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Consumption and Consumer Footprint: methodology and results

Indicators and assessment of the environmental impact of European consumption

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Taija Sinkko: support to the extension of the Consumer Footprint Food and contribution to assessment of different consumer profiles.

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Abstract

This report presents the results of the **Life Cycle Indicators** (LC-IND2) **project**[3], aimed at developing two sets of Life Cycle Assessment-based indicators for assessing the environmental impact of EU consumption: the **Consumer Footprint** and the **Consumption Footprint**. The indicators have been designed aiming at:

- building a **Life cycle assessment-based framework** for monitoring of sustainable production and consumption (e.g. in relation to the Sustainable Development Goal 12). The methodology allows assessing 16 environmental impacts from three different perspectives: **end-consumer product groups level**; **areas of consumption** (food, housing, mobility, consumer goods, and appliances); the **average EU consumer**;
- developing a **single headline indicator to monitor** the evolution of the overall environmental impacts of EU consumption and production at Member State level, as well as the progress towards decoupling economic growth from environmental impacts. The single headline indicator is the results of weighting the 16 indicators mentioned above;
- testing **ecoinnovation scenarios** along the supply chains, from extraction of raw materials, to consumer behaviour, up to end of life options.

Main results indicate that the EU can be considered a "**net importer of environmental impacts**". This implies that the **Consumption Footprint** (overall impacts related to consumption of good and services, including trade) **is higher than the Domestic Footprint** (impacts generated in the EU area).

Five areas of consumption (food, mobility, housing, household goods, and appliances) have been assessed through the Life Cycle Assessment of more than 130 representative products. **Consumption of food emerged as one of the main driver of impacts** generated by household consumption, followed by housing (especially for space heating) and mobility (especially the use of private cars). **Consumer Footprint was increasing between 2010 and 2015, at a rate of 6% over the 5 years**.

The environmental impact of the **consumption of an average EU citizen is outside the safe operating space for humanity** for several impact categories, namely climate change, resource use (fossils fuels, minerals and metals), freshwater eutrophication, photochemical ozone formation, land use, and particulate matter. Despite the differences in the robustness of the impact categories, results conclude that for most categories the impacts are close (if not over) to the planetary boundary.

