Table 127. BoM of the dishwasher 10ps, including packaging

Material component	Amount (kg)	Note
Ferrous metals	18.921	Steel, galvanized steel and ferrite
Non ferrous metals	5.829	Copper and copper-zinc (CuZn)
Plastics	8.431	ABS, PE, PS, PMMA, PA6, PC, PP, PUR, E-glass fiber, PET
Electronic	1.205	Cables, PCB, steel and PVC
Cardboard and paper	2.178	
Bitumen	4.954	
Tot	41.522	
Product Packaging	**Amount (kg)**	**Note**
Cardboard and paper	0.305	
Plastics	0.768	EPS and PE
Tot	1.073	

Assumptions for the manufacturing of the product

The electricity and heat for the manufacturing of the dishwasher is taken from an older preparatory study for dishwashing and washing machine (ISIS, 2007a) because the most recent one does not include this information.

Assumptions for the use phase

Based on information reported in the preparatory study[25], the use phase of the dishwasher includes 280 washings per year. Each cycle, includes the consumption of 20g of detergent, 3g of rinsing agent and 19g of regeneration salt.

It has been assumed that each cycle is conducted in the same conditions as specified for the detergent model of the Ecolabel background study (Arendorf et al., 2014a), i.e. normal program, at 60 degree. The electricity and water consumption are 1.42 kWh and 18.5 L, respectively.

The rinsing agent has been modeled with the process "Chemical, inorganic {GLO}| production | Alloc Def, U".

Assumptions for the maintenance

It is assumed that in the maintenance phase 1% of the product's materials is replaced.

Assumptions for the EoL of Dishwasher

The end of life of the product occurs after 12.5 years of service life. The preparatory study does not provide a specific EoL scenario. It just provides rates for recycling, reuse, landfill and incineration for the different materials and does not consider the energy (electricity) consumption for the shredding and sorting of the different materials/components. Therefore, additional sources were used to model this stage.

[25] Working document accessed at http://susproc.jrc.ec.europa.eu/Dishwashers/documents.html in March 2017

Firstly, it is important to underline that a defined scenario does not exist. A study was developed in Italy (Biganzoli et al, 2015) concerning the WEEE management and including the category "large household appliances", for which the following steps were identified: i) manual dismantling to remove cables, concrete, counterweight, wood and capacitor, ii) shredding, iii) manual sorting to obtain ferrous metal, non-ferrous metal and plastic. The mixed flow "PS plastic + metals" is then further treated (material separation process, energy consuming, not specified) to sort residues of aluminum/copper. The fractions remaining after this sorting process (PS and plastic mixture) are not further separated and are sent to energy recovery. As far as the Printed Circuit Boards (PCBs) is concerned, they are not included in the list of components/materials taken out before the shredding. In different studies by the EC-JRC (Tecchio et al 2016; Ardente and Talens Peiró, 2015), in the shredding-based scenario a two-steps shredding process (pre-shredding and shredding) is assumed. In this scenario, the external cables are manually removed before the pre-shredding and PCBs and capacitors are hand-picked after the pre-shredding. All materials in output from the second step of the shredding are mechanical separated (ferrous, non ferrous, plastic and residuals), sent to further sorting (e.g. density separation for plastic) and, in the end, to recycling treatment.

In the present study, a shredding process is supposed for the whole product (materials and components). The related electricity consumption (modeled as described in the general assumptions) is considered for all materials/components entering S and R systems. The recycling, reuse, landfill and incineration rates from preparatory study[26] were applied with few variations/integrations as below specified:

i) The bitumen is part of the category "Miscellaneous" for which a recycling rate is specified. However, it is not recyclable, thus the share theoretically recyclable is moved to landfill.
ii) Cardboard and paper are part of the Miscellaneous, and are partly (according to the recycling rate specified for the category) sent to recycling, even if the preparatory study specifically define them as not recyclable.

Finally, in order to account for the amount of precious metals recoverable, PCBs at EoL are assumed to have the average composition reported by Ardente et al 2015.

Upscaling to the stock of the BoP appliances

The preparatory study reports the stock data at 2010, based on information by VHK (2014). Moreover, the market share of each Dishwasher size is reported. As 9-10 and 12-13ps have the highest shares of the market, the 13ps model has been selected to represent Dishwashers of size ≥ 12 ps and the 10ps model to represent Dishwashers of size ≤ 11ps. Thus, it results that the Dishwasher 13ps covers the 85% of the stock whereas the remaining 15% is covered by the Dishwasher 10ps.

In order to account for the annual impact from the consumption/use of appliances at EU level, the LCI of the product is divided by its life time, multiplied for the stock and for its stock share (Table 128).

Table 128. Total stock for Dishwashers and amount accounted for in the BoP

Total stock (unit)	**% of DW 13ps**	**% of DW 10ps**
82,799,000	85	15
Use stage (years)	**Share of life cycle to be accounted for in the BoP**	
12.5 years	1/12.5 = 0.08	1/12.5 = 0.08
Volume to be accounted for in each life cycle stage	**1/12.5 * 82,799,000*0.85 = 563,0332**	**1/12.5 * 82,799,000*0.15 = 993,588**

[26] Working document accessed at http://susproc.jrc.ec.europa.eu/Dishwashers/documents.html in March 2017

Annex 2. Additional information for washing machine

For the product "washing machine", the BoP includes one model corresponding to the base case modeled in the last preparatory study for Ecodesign requirements development[27] (hereinafter the preparatory study), namely a washing machine of 7 kg capacity.

Assumptions for the production of materials/components

The Bill of Materials (and components) (BoM) is taken from the preparatory study, published on http://susproc.jrc.ec.europa.eu/Washing_machines_and_washer_dryers/index.html, in November 2015. For the talcum filler, it has been used the LCI provided in Hischier et al., 2015.

The BoM of the washing machine for the BoP is reported in Table 129.

Table 129. BoM of the washing machine, including packaging

Material component	**Amount (kg)**	**Note**
Ferrous metals	28.527	Steel, galvanized steel and iron
Non ferrous metals	4.082	Copper and aluminum
Glass	1.87	
Concrete	20.186	
Plastics	11.796	ABS, PP, PE, PVC, PET, PMMA, PA6, Talcum filler, E-glass fiber, PET, PUR
Electronic	0.225	PCB
Tot	66.686	
Product Packaging	**Amount (kg)**	**Note**
Cardboard and paper	2.276	
Plastics	0.64	EPS and PE
Tot	2.916	

Assumptions for the manufacturing of the product

The preparatory study does not consider the electricity, heat and water for the manufacture of the product. Consistently with the work done for the Dishwashers, energy consumption for manufacturing has been taken from ISIS 2007a, although the washing machine in that report is different in capacity and overall mass. However, a similar approach has also been applied in Tecchio et al. (2016).