Disclaimer

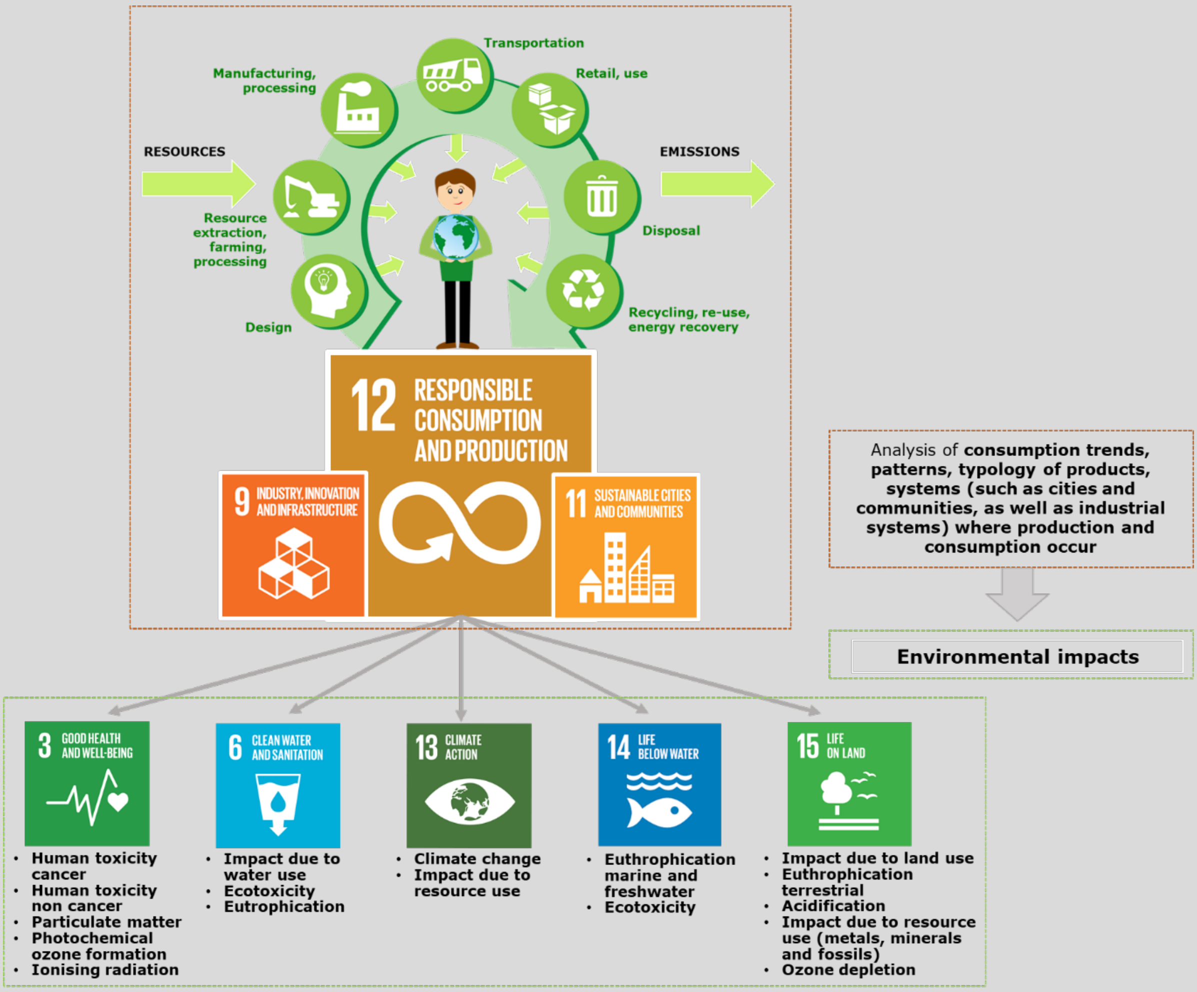
The study underpinning the calculation of the Life Cycle Assessment (LCA)-based indicators started in 2016 and ran in parallel to the Environmental Footprint (EF) pilot phase. Hence, the modelling approach adopted and the life cycle inventory data used are not fully compliant with EF rules and are only intended to illustrate the use of (LCA) to define the baseline of impacts due to consumption in Europe and to test eco-innovation and policy options against that baseline.
Moreover, the results presented in this report are calculations based on i) public statistics, environmental modelling for data gap filling, life cycle inventories, multi-regional input-output databases, used to assess the inventory of emissions and resources; and on ii) environmental impact assessment characterisation models for assessing the potential impacts on the environment. The complexity of the exercise (bringing together more than 3000 emissions and resources, over 15 years and for 28 EU Member States) and the use of a multiplicity of models imply uncertainties. The set of indicators here developed should be, hence, considered a living organism, subject to continuous improvement and refinement. The reader is referred to the European Platform on LCA website for updates. 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**.

[3] LC-IND2 is the acronym of the project "Indicators and assessment of the environmental impact of EU consumption", supported by DG ENV through the AA N. 070201/2015/SI2.705230/SER/ENV.A1

1 Introduction

Consumption of goods is recognised as one of the main drivers of environmental impacts. Assessing those impacts is a crucial step towards achieving the sustainable development goals (SDGs) (UN, 2015) including those on responsible production and consumption (SDG 12) and aiming to sustainable economic growth (SDG 8). As part of its commitment towards more sustainable production and consumption, the European Commission has developed a Life Cycle Assessment (LCA)-based framework to monitor the evolution of environmental impacts associated to the European consumption adopting LCA as reference methodology. This report illustrates the result of the Administrative Arrangement (AA) between DG ENV and DG JRC entitled “Indicators and Assessment of the environmental impact of EU consumption (LC-IND2)”. The LC-IND2 indicators project is the continuation and evolution of the JRC project on relevant indicators of environmental impact of consumption, started back in 2010[4] and which has resulted in prototype indicators that in the current project were expanded and improved.

Box 1. Overview of the link between SDGs, the assessment of the potential environmental impact of consumption, and the calculation of these impacts with Life Cycle Assessment



Source: modified from Sala (2019).

[4]EC-JRC (2012a), Life cycle indicators framework: development of life cycle based macro-level monitoring indicators for resources, products and waste for the EU-27. Available at http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/31346/1/lbna25466enn.pdf
EC-JRC (2012b). Life cycle indicators basket-of-products: development of life cycle based macro-level monitoring indicators for resources, products and waste for the EU-27. Available at http://eplca.jrc.ec.europa.eu/uploads/LC-indicators-Basket-of-products.pdf

Developing a systemic and systematic framework to assess consumption is crucial to monitor progress towards the goal of decoupling economic growth from the use of resources and the environmental impacts and to support the reduction of overall environmental burdens. This framework apply the integrated perspective given by Life Cycle Thinking and investigates the changes in both production and consumption patterns and the evolution of their impacts. Through modelling the overall consumption in EU, the framework for assessing the Consumption Footprint and the Consumer Footprint has also the potential to support the transition towards a bio- and circular economy (EC, 2017; EC, 2015b). Indeed, current European Union's (EU) consumption patterns are mainly based on the use of fossil resources and linear economic systems. These two developed indicators help to identify the most critical areas of consumption as well as possible efficient approaches to change from a linear to a circular economy paradigm. Furthermore, on the methodological side, the project has ensured possible synergies between Consumption Footprint and Consumer Footprint, and the EU Pilot on the Product Environmental Footprint (EC, 2013a).

The **project activities** have focused on:

- further developing a **LCA-based framework**, including modelling, for assessing relevant impacts due to consumption and benefits of eco-innovation policies. The methodology allows measuring the environmental impacts from **three different perspectives**: i) at **micro (product) / meso (production system) level**, ii) at **end consumer product groups**: food, housing, mobility, household goods and appliances; and iii) at **the average EU consumer**. The indicators per consumption area under point ii) above are based on representative products and are called "Basket of Products (BoP)" indicators;
- developing two headline indicators to monitor the evolution of the overall environmental impacts of EU consumption and production at macro level: the **Consumption** and the **Consumer Footprint**. The Consumption footprint assessing the performance of countries and the Consumer Footprint the performance of consumers.
- collecting of complete time-series for each Member State (MS) and European Union as a whole for the Consumption Footprint;
- addressing EU consumers' lifestyle aspects, **analysing consumption patterns and consumer behaviour** features in the overall framework for the assessment of the impacts;
- assessing **scenarios**, focusing on solutions and options **related to a wide spectrum of existing and potentially upcoming policies**, such as circular economy, green public procurement, ecodesign and ecolabel, resource efficiency, bio-economy, and eco-innovation;
- developing an **online platform** to communicate the results of Consumption and Consumer Footprint;
- developing a beta version of a **Consumer Footprint tool**, for customizing the assessment of consumer profiles.

The study aims at answering the following **questions**:

- Which is the environmental impact of consumption at EU and at Member State scale?
- Is there a decoupling of environmental impact from economic growth in EU?
- Which are the main areas of consumption driving the impacts? Which are the products driving the impacts in the main areas of consumption?
- Which are the main processes driving the impacts across the 16 impact categories considered?

- Which is the environmental impact associated to EU citizens lifestyle?
- Is consumption in the EU environmentally sustainable and within planetary boundaries?

1.1 Policy context

The European Commission DG ENV and JRC have jointly developed a set of policy relevant indicators (**Consumption Footprint** and **Consumer Footprint**) and an assessment framework that contribute to monitor the evolution of the overall environmental impact of EU consumption. The present study is expanding the initial assessment framework to ensure a more complete and robust evaluation of the impacts, to measure the success of policies, and to guide the transition to a resource efficient and circular economy (EC, 2015a) as well as other related EU policies (e.g. Product Environmental Footprint (PEF), EC, 2013a). Specifically the two indicators aims at:

- **addressing SDG 12 (Responsible consumption and production)**, partially SDG 8 (with reference to decoupling economic growth to environmental impacts), SDG 9 (on industry, innovation and infrastructure), SDG 11 (on sustainable cities and communities), and assessing impact on a number of environmental impact categories related to other SDGs, mainly the ones addressing ecosystems and human health. Indeed, assessing environmental impact of consumption is primarily linked to SDG 12, and it implies the evaluation of the level of decoupling of environmental impact from economic growth (usually measured by Gross Domestic Product - GDP) (target 8.4 of SDGs), and related consumption patterns. However, assessing impact of production and consumption means, as well, understanding to which extent production and consumption may have an impact on other SDGs (Box 1);
- supporting the design of better solutions and policy options in the context of the **European Green Deal** defined in the political guidelines of the President-elect of the European (von der Leyen, 2019);
- identifying **indicators of decoupling of environmental impact from economic growth**, serving both the Europe 2020 strategy (EC, 2010), and its flagship initiative A resource-efficient Europe (EC, 2011b), as well as the Circular Economy Action Plan (EC, 2014b);
- **monitoring progress towards** environmental targets, such as related to climate change and energy, as reported in the **7th European Environment Action Program** (7th EAP) (EU, 2013). This serves the need expressed as "[...] the development of methodologies for measuring and benchmarking the efficiency of land, carbon, water, and material use by 2015 and assessing the appropriateness of the inclusion of a lead indicator and targets" as foreseen in the 7th EAP (EU, 2013);
- developing of methodologies for **measuring to which extent the EU is ensuring living well within the limits of our planet**;
- supporting the Europe 2020 strategy (EC, 2010), its flagship initiative "**A resource-efficient Europe**" (EC, 2011b), as described in the "Roadmap to a Resource Efficient Europe" (EC, 2011a), which, among the others, has the objective to increase resource productivity and to decouple economic growth from resource use and its environmental impact (Sala et al., 2014). Moreover, the indicators address as well the communication on Circular Economy (EC, 2014b);
- contributing to the implementation of the **Beyond GDP Roadmap** (EC, 2009a) which foresees five actions, one on Complementing GDP with highly aggregated environmental and social indicators;
- contributing to the **Better regulation** (EC, 2015a), unveiling the potential role of LCA for defining baseline scenarios to be used in policy impact assessment.