Assumptions for use phase

Based on information reported in the preparatory study, the use phase of the washing machine includes 220 washings per year. Each cycle includes the consumption of 75 ml (or g) of detergent.

It has been assumed that washing cycles are conducted in the same conditions specified for the considered detergents. More in detail, 50% of the cycles are assumed to be done with the powder detergent, which is based on the reference product of the Ecolabel background study (Arendorf et al., 2014b). The remaining cycles (50%) are assumed to be done with the liquid detergent from the screening report of the PEF pilot on household heavy duty liquid detergents. The washing cycle assumed in both cases corresponds to a normal washing at 40 degrees, requiring 0.638 kWh of electricity and 50 L of water.

Assumptions for the maintenance

It is assumed that in the maintenance phase 1% of the product's materials is replaced.

Assumptions for the End of Life

[27] Working document accessed at http://susproc.jrc.ec.europa.eu/Washing_machines_and_washer_dryers/documents.html in March 2017

The end of life of the product occurs after 12.5 years. The EoL scenario is similar to that one for the Dishwashers. For Printed Circuit Boards (PCBs) the same assumptions done for Dishwashers are considered.

The glass fiber filler is modeled as glass-fibre. For this material as well as for the talcum filler, the recycling, reuse, incineration, energy recovery and landfill rates for plastics are applied. However, as the preparatory study defines it not recyclable, the share theoretically recyclable/reusable is assumed to be incinerated.

Upscaling to the stock of the BoP appliances

The preparatory study report the stock data at 2010, based on information by VHK, 2014. The modeled case study is considered representative of the whole market and thus it is assumed to cover the 100% of the stock (Table 130).

Table 130. Total stock for washing machines and amount accounted for in the BoP

Total stock (unit)	**% of washing machines covered by the case study**
185,828,000	100
Use stage (years)	**Share of life cycle to be accounted for in the BoP**
12.5 years	1/12.5 = 0.08
Volume to be accounted for in each life cycle stage	**1/12.5 * 18,582,800 = 1,486,624**

Annex 3. Additional information for laundry dryer (tumble dryer)

For the product "laundry dryers", the BoP includes one model corresponding to one of the base cases modeled in the last preparatory study for Ecodesign criteria development (Ecobilan - PricewaterhouseCoopers, 2009), hereinafter the preparatory study, namely a (electric) condensed laundry drier of 3.4 kg capacity. The chosen product is the most used as it results from data presented in the section "upscaling to the stock of the BoP appliances".

Assumptions for the production of materials/components

The Bill of Materials (and components) (BoM) is taken from the preparatory study.

The component "other" in the category "bulkplastic" has been modeled as PVC, whereas the component "other" for which the category is not specified has been modeled as glass, assuming that it could be the round window as in the washing machine. The composition of the packaging is not specified. Thus, it has been assumed similar to that one of the washing machine, which also has similar size. The total weight of packaging is 2.9 kg. It has been considered made of wood, coated (77%), packaging EPS (18%) and LDPE (5%).

It is assumed that the electronic is composed by steel, PCB, cables and plastic. This composition is retrieved from the Ecoinvent process "electronic for control unit/RER", however the percentages of each component have been revised, based on Tecchio et al. (2016). Thus, cables are the 38% of the electronic mass, PCB is the 37%, 24% is assumed steel (in Tecchio et al. 2016 this % includes 8.6% of motor, 2% of display and 13.4% of other electronics), whereas the remaining 1% is plastic and it is assumed PVC. For the PCB the Ecoinvent process "Printed wiring board, surface mounted, unspecified, Pb free {GLO}| market for | Alloc Def, U" is used.

The BoM of the laundry dryer is reported in Table 131.

Table 131. BoM of the laundry dryer, including packaging

Material component	**Amount (kg)**	**Note**
Ferrous metals	23.473	Steel, galvanized steel
Non ferrous metals	1.363	Copper and aluminum

Glass	1.856	
Plastics	13.478	ABS, PP, PS, PVC, PUR, PA6, PC, PMMA
Electronic	1.987	Cables, PCB, steel and PVC
Tot	42.159	
Product Packaging	**Amount (kg)**	**Note**
Cardboard and paper	2.233	
Plastics	0.667	EPS and PE
Tot	2.900	

Assumptions for manufacturing of the product

No data are provided for the assembly. Energy and heat inputs have been assumed similar to that one of washing machine.

Assumptions for use phase

As the preparatory study were conducted in 2008 (with data related to 2005), data from VHK, 2016 (related to 2010) are considered more representative for the average situation in 2010. The electricity consumption for the electric condensed laundry dryer at 2010 is derived from the graphic on the average annual electricity consumption of laundry dryers and is 450 kWh/year.

Assumptions for the maintenance

It is assumed that in the maintenance phase 1% of the product's materials is replaced.

Assumptions for the EoL

The EoL occurs after 13 years. The EoL scenario is similar to that one for Dishwashers and washing machines. For PCBs the same assumptions done for Dishwashers are considered.

Upscaling to the stock of the BoP appliances

Quantitative data about the characteristics of the stock are not reported in the preparatory study. However, the preparatory study report sales data at 2005, confirming that (electric) condensed laundry dryers cover respectively the 55% of total sales in Western Europe (and 75.1% in Eastern Europe). VHK (2016) reports the stock at 2010. It also reports that sales of electric condensed laundry dryers were, at Europe level, 60% of total sales. The stock reported by VHK (2016) was considered for the BoP. The % of sales for electric condensed laundry dryers by VHK (2016) was applied (Table 132).

Table 132. Total stock of laundry dryers and amount accounted for in the BoP

Total stock (unit)	**% of laundry driers covered by the case study**
63,037,000	60
Use stage (years)	**Share of life cycle to be accounted for in the BoP**
13 years	1/13 = 0.0769
Volume to be accounted for in each life cycle stage	**1/13 *0.6* 63,037,000= 2,909,400**

Annex 4. Additional information for the refrigerator

For the product "refrigerator", the BoP includes one model corresponding to one of the base cases modeled in the last preparatory study for Ecodesign requirements development (VHK, 2015), hereinafter the preparatory study, namely a combined refrigerator-freezer. This model is identified in the preparatory study as COLD 7 as it covers the category 7 and 6 (partly) of the household refrigerating appliances categories defined by the EC Regulation n. 643/2009. As showed in the section "upscaling to the BoP", the selected product is the most representative.

Assumptions for the production of materials/components

The Bill of Materials (BoM) is taken from the preparatory study. The lubricating oil is not modeled as well as the fraction of materials classified as "other", which includes a mix of not specified plastic, adhesive taper, dessicant, glue, magnet, hermostat, others. The total excluded mass accounts for less than 1% (in mass). For the glass for lamp, we used a dataset about packaging glass.

The BoM for the refrigerator in the BoP is reported in Table 133.

Table 133. BoM of the refrigerator, including packaging

Material component	**Amount (kg)**	**Note**
Ferrous metals	34.094	Steel, galvanized steel and iron
Non ferrous metals	3.965	Copper and aluminum
Glass	6.966	
Paper	0.307	
Plastics	23.657	ABS, EPS, PP, PE, PVC, PUR, PA6, PMMA
Capacitor	0.022	
Electronic	0.365	Cables, PCB, steel and PVC
Refrigerant	0.049	
Coating	0.224	
Tot	69.649	
Product Packaging	**Amount (kg)**	**Note**
Cardboard and paper	2.940	
Plastics	1.705	EPS, PP and PE
Tot	4.645	

Assumptions for the manufacturing of the product

The energy inputs for the manufacturing of the product include electricity and heat and are retrieved from the old preparatory study for the household refrigeration (ISIS, 2007b).

Assumptions for the use phase

Stock data at 2010 are reported in VHK (2016) together with the total annual energy consumption. By dividing the consumption for the stock, the annual average energy consumption (AEC) of a unit is 347.49 kWh/year (for the 2010). However, this average consumption includes the stock of all household models. In the preparatory study, conducted in 2015 the AEC by unit of sales is provided for 2005 and 2014. Also stock data for 2005 and 2014 are reported and the represented model (COLD 7) at 2014 covers the 56% of the stock. For the BoP, the AEC at 2010 has been calculated by interpolating AEC between 2005 and 2014 for COLD7 model (290.11 kWh/y) (Table 134).

Table 134. Definition of the energy consumption by a refrigerator (COLD7) at 2010.

Average electricity consumption (kWh/y)	Delta consumption between 2014 and 2005 (kWh/y)	Delta years	Average Electricity consumption in2010 (kWh/y)
329 (in 2005)	70	9	= 329 - (70/9 * 2010-2005) = 290
259 (in 2014)			

Assumptions for the maintenance

It is assumed that in the maintenance phase 1% of the product's materials is replaced.

Assumptions for the EoL

In the preparatory study a specific EoL is not mentioned, however the shredding of the base cabinet (in a closed environment) is mentioned as one of the most common solutions to recover the polyurethane and polystyrene (PUR-PS) fraction. Thus, the EoL scenario includes a phase of manual dismantling where cables, compressors and refrigerants are taken out and a shredding stage from which metals and plastics are separated.

In our BoP it has been considered that the refrigerant is taken out (as it has to be properly disposed by law) and the appliance is sent to shredding. We applied the recycling, reuse, incineration, energy recovery and landfill rates applied for Dishwashers and washing machines, considering them applicable to all large appliances.

The EoL occurs after 15 year of service life. The coating is supposed to be applied to the aluminum and, as such, it is supposed to be in the aluminium flow at EoL, both for recycling and for landfill.

Upscaling to the stock of the BoP appliances

The overall stock of refrigerators is reported in VHK (2010). However, the source does not report more detailed information (stock for refrigerators typology). For this reason, it was considered that, as in 2014, 56% of the stock is composed by COLD7 (Table 135).

Table 135. Total stock of refrigerators and amount accounted for in the BoP

Total stock (unit)	**% of refrigerators covered by the case study**
299,289,000	56
Use stage (years)	**Share of life cycle to be accounted for in the BoP**
15 years	1/15 = 0.0667
Volume to be accounted for in each life cycle stage	**1/15*0.56* 299,289,000 = 11,173,456**

Annex 5. Additional information for the room air conditioner (RAC)

For the product "room air conditioner", the BoP includes one model corresponding to one of the base cases defined in the preparatory study for Ecodesign requirements development, namely a reversible air conditioner in the 0-6 kW range (ARMINES, 2008). The selected product is considered to be the most representative. More in detail, the model represents a reversible single split unit with cooling capacity of 3.5 kW.

Assumption for the production of materials/components

The Bill of Materials reported in ARMINES (2008) provides just an average composition in terms of material class (e.g. ferro metals, non ferro metals, bulk plastics, electronics, etc), without any detail level on the specific materials. However, the average weight of the Room Air Conditioner is defined, namely 14 kg/kW, of which 10 kg/kW for the outdoor unit and 4 kg/kW for the indoor unit. Based on this information it was possible to account for the total weight of a 3.5 kW RAC (49 kg, of which 35 for the outdoor unit and 14 for the indoor unit). For a more detailed definition of the Bill of Materials we referred to other literature sources, namely Grignon-Masse' et al. 2011 and Almutairi et al. 2015. More in detail, Grignon-Masse' et al. 2011 provides additional information on the type and amount of refrigerant used by a room air conditioner, whereas Almutairi et al. 2015 provides a list of materials and their weight (%) on the total weight of the conditioner.

The BoM for the RAC in the BoP is reported in Table 136.

Table 136. BoM of the room air conditioner, including packaging

Material component	**Amount (kg)**	**Note**
Ferrous metals	22.050	Steel, galvanized steel and iron
Non ferrous metals	11.760	Copper and aluminum
Plastics	8.076	ABS, EPS, PP, PE, PVC, PUR, PA6, PMMA
Coating	0.229	
Refrigerant	1.200	
Electronic	1.470	Cables, PCB, steel and PVC
Tot	44.785	
Product Packaging	**Amount (kg)**	**Note**
Cardboard and paper	3.018	
Plastics	0.902	EPS, PP and PE
Tot	3.920	

For materials processing the following assumptions were made by the authors of this study:

- for copper: 50% is considered in tube and 50% in wire
- for steel: all steel (iron, stainless, and steel) is considered in sheet (sheet rolling process)
- for aluminium: it is adopted a casting process
- for plastic: it is assumed an average injection moulding.

The following other assumptions were made:

- the High Impact Polystyrene (HiPS) is modeled as polystyrene (PS).
- the polybutylene terephthalate (PBT) is modeled as PET.
- the lacquer is a coating (solvent-based) and it is supposed applied on the aluminium; it is modeled as Alkyd paint.
- It is assumed that the electronic part is composed by steel, PCB, cables and plastic. This composition is retrieved from the Ecoinvent process "electronic for control unit/RER", however the percentages of each component have been revised, based on Tecchio et al. (2016). Thus, cables are the 38% of the electronic mass, PCB is the 37%, 24% is assumed steel (in Tecchio et al. 2016 this % includes 8.6% of motor, 2% of display and 13.4% of other electronics), whereas the remaining 1% is plastic and it is assumed PVC.

- For the PCB the Ecoinvent process “Printed wiring board, surface mounted, unspecified, Pb free {GLO}| market for | Alloc Def, U” is used.
- the component “other” is not modeled.
- the packaging represents 8% of the overall weight and it is assumed made of wood, coated (77%), packaging EPS (18%) and LDPE (5%).