1.2 State of the art in assessing the environmental impact of consumption

The assessment of the environmental impacts generated by consumption and, more generally, by citizens' lifestyle is a growing topic in the scientific literature. Carbon, water, land, material, and other footprints adopt a consumption-based approach, i.e. they consider the full life cycle of products and they allocate the impacts to the final consumer (differently from a production-based approach, which allocates the impacts to the producer of goods) (Hertwich and Peters, 2009; Davis and Caldeira, 2010; Hoekstra and Mekonnen, 2012; Bruckner et al., 2015; Wiedmann et al., 2013).

Various methods for estimating the footprint of European households and governments have been developed over the last years, e.g. as reported by the European Environment Agency (EEA, 2012). In the EIPRO study (Tukker et al., 2006; Huppes et al., 2006) as well as in EC-JRC (2010a), three main typologies of modelling frameworks to assess the environmental pressures and impacts associated with consumption have been identified which can be classified in: top-down, bottom-up, and hybrid approaches (Table 1).

Table 1. State of the art of available approaches to assess the impacts of consumption.

Typology of models	Top-down	Hybrid	Bottom-up
Model objective	Estimating global environmental pressures and impacts, caused directly and indirectly by consumption patterns.		
Approach implemented	Environmentally Extended Input-Output tables (EEIOTs) combined with households' expenditure statistics.	Hybrid LCA/EEIO	LCA of representative products up-scaled to overall consumption.
Most up-to-date existing databases	Examples: - WIOD - EORA - EXIOBASE 3		Examples: - Ecoinvent 3 - GaBi
Key pros and cons	- Consistent framework for the allocation of environmental burdens from the economic systems at macro scale to the final consumption expenditures: - Yet lack of details and realism in representing physical mass balances at the product level.	- Filling some gaps encountered in each approach: lack of details and realism in top-down approach compensated by use of LCA data; - Cut-offs on services in bottom-up approach compensated by comprehensive sectorial IO tables.	- A realistic picture and a high level of detail at the level of specific products; - But not designed to be consistent with national or sectorial statistics; reporting total emissions - Cut-offs on services.

Top-down methods combine Environmentally Extended Input-Output tables (EEIOTs) and households' expenditure statistics to account for the impacts of household consumption. This accounting method builds on economic input-output tables (Leontief, 1936) which are complemented with environmental extensions so to attribute emissions to the environment or resource use from the production stages (economic activities) to final demand in proportion to consumption expenditures (Leontief and Ford, 1970; Miller and Blair, 2009; Wiedmann, 2009).

Bottom-up methods are based on Life Cycle Assessment (LCA) studies for specific representative products which are then up-scaled to overall consumption figures through up-scaling techniques (e.g. EC-JRC, 2012a; EC-JRC, 2012b; Frischknecht et al., 2013; Notter et al., 2013). Some LCA-based studies aim to monitor the impacts of the whole household consumption at national scale, either focusing on specific impact categories (e.g. carbon footprint by ADEME, 2012, for France), or considering a wider set of LCA indicators (e.g. Kalbar et al., 2016, for Denmark). Other studies focus on a specific area of consumption in a geographical region (e.g. Greiff et al., 2017, and Teubler et al., 2018, on household goods in Germany; Saner et al., 2013, on housing and mobility in Switzerland;

Eberle and Fels, 2016, on food consumption in Germany; Lavers et al., 2017, on overall consumption in urban areas in four Swedish cities), or across spatial scale (e.g. Mastrucci et al., 2017, for building, from urban to macro scale).

Thanks to the use of representative products with detailed life cycle inventories, the bottom-up methods hold a more realistic picture and a high level of detail for what concerns specific products, and they are more useful when modelling scenarios acting on specific features of single products or on user behaviour. However, the use of representative products implies the exclusion of products that are less relevant in terms of the amount consumed and distanced to the performance of an "average" product of this category.