Assumption for the manufacturing

The same average energy intensity for manufacturing reported in Almutairi et al. 2015 was assumed in the BoP.

Assumption for the distribution and Retail

The share of import on apparent consumption is 57%. As specified in the general assumptions, for the share of product coming from outside EU, the transport is modeled according to PEFCR rules for the international supply chain.

Assumptions for the use phase

The energy consumption is taken by VHK (2016) and it is expressed in kWh/year for a unit. It is calculated by dividing the energy consumption in cooling mode by the total stock of room air conditioning.

A service life of 15 years is assumed, as reported in Almutairi et al. (2015).

Assumptions for maintenance

It is assumed that in the maintenance phase 1% of the product’s materials is replaced. This is not specified in the preparatory study, however the same assumption is always adopted for other household appliances. For the refrigerant, it is assumed a leakage of 50% during the service life (Almutairi et al., 2015).

Assumptions for EoL

It occurs after 15 years. The EoL scenario is similar to that one for refrigerators. For PCBs the same assumptions done for Dishwashers are considered.

Upscaling to the stock of the BoP appliances

According to data reported in ARMINES (2008), the residential market is dominated by single split units: 85% of residential power for air conditioning is associated to single split units, followed by 11% moveable units. It is important to underline that these percentages take into accounts the room air conditioning appliances below 12kW, that are the ones of major use in the residential sector.

The stock of residential room air conditioners is calculated by multiplying the dwelling stock reported in the BoP Housing for the penetration rate of air conditioning system in residential, i.e. the share of dwellings, in ther EU, having the air conditioning system (based on the reworking of data from ODYSSEE - IEE Project ODYSSEE database - for the reference year 2010). The final arising European penetration rate of air conditioning systems for the BoP model is 14% (in line with the 12-15% reported by VHK, 2016). Finally, it is assumed that one unit is installed for each dwelling with air conditioning system and that the selected representative product covers 100% of the stock (Table 137).

Table 137. Total stock of room air conditioners and amount accounted for in the BoP

Total stock	**% of RACs covered by the case study**
28,077,000	100
Use stage (years)	**Share of life cycle to be accounted for in the BoP**
15 years	1/15 = 0.066667
Volume to be accounted for in each life cycle stage	**1/15 * 28,077,000 = 1,871,800**

Annex 6. Additional information for the electric oven

For the product "electric oven", the BoP includes one model corresponding to one of the base cases defined in the preparatory study for Ecodesign criteria development (BIO Intelligence Service, 2011), namely an electric oven of built-in (BI) type, which is considered the most representative for this product group.

Assumptions for the production of materials/components

The Bill of Materials is taken from the preparatory study (BIO Intelligence Service, 2011). It is assumed that the electronic is a PCB. It has been modeled with the Ecoinvent process "Printed wiring board, surface mounted, unspecified, Pb free {GLO}| market for | Alloc Def, U".

The BoM for the electric oven is reported in Table 138.

Table 138. BoM of the electric oven, including packaging

Material component	**Amount (kg)**	**Note**
Ferrous metals	22.095	Steel, galvanized steel and ferrite
Non ferrous metals	1.434	Copper and aluminum
Glass	4.12	
Plastics	0.643	PVC and E-glass fiber
Electronic	0.125	PCB
Tot	28.418	
Product Packaging	**Amount (kg)**	**Note**
Cardboard	1.2	
Office paper	0.11	
Ferrous metals	1.08	
Tot	2.39	

Assumptions for the Manufacturing of the products

Since input data for oven assembly are missing in the preparatory study, we applied the same electricity input (kWh/kg) used for washing machine 13 ps.

Assumptions for the Use phase

The use phase includes the energy consumption. Consumption data reported in Bio Intelligence Service 2011 are considered. More in detail, the electricity consumption is 164 kWh/year and it considers the following use mode:

— Electricity consumption per cycle: 1.1 kWh

— Number of cycle per year: 110

— Average duration of a cycle: 55 min

— Number of hours in stand-by mode: 8595

— Electricity consumption in stand-by mode: 0.005 kWh.

Assumptions for Maintenance and Repair

As for the other large domestic appliances, it is assumed that on average the 1% of materials is substituted during the lifetime.

Assumptions for EoL

The EoL occurs after 19 years. The same assumptions made for the other large domestic appliances are done. For PCBs the same assumptions done for Dishwashers are considered.

Upscaling to the stock of the BoP appliances

According to data reported in BIO Intelligence Service, 2011, the total number of convection ovens at 2010 (estimate done in 2007) is about 216 million. This amount includes built-in (BI) electric ovens, BI electric cookers, free standing (FS) electric cookers, FS gas cookers and FS mixed cookers. The category BI electric ovens is the most important, with a total number of 97,878,595 units, about the 46% of the total stock (Table 139).

Table 139. Total stock of ovens and amount accounted for in the BoP

Total stock of ovens	**% of ovens market covered by the case study**
216,000,000	46
Use stage (years)	**Share of life cycle to be accounted for in the BoP**
19 years	1/19 = 0.053
Volume to be accounted for in each life cycle stage	**1/19*97,878,595 = 5,151,505**

Annex 7. Additional information for lighting

The category "lighting" include five types of lamps which are part of the preparatory study on lighting (VITO, 2017) and are among the most used in the residential sector:

1. Compact fluorescent lamp with integrated ballast - CFLi
2. Incandescent lamp – GLS (model GLS X, as it is the most used in domestic sector)
3. Low voltage halogen lamp – HLLV (model HLLVR, with reflector - R, as it is the most used among the low voltage ones)
4. Mains voltage halogen lamp – HLLM (model HLLME, as it is the most used among the mains voltage ones)
5. Light Emitting Diodes – LED.

Assumptions for the Production of materials/components

The Bill of Materials, for all included lamps, is taken from the Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements - Lot 8/9/19 (VITO, 2015).

CFLi

The copper has been used to represent the Cu/Ni/Cr coating. The input of gases is not modeled, because it is not specified the type of gas. Anyway, it accounts for less than 1% of the total mass. The used BoM for the CFLi is reported in Table 140.

Table 140. BoM of the CFLi, including packaging

Material component	**Amount (kg)**	**Note**
Glass	0.027	
Plastics	0.0137	PVC and Epoxy
Electronic	0.0146	PCB
Electronic	0.0002	Solder
Non ferrous metals	0.0022	Copper-Zinc (CuZn)
Coating	0.0004	Cu/Ni/Cr plating
Phosphors	0.0015	
Mercury	0.000003	
Tot	0.059	
Product Packaging	**Amount (kg)**	**Note**
Cardboard and paper	0.690	
Plastics	0.206	EPS and PE
Tot	0.896	

GLS (GLS X)

The getter (phosphoric acid) and the filament tungsten are not modeled as a proper material was not found in Ecoinvent They overall represent less than 1% of the total mass. The BoM of the GLS X lamp used in the BoP is reported in Table 141.

Table 141. BoM of the GLS X, including packaging

Material component	Amount (kg)	Note
Glass	0.022335	
Plastics	0.001292	PVC and Epoxy
Electronic	0.00015	Solder
Non ferrous metals	0.001058	Copper-Zinc (CuZn)
Coating	0.00005	Cu/Ni/Cr plating
Molybdenum	0.000013	
Argon gas	0.000137	
Tot	0.025	
Product Packaging	**Amount (kg)**	**Note**
Cardboard and paper	0.054	
Plastics	0.006	PET
Tot	0.06	

Halogen lamps (HLLVR and HLMVE)

As for the GLS, the gas filling and the filament tungsten are not modeled. They overall represent less than 1% of the total mass.

The BoM for the HLLVR and HLMVE are reported in Table 142 and Table 143, respectively.

Table 142. BoM of the HLLVR, including packaging

Material component	Amount (kg)	Note
Glass	0.02904	
Electronic	0.0001	Solder
Non ferrous metals	0.0005	Copper
Ferrous metals	0.000022	
Molybdenum	0.000055	
Cement	0.00025	
Tot	0.029	
Product Packaging	**Amount (kg)**	**Note**
Cardboard and paper	0.027	
Plastics	0.003	PET
Tot	0.03	

Table 143. BoM of the HLMVE, including packaging

Material component	Amount (kg)	Note
Glass	0.02081	
Electronic	0.0002	Solder
Non ferrous metals	0.00122	Aluminum and Copper
Ferrous metals	0.00037	Steel
Coating	0.00012	Cu/Ni/Cr plating
Cement	0.00145	
Tot	0.024	
Product Packaging	**Amount (kg)**	**Note**
Cardboard and paper	0.054	
Plastics	0.006	PET
Tot	0.06	

LED

No relevant assumptions are done for the LED. The BoM is reported in Table 144.

Table 144. BoM of the LED, including packaging

Material component	Amount (kg)	Note
Glass	0.015997	
Electronic	0.003728	LED filament

Electronic	0.023206	PCB
Electronic	0.000061	Solder
Plastics	0.029612	PC and Epoxy
Ferrous metals	0.00054	Cast iron
Non ferrous metals	0.076855	Aluminum and Copper-zinc (CuZn)
Tot	0.149	
Product Packaging	**Amount (kg)**	**Note**
Cardboard and paper	0.036	
Plastics	0.004	PET
Tot	0.04	

Assumptions for the Manufacturing of the product

The electricity needed for the assembly of all lamps is calculated based on the electricity used for the assembly of an LCD screen (4.79 kWh/kg). In fact, in the preparatory studies above mentioned it is not specified. The same approach has also been adopted in literature on LCA of lamps (Chen et al. 2017).

Assumptions for the use phase

For the use phase, a top-down approach has been applied.

We considered the overall electricity annual consumption for lighting in residential as it arises from the reworking of data from ODYSSEE (IEE Project ODYSSEE database). The annual consumption of electricity for lighting was distributed among the different lamp technologies used in the residential sector, proportionally to the installed power for each of them (% of installed power on the total installed power for Linear fluorescent lamps - LFL, Compact fluorescent lamps - CFL, Halogen lamps - HL, Incandescent lamps - GLS, High intensity discharge lamps - HID, Light emitting diodes - LED). Power installed for each lamp technology is reported in the last preparatory study (VITO, 2015) with reference to 2010.

The annual electricity consumption associated to each lamp technology was divided by the related average annual operating hours, as reported in VITO, 2015, to obtain the overall kW per light source. This value was divided for the average power of each light source so as to find out the total stock in residential. Finally, the electricity consumption associated to each lamp technology (as previous distributed) was divided by the related stock so as to find out the average annual electricity consumption by a single lamp.

Stock and consumption data are reported in the Annex 10 (excel file, sheet "lighting stock").

Assumptions for the maintenance

It is assumed that there is no maintenance phase for lamps.

Assumptions for the EoL

In the old preparatory studies (2006) is already mentioned that all compact fluorescent lamps should be collected separately. Average rates for recycling, reuse, incineration, energy recovery and landfill are specified for all materials. Also, an emissions of 80% of mercury to air considered is based on the EoL processing. For the other type of lamps the EoL scenario reported in the preparatory study is the domestic mixed waste.

In order to define the amount of fluorescent lamp addressed to proper treatment, the amount reported in the statistic on WEEE (Eurostat database env_waselee) for the category "lighting", were compared with the total stock of fluorescent lamp. It arises that just the 28% of the fluorescent lamp are properly disposed.

For this reason, the EoL of the CFLi is composed as follows:

- system S - it includes "domestic waste_S" and 'WEEE_S"; the % of each process expresses the rate of CFLi addressed to (e.g. if the 28% of the CFLi at end of life

are addressed to the proper WEEE treatment the sub-system WEEE_S will account for 28%)
- system R - it includes "WEEE_R"; the % of this process expresses the rate of CFLi addressed recycling (e.g. if the 28% of the CFLi at end of life are addressed to the proper WEEE treatment the sub-system WEEE_R account for 28%). The sub-system "domestic waste_R" is not built because, when CFLi goes in the domestic waste flow they are addressed to incineration.

For fluorescent lamps at EoL treated as WEEE, the EoL mass fractions (reuse, recycling, landfill, energy recovery and incineration) by VITO (2015) are applied.

On the contrary, for the other types of lamps, just the scenario domestic waste is considered, in consistency with the preparatory study.

Upscaling to the stock of the BoP appliances

The process followed to define the stock of lamp is already explained in the section "assumption for the use phase". Table 145 summarizes stock data and amount accounted for in the BoP.

Table 145. Total stock of lamps (for typology) and amount accounted for in the BoP

Total stock of CFLi	Total stock of HL LV R
1,485,936,824	902,902,229.2
Use stage (years)	**Use stage (years)**
12	4.4
Volume to be accounted for in each life cycle stage	**Volume to be accounted for in each life cycle stage**
1/12*1,485,936,824 = 123,828,068.7	**1/4.4*902,902,229.2 = 902,902,229.2**
Total stock of GLS X	**Total stock of HL MV E**
1,575,695,794	1,058,346,935
Use stage (years)	**Use stage (years)**
2.2	3.3
Volume to be accounted for in each life cycle stage	**Volume to be accounted for in each life cycle stage**
1/2.2* 1,575,695,794 = 716,225,361	**1/3.3* 1,058,346,935 = 1,058,346,935**

Annex 8. Additional information for laptop

The selected product is the laptop identified in Tecchio et al. (2017). It is derived from available scientific literature about LCA and material flow analysis (MFA) on notebooks (Chancerel and Marwede, 2016; Kahhat et al., 2011; Kasulaitis et al., 2015; Seagate, 2016; Talens Peiró et al., 2016; von Geibler et al., 2003).