The different approaches are all affected by limits that could be overcome looking at the complementarity of their results (Dewulf et al., 2014; Sala et al., 2016a).

In the context of the present project, the complementarity of top-down and bottom-up approaches has been explored further, as illustrated in section 2.2.

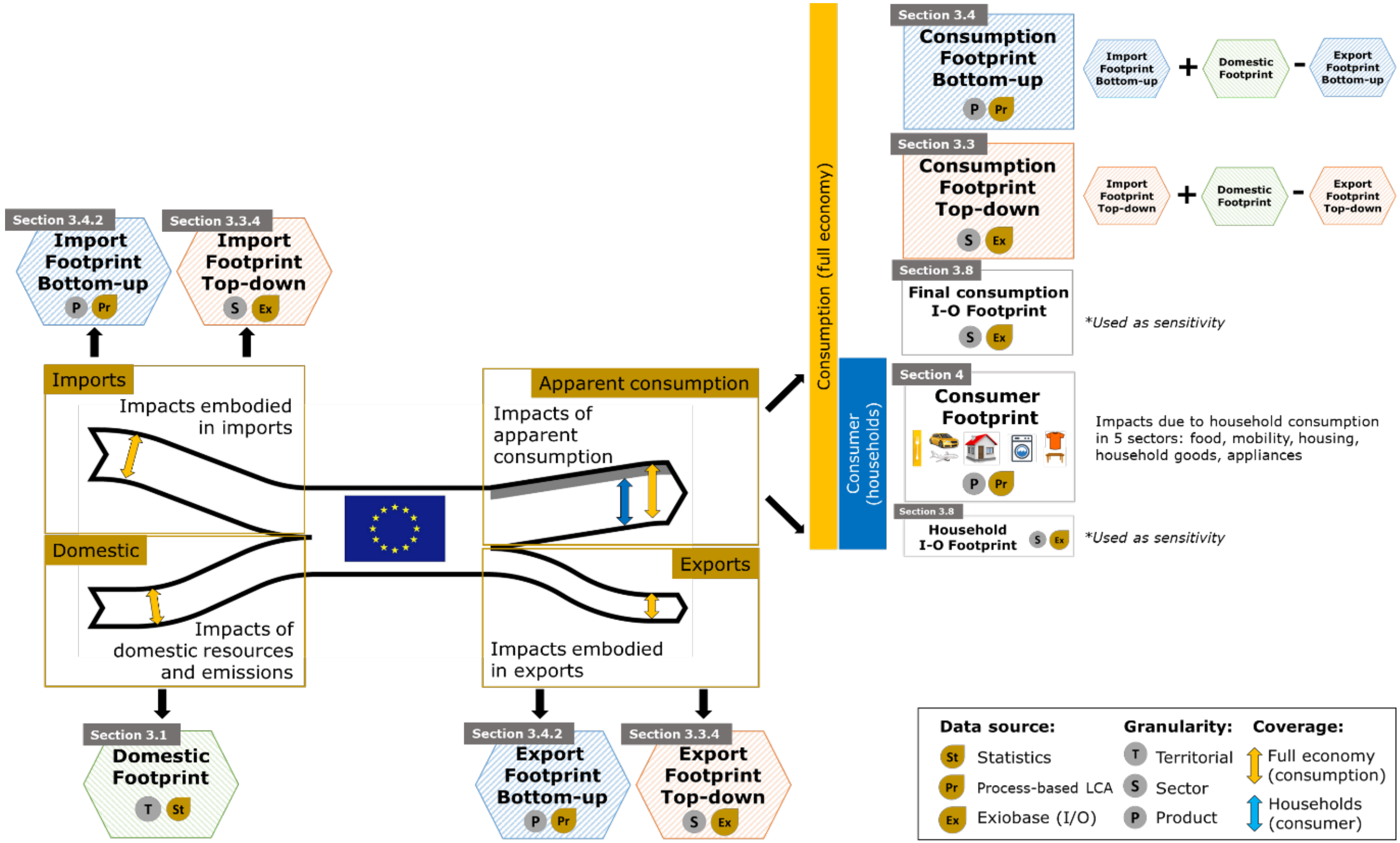
1.3 Outline of this report

The two indicators calculated in this study and analysed in this report (respectively, Consumption Footprint and Consumer Footprint), have been calculated both considering a bottom-up approach on the one hand, and a top-down approach on the other hand. For each indicator, the results of the impact assessment are put in perspective, in order to capitalize the main advantages of each approach undertaken, and subsequently to derive the main key converging messages obtained from the two different modelling frameworks implemented. Figure 1 presents the general scheme adopted in the present report.