Assumptions for the production of materials/components

The Bill of Materials for laptop is taken from Tecchio et al. (2017). Here, the reference BoM for the Notebook product group is reported, based on previous work by JRC (Talens et al. 2016) for the Ecolabel criteria development for personal computer and electronic display. The main PCB includes Motherboard, RAM, CPU and other PCB, for a total weight of 265g. The process "Printed wiring board, mounted mainboard, laptop computer, Pb free {GLO}| market for | Alloc Def, U" is used to represent this component as well as the PCBs in the Optical Disk Drive (ODD), in the storage system and in the battery. For the ODD, the composition is taken by Tecchio et al. (2017). Shares of the different materials/components are based on the previous work by Talens Peiró and Ardente (2015). Also in this case, electricity and material processing are accounted based on information reported in Ecoinvent (Dataset "Disk drive, CD/DVD, ROM, for laptop computer {GLO}| production | Alloc Def, U"). The process "Battery, Li-ion, rechargeable, prismatic {GLO}| production | Alloc Def, U" has been used to model the prismatic Li-ion battery. However, this process has been modified to represent the technology change related to the cathode materials used for the battery cell. In fact, the Ecoinvent original process includes a cathode based on Lithium Manganese Oxide ($LiMn_2O_4$) but in 2010 the cathode based on Lithium Cobalt Oxide ($LiCoO_2$) was the most used; in addition in 2014 the use of $LiCoO_2$ is diminished in favour of the Lithium-Nickel-Manganese-Cobalt-Oxide ($LiNi_{0.4}Co_{0.2}Mn_{0.4}O_2$) and this trend is expected to remain stable (Tecchio et al. 2017). The $LiCoO_2$ and $LiNi_{0.4}Co_{0.2}Mn_{0.4}O_2$ are missing in Ecoinvent. They have been modeled based on Dunn et al. (2015) and Majeau-Bettez et al. (2011), respectively. Then, it has been assumed a composition of the cathode based on equal amount of $LiMn_2O_4$, $LiCoO_2$, $LiNi_{0.4}Co_{0.2}Mn_{0.4}O_2$.

To represent the average situation of the stock, where some notebooks have as storage system a Hard Disk Drive (HDD) and some others (usually the newest) a Solide State Drive (SDD), the storage system of the representative product is assumed to be composed for 80% by HDD and 20% by SSD. The ratio of HDD and SDD is taken by the average BoM for notebook reported in task 4 of the last preparatory study (VITO, 2017). In that study, out of 0.1 kg of Storage system, 0.08 is HDD and 0.02 is SSD. The average composition of HDD and SSD are taken by Tecchio et al. (2017). Energy and processing for the manufacture are retrieved by the dataset "Hard disk drive, for desktop computer {GLO}| production|Alloc Def, U. The overall BoM of the laptop used in the BoP is reported in Table 146.

Table 146. BoM of the laptop, including packaging

Material component	**Amount (kg)**	**Note**
Ferrous metals	0.077	Steel
Non ferrous metals	0.383	Copper and aluminum
Glass	0.008	
Plastics	0.446	PC, PVC, PMMA
Main PCB	0.265	Motherboard, RAM Card, CPU, other PCBs
Battery	0.263	
ODD	0.212	
LCD	0.16	
Storage system	0.096	HDD (80%) and SSD (20%)
Tot	1.910	
Product Packaging	**Amount (kg)**	**Note**
Cardboard and paper	0.14861	
Plastics	0.04439	EPS and PE
Tot	0.193	

Assumptions for the manufacturing

The energy input for the manufacturing of the laptop are retrieved in the Ecoinvent dataset "Computer, laptop {GLO}| production | Alloc Def, U".

Assumptions for the use phase

Based on literature data (Subramamian et al., 2017), an average use mode has been assumed as follows:

- 6hr/day * 7 days * 53 week – active mode
- 18hr/day *7 days * 53 week – off mode

Consumption in active and off mode are retrieved in Ecoinvent (from "Use, computer, laptop, active mode/RER U" and from "Use, computer, laptop, off mode/RER U"). The electricity consumption arising from the assumed use mode and Ecoinvent data is about 52 kWh/year. This consumption is slightly lower that average annual electricity consumption reported in VHK (2016) for notebook.

Assumptions for maintenance and repair

It is assumed that during the service life the battery is changed. In Tecchio et al., 2017, it is reported that, in a survey (IDC, 2010), respondents indicated that 22% of notebook computers required the purchase of a replacement battery during their lifetime. For this reason, in the maintenance stage it is considered that the 22% of battery is substituted.

Assumption for EoL

The EoL is assumed occurring after 5 years. It is assumed a two-step EoL.

1 Manual disassembly

The Battery is removed and sent to proper EoL as well as the display.

HDD/SDD and ODD are removed and sent to medium shredder to recover iron, aluminium, magnets and PCB fraction. We assume to apply the same reuse/recycling/landfill/recovery and incineration rates applied for "electronic" in the preparatory studies for large household appliances, e.g. for washing machine (Working document EU Ecodesign for washing machines and washer dryers, 2015b), thus 50% recycling, 1% reuse, 30% incineration and energy recovery, 19% landfill.

- For ODD (as they are assumed) the materials/components of interest are steel, copper, aluminium and PCB. The fraction of PCBs extracted is sent to the PCB further treatment for the extraction of special/precious metals according to rate specified in Tecchio et al. 2017
- For HDD/SDD (as they are assumed) the materials of interest are steel, copper, aluminum, PCB and magnets. The fraction of PCBs extracted is sent to the PCB further treatment for the extraction of special/precious metals according to rate specified in Tecchio et al. 2017. Magnets scrap is supposed to go in the loop of iron/steel.

The main PCBs (mother boards, RAM, etc) are removed and sent to recycling treatment for the extraction of special/precious metals, according to extraction rates by Mathieux and Talens Peirò (2016). In this treatment, part of the plastic is also separated for energy recovery, according to Mathieux and Talens Peirò (2016). The other metals included in the PCBs are out of the system, according to what is already mentioned in the chapter Life Cycle Inventory of the BoP, par. LCI of the EoL phase.

2 Shredding

All remaining mass is sent to shredding – material recovered are: metals, few plastic, few glass. The same reuse/recycling/landfill/recovery and incineration rates considered for large household appliances, e.g. for washing machine (Working document EU Ecodesign for washing machines and washer dryers, 2015b) are applied.

Upscaling to the stock of the BoP appliances

The estimated stock of computers (all computer types) is 402.50 million, of which 178.63 million are notebook. This is an estimation reported in the last preparatory study, task 2, pag 29 (VITO, 2017). We considered that just the 40% of the total stock is for private use (Table 147). This % is retrieved in the previous version of preparatory studies for Personal Computers and Computer Monitors and it refers to the 2008 (IVF, 2007).

Table 147. Total stock of laptops and amount accounted for in the BoP

Total stock	**% of market covered by Notebook**
71,452,000 (178,630,000*0.4)	100
Use stage (years)	**Share of life cycle to be accounted for in the BoP**
5 years	1/5 = 0.2
Volume to be accounted for in each life cycle stage	**1/5 * 71,452,000 = 14,290,400**

Annex 9. Additional information for TV screen

For the product "TV screen", the BoP includes one model corresponding to one of the base cases defined in the preparatory study for Ecodesign criteria development (Fraunhofer IZM, 2007), namely a LCD-TV screen 32", which is considered the most representative for this product group.

Assumptions for the production of materials/components

The Ecodesign criteria are currently under review and the preparatory studies are not available yet. The previous preparatory studies have been published in 2007 (Fraunhofer IZM, 2007) and include the BoM of LCD-TV for 32 as main base case. The BoM for the 32'' LCD-TV has then been averaged to obtain smaller and bigger TV (26'', 37'' and 42''). It is not specified the extent to which reported case studies cover one single technology or an average technology.

An additional source of information for the modeling of TV screen is the 2016 JRC Technical Report "Analysis of material efficiency aspects of Energy related product for the development of EU Ecolabel criteria. Analysis of product group: personal computers and electronic display" by Talens Peiró et al. (2016). Here a bill of material for a 20.5'' LCD-TV is reported (exemplary case study). In this case study, the technology represented for the LCD is the cold cathode fluorescent lamp (CCFL). Another source of information is the Technical report EU Ecolabel Electronic Displays v3 (Vidal-Abarca Garrido et al., 2014). It includes a case study for a 21.5'' LCD-TV. Technology not specified.

We used the BoM reported in Talens Peiró et al. (2016). We averaged the BoM on a 32'' TV screen. The final product (excluding packaging) is 11.21 kg. The averaging method has been used in the past (in the context of preparatory studies for TV, for averaging a 32'' screen to a 26'', 37'' and 42'' screens). The weight obtained is comparable to the weight of current 32'' LCD screen in the market (e.g. http://www.philips.it/c-p/32PFL5605H_12/serie-5000-tv-led-con-pixel-plus-hd/specifications).

The fluorescent lamp is taken by the model built for the section "lighting". The weight of film connector (linked to PCB very rich in precious metal) is summed up to the PCB itself. The rigid unspecified plastic is modeled as PVC whereas the plastic foil is modeled as PE. The process "Printed wiring board, mounted mainboard, laptop computer, Pb free {GLO}| market for | Alloc Def, U" is used to represent all the PCB in the TV screen. The same packaging assumed for the notebook is assumed for the TV screen.

The overall BoM of the TV screen used in the BoP is reported in Table 148.

Table 148. BoM of the TV screen, including packaging

Material component	**Amount (kg)**	**Note**
Ferrous metals	3.049	Steel
Non ferrous metals	0.824	Copper and aluminum
Plastics	5.191	PE, PVC, PMMA, PC, ABS
LCD	0.738	
PCB	1.052	
Lamps	0.012	
Fan	0.03	
Capacitor	0.014	
Tot	10.91	
Product Packaging	**Amount (kg)**	**Note**
Cardboard and paper	0.690	
Plastics	0.206	EPS and PE
Tot	0.897	

Assumptions for the Manufacturing

The electricity input for the manufacturing is taken from the Ecoinvent dataset "LCD assembly GLO/U".

Assumptions for the use

Different sources were evaluated to define an average energy consumption in the use phase.

The first one is VHK (2016). The total number of electronic displays at 2010 (stock) is here reported, together with the overall arising electricity consumption. These data include all TVs, computers displays and digital photo frames. By dividing the total consumption for the total stock it is possible to obtain the electricity consumption by a single unit (tot consumption by unit 145 kWh/year).

The second source is the "EuP Preparatory Studies "Televisions" (Lot 5) (2007), where a pattern of use is defined for TVs (active-mode and standby mode hours) and the associated consumption, with specific reference to the LCD TV screen 32'' (tot consumption by unit 237 kWh/year).

Finally, in the Report "Electricity Consumption and Efficiency Trends in European Union - Status Report 2009" by Bertoldi and Atanasiu 2009 the total consumption by TV for 2007 is 60TWh. A total number of (for residential) of 310 million units is considered, resulting in a consumption by unit of 193 kWh/year.

The TVs consumption changed and is still changing fast. According additional details reported in VHK (2016) it dropped from 8.6 W/dm^2 of display in 2000 to 0.8 in 2015. We take for granted the data reported by Bertoldi and Atanasiu (2009). Since it relates to 2007, it is a pessimistic estimate when considered for 2010.

About the lifetime, different hypothesis are done in Osmani et al. (2013), running from 6 to 12 years. We assumed 6 years which is also in line with the life time of notebook.

Assumptions for Maintenance and Repair

It is assumed that in the maintenance phase 1% of the product's materials is replaced.

Assumptions for EoL

The most common method to process LCD TV at EoL is the manual dismantling, even if according to various authors, the most effective approach (to rich/comply with requirement from the WEEE Directive) would be a combination of both manual and mechanical dismantling. Based on information reported in the past preparatory study (Fraunhofer IZM, 2007) and in the above mentioned report by Talens Peiró et al. (2016), a manual dismantling is assumed. The following assumptions are done:

- LCD display is manually removed and sent to proper treatment as well as the capacitors and the fluorescent lamps.
- PCBs are manually removed and sent to proper recycling.
- Remaining mass is sent to shredding so as to separate plastics and metals. Plastics is energy recovered for 90%, whereas just the 10% is recycled Metals are recycled for 95% whereas the remaining 5% is sent to landfill.

Upscaling to the stock of the BoP appliances

In the "EuP Preparatory Studies "Televisions" (Fraunhofer IZM, 2007), a perspective for TV stock in 2010 is provided (Table 149).

Table 149. TV Stock perspective for 2010 by Fraunhofer IZM, 2007

	Size small (14"- 26")	Size Medium (27"–39")	Size large (40"- 65")
CRT	176.049	75.450	-
LCD	40.982	53.702	17.910
PDP	-	646	24.614
RP	-	-	2.159
TOT			

The LCD technology (in all the three size) represents about the 29% of the total stock, whereas the CRT represents about the 64%. Data here reported have been calculated in 2005. However, a fast change in technology occurred in the meantime.