The general aim is to assess the impact of the so-called apparent consumption, namely the consumption happening in one country which relies on domestic production of the country complemented with imported goods. Since the domestic production could also produce product to be exported, the export is then subtracted. When assessing the footprint of consumption, the apparent consumption results from:

(Apparent) Consumption footprint= domestic footprint +import footprint –export footprint.

Figure 1. General overview of the indicators presented in the report.



According to Table 1 there are different ways to assess the footprint of consumption, in terms of data sources, granularity, and coverage.

The building blocks of the **consumption footprint** are the domestic footprint and the import footprint. Those footprint are assessed per country.

The **Domestic Footprint** is assessed by means of collecting environmental statistical data of emission and resource use, complemented by modelled emissions when statistical data are missing. The granularity of data collection and modelling is the country. An overview of the adopted approach and data sources is provided in Sala et al. (2014, 2015) and in section 3.1.

The **Trade Footprint** (either import of export) could be estimated either assessing the impacts of imported and exported representative products (bottom-up) or assessing the impact relying on I/O modelling of the trade (top-down). For this study, Exiobase has been used as source of data for the I/O modelling.

The combination of the domestic footprint with the trade footprint bottom-up or top-down is allowing the assessment of the consumption footprint bottom-up (section 3.4) or top-down (section 3.3) respectively. Beyond this hybrid approach (which combines statistic at the country level with the modelling of traded goods or with the I/O modelling) a consumption footprint fully based on the I/O modelling is possible and has been used in this project to perform a sensitivity analysis with the results of the two hybrid consumption footprint (section 3.8 illustrate the comparison done).

When looking specifically at the average EU citizen, the **Consumer Footprint** has been assessed by mean of process-based LCA of representative products, selected to give an overview of the most relevant areas of consumption (food, mobility, housing, household goods, appliances) as illustrated in section 4. An I/O modelling based estimate of the consumer footprint (Household_I/O Footprint) has been performed as well and presented as sensitivity in section 3.8.

Methodological details and results of the two indicators (Consumption Footprint and Consumer Footprint) are reported in next sections, as for Table 2. A summary of the main results and their policy relevance is reported in a dedicated JRC science for policy report (Sala et al., 2019a).

Table 2. Sections of the report and related content.

Section 1	Introduction on the project and the policy context.
Section 2	Description of the LCA-based methodology for calculating the different indicators.
Section 3	Consumption Footprint at the EU and at country scale, calculated with a top down and a bottom up approach for trade combined with the Domestic Footprint based on statistical data.
Section 4	Consumer Footprint for 5 areas of consumption, identifying their relative relevance and the products driving the impacts.
Section 5	Role of lifestyles and differences in consumer profiles.
Section 6	Comparison of results of Consumption Footprint and Consumer Footprint indicators.
Section 7	Environmental sustainability of EU consumption in terms of impact on human health and biodiversity, as well as the overcoming of planetary boundaries.
Section 8	Assessing eco-innovation scenarios with the Consumer Footprint.
Section 9	Role of the indicators in support to policies.
Section 10	Main conclusions and outlook.

2 Consumption Footprint and Consumer Footprint: assessing the impacts of consumption from different perspectives

Consumption Footprint and Consumer Footprint are the two life cycle assessment-based indicators developed to assess the environmental impact of EU consumption. The indicators have a different scope and purpose, even though they remain coherent being based on the same underlying principle of life cycle thinking (EC-JRC, 2012b).

The indicators' names identify the underpinning calculation approach and the final scope:

- **Consumption Footprint:** this indicator aims at tracking the overall environmental impacts of apparent consumption in the EU, corresponding to the sum of the impacts due to domestic production plus imports minus exports, assessed at overall EU scale and at country scale;
- **Consumer Footprint**: this indicator aims at assessing the environmental impacts of household consumption in EU. In this report, results relative to the Consumer Footprint are based on a bottom-up approach to assess the impact of consumption patterns of citizens in different areas of consumption.

This chapter illustrates the main methodological aspects of the calculation of the indicators, including: the overview of the assessment framework (section 2.1), the general description of the applied methods (section 2.2), and the description of the calculation principles of both the Consumption Footprint (section 2.3) and of the Consumer Footprint (section 2.4).

2.1 Key principles adopted in the project

The framework for assessing the impact of EU consumption has been built considering a number of **key principles**. Firstly, the modelling approach is **consumption-oriented**, namely it aim to assess impact arising from final consumption encompassing all life cycle stages, from extraction of raw material to waste management at the end of life. Secondly, the framework applies a **system thinking approach**, namely including different interlinked components of production and consumption to assess the impacts. Finally, **life cycle thinking** and assessment are the basis for modelling and impact assessment. This section illustrates the key principles and methodological choices adopted in the project.

2.1.1 Consumption-based approach

The Consumption and Consumer footprint are calculated adopting a consumption-based approach. This means that the **impacts generated throughout the full life cycle of products or services are allocated to the final consumer of those products or services** (differently from a production-based approach, which allocates the impacts to the producer of goods). This approach allows avoiding burden shifting based on a territorial basis. With a consumption-based approach it is possible to take into account the indirect impacts generated outside the EU territory but induced by the final demand of goods and services by EU citizens and their lifestyles.

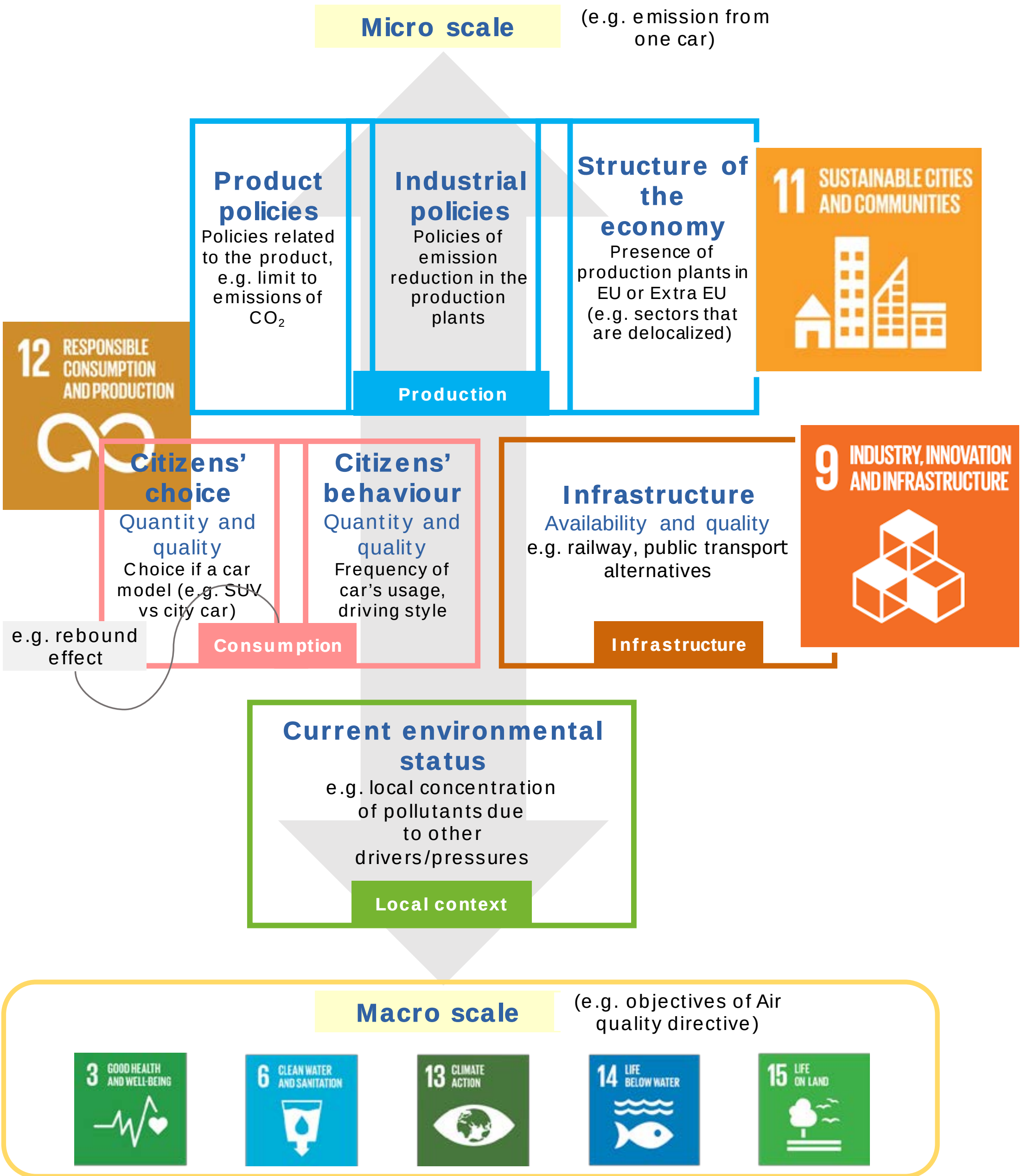
A consumption-based approach is essential to evaluate the **decoupling of environmental impacts from economic growth at country level** as the embodied impacts in trade are of great relevance to determine the overall environmental impacts of consumption, including the impacts which have been displaced to developing countries due to e.g. relocated production or changes in import patterns.

2.1.2 System thinking

The transition to sustainability requires a systemic approach, in which the complex shifts towards sustainable production and consumption need to be assessed carefully (EEA, 2017a). One of the main challenges of the assessment of the impact of consumption is to produce results which may support more coherence between product policies and territorial policies, assessing links and overlaps between micro (e.g. products), meso (e.g. sectors) and macro (e.g. region and countries) scales.

The proposed assessment framework is defined to enable the assessment of aspects of production and consumption from the micro to the macro scale (Figure 2).

Figure 2. Key elements in the relationship between intervention at micro scale (e.g. a product) and effect at the macro scale (e.g. at country scale) and application of system thinking to model production and consumption.



The elements of the relationship between micro and macro level are complex and interrelated. This is the reason why system thinking in environmental assessment is increasingly advocated. Indeed, moving from the traditional IPAT equation (**I**mpact resulting from **P**roduction, **A**ffluence and **T**echnology) towards an **improved** and **system thinking-oriented framework** should take into account at least the following issues:

- **production**: the main aspects to be addressed are: 1. understanding the structure of the economy and its evolution over time (share of primary, secondary and tertiary economic sectors; incidence of SMEs (Small and Medium Enterprises); etc.); 2. industrial policy affecting the level of clean production; 3. product policies: environmental performance of products, from raw material extraction to end of life;

- **consumption**: product's choices in a global market and the behaviour in the use phase influence greatly the overall environmental performance of a product. The central role of consumer behaviour is recognised both in scientific literature and within the policy context (see Polizzi di Sorrentino et al. (2016) for a state of the art on behavioural economics);
- **local context**: the current environmental status at local scale may imply local impact as well as impact at the macro-scale. Sometimes, the local context exacerbates some impacts and require adjustment of the policies. Local territorial policies should be also taken into account;
- **infrastructure**: the presence and the quality of the infrastructure may influence the overall contribution of a product to the achievement of goals at the macro scale (e.g. level of intensity in the wastewater treatment, from primary to tertiary ones).

Therefore, the overall environmental impact (I) at macro-scale is function of the above-mentioned elements:

I= Production x Consumption x Infrastructure x Local context

This equation could be considered as an evolution of the well-known I=PAT equation (I= impact, P= production, A= affluence, T= technology) in light of adding elements related to the infrastructures and the role of local context. The "T" elements in I=PAT equation is embedded in all the elements of our equation (as technology affects the product, the production process, the use of a product as well as the infrastructure, etc.).

This implies that achieving macro scale objectives - in terms of impact reduction-requires actions in all the elements of the scheme (Figure 2), namely implementing actions and eco-innovations that entail technological, behavioural, organisational, and logistic interventions. Additional parameters to consider in the overall micro-macro relationship are the time dimension (e.g. if we are considering product with a short life cycle like food products, or with a long life cycle e.g. housing) and the geographical dimension (e.g. if production is happening within or outside of EU). Adopting LCA allows all these elements to be incorporated in the models and considered in the assumption of the analysis.

2.1.3 LCA as reference methodology for assessing impacts

Life cycle thinking (LCT) is a basic concept and approach referring to the need of assessing burdens and benefits associated to products/sectors/projects **adopting a life-cycle perspective, from raw material extraction to end of life**. LCT can be applied to both economic, social and environmental pillars. The environmental pillar of LCT is primarily supported by Life Cycle Assessment (LCA) (Figure 3).

According to ISO (2006a, b), LCA is a methodology for integrated impact assessment in which the (environmental) burdens associated to the whole life cycle of products are quantified. Such impacts refer to a wide range of categories, the so-called impact categories, such as climate change, resource depletion, ecotoxicity, etc.

The environmental impacts are the consequences of human interventions (either physical, chemical or biological) on the environment, such as resource extraction, emissions (incl. noise and heat) and land use (Guinée et al., 2002). Human interventions associated to a product system are modelled through the description of all activities (unit process) occurring in its life cycle and linked by physical exchanges (of resources and emissions