Information in "Electricity Consumption and Efficiency Trends in European Union - Status Report 2009" by Paolo Bertoldi and Bogdan Atanasiu reports that already in 2007, the CRT TVs (35% market share) lost EU market leadership in favor of LCDs (53% market share). Since a more recent data was not found about the technologies share, the data at 2007 was used and it was considered that LCD TVs covers at least the 53% of the stock. This can be in line with data reported in the last JRC Reports for GPP criteria development (Osmani et al, 2013) where, sales data in 2007, 2008, 2009 and 2010 run from about 40% to 70% of the whole TV market.

On the same line, we use information reported in the above mentioned report for the stock. The residential TV stock is assumed about 310 million units. The penetration rate is 150%, with about 2 TV for household. We applied this penetration rate to the total number of dwellings at 2010, obtaining a stock of 332,254,364.54 (Table 150).

Table 150. Total stock of TV and amount accounted for in the BoP

Total stock	**% of market covered by the LCD TV screen**
332,254,364	53
Use stage (years)	**Share of life cycle to be accounted for in the BoP**
6 years	1/6 = 0.16
Volume to be accounted for in each life cycle stage	**1/6 * 0.53*332,254,364 = 29,349,135**

Annex 10. Datasets used to model packaging production and end of life

Table 151. Production of materials and waste treatment (incineration and landfilling) are included in system S, whereas burdens and benefits from recycling are included in System R.

	Production of material	Waste treatment (System S)				Recycling (System R)	
Material	**Ecoinvent process**	**Ecoinvent process (waste treatment)**	**% to landfill**	**% to incineration**	**% to recycling**	**Ecoinvent process (burdens)**	**Ecoinvent process Avoided products (benefits)**
Aluminium	Sheet rolling, aluminium {GLO}| market for | Alloc Def, U + Aluminium removed by milling, average {GLO}| market for | Alloc Def, U	Scrap aluminium {RoW}| treatment of, municipal incineration | Alloc Def, U + Waste aluminium {RoW}| treatment of, sanitary landfill | Alloc Def, U	20.1	10.7	69.2	Aluminium, wrought alloy {RoW}| treatment of aluminium scrap, post-consumer, prepared for recycling, at remelter | Alloc Def, U	Aluminium, primary, ingot {IAI Area, EU27 & EFTA}| market for | Alloc Def, U
	Aluminium removed by milling, average {GLO}| market for | Alloc Def, U						
Cardboard	Corrugated board box {GLO}| market for corrugated board box | Alloc Def, U	Waste paperboard {RoW}| treatment of, municipal incineration | Alloc Def, U + Waste paperboard {RoW}| treatment of, sanitary landfill | Alloc Def, U	11	0.58	83.2	Waste paperboard, sorted {GLO}| market for | Alloc Def, U	Sulfate pulp {GLO}| market for | Alloc Def, U
	Core board {GLO}| market for | Alloc Def, S		11	0.58	83.2		
Glass	Packaging glass, brown {GLO}| market for | Alloc Def, U	Waste glass {CH}| treatment of, municipal incineration with fly ash extraction | Alloc Def, U + Waste glass {CH}| treatment of, inert material landfill | Alloc Def, U	21.2	11.2	67.6	Glass cullet, sorted {GLO}| market for | Alloc Def, U	Packaging glass, brown {GLO}| packaging glass production, brown, without cullet and melting | Alloc Def, U
	Packaging glass, white {GLO}| market for | Alloc Def, S		21.2	11.2	67.6		
PE	Polyethylene, high density, granulate {GLO}| market for | Alloc Def, U	Waste polyethylene {CH}| treatment of, municipal incineration with fly ash extraction | Alloc Def, U + Waste polyethylene {CH}| treatment of, sanitary landfill | Alloc Def, U	44.5	23.6	31.9	Electricity, medium voltage {RoW}| market for | Alloc Def, U	Polyethylene, high density, granulate {RER}| production | Alloc Def, U
	Polyethylene, low density, granulate {GLO}| market for | Alloc Def, U						

	Production of material	Waste treatment (System S)				Recycling (System R)	
Material	**Ecoinvent process**	**Ecoinvent process (waste treatment)**	**% to landfill**	**% to incineration**	**% to recycling**	**Ecoinvent process (burdens)**	**Ecoinvent process Avoided products (benefits)**
PET	Polyethylene terephthalate, granulate, bottle grade {GLO}| market for | Alloc Def, U copia basket + Blow moulding {GLO}| market for | Alloc Def, U copia basket + Plastic processing factory {RER}| construction | Alloc Def, S	Waste polyethylene terephtalate {CH}| treatment of, municipal incineration with fly ash extraction | Alloc Def, U + Waste polyethylene terephtalate {CH}| treatment of, sanitary landfill | Alloc Def, U	44.5	23.6	31.9	Electricity, medium voltage {RoW}| market for | Alloc Def, U	Polyethylene terephthalate, granulate, bottle grade {RER}| production | Alloc Def, U
PP	Polypropylene, granulate {GLO}| market for | Alloc Def, U	Waste polypropylene {CH}| treatment of, municipal incineration with fly ash extraction | Alloc Def, U + Waste polypropylene {CH}| treatment of, sanitary landfill | Alloc Def, U	44.5	23.6	31.9	Electricity, medium voltage {RoW}| market for | Alloc Def, U	Polypropylene, granulate {RER}| production | Alloc Def, U
PS	Polystyrene, general purpose {GLO}| market for | Alloc Def, U	Waste polystyrene {CH}| treatment of, municipal incineration with fly ash extraction | Alloc Def, U + Waste polystyrene {CH}| treatment of, sanitary landfill | Alloc Def, U	44.5	23.6	31.9	Electricity, medium voltage {RoW}| market for | Alloc Def, U	Polystyrene, general purpose {RER}| production | Alloc Def, U

Annex 11. Global normalization factors for the Environmental Footprint method (EF 3.0)

This annex reports the updated global normalization factors by impact category for the Environmental Footprint method version employed in this report (EF 3.0). The update includes modifications of specific inventory flows from Crenna et al. (2019).

Impact category	Per person	Global NFs
Climate change	8.10E+03	5.58E+13
Ozone depletion	5.36E-02	3.70E+08
Particulate matter	5.95E-04	4.11E+06
Ionising radiation	4.22E+03	2.91E+13
Photochemical ozone formation	4.06E+01	2.80E+11
Acidification	5.56E+01	3.83E+11
Terrestrial eutrophication	1.77E+02	1.22E+12
Freshwater eutrophication	1.61E+00	1.11E+10
Marine Eutrophication	1.95E+01	1.35E+11
Water use	1.14E+04	7.89E+13
Land use	1.04E+06	7.19E+15
Resource depletion, fossils	6.50E+04	4.48E+14
Resource depletion, minerals and metals	6.36E-02	4.39E+08
Human toxicity, cancer	1.69E-05	1.17E+05
Human toxicity, non-cancer	2.30E-04	1.58E+06
Ecotoxicity freshwater	4.27E+04	2.94E+14

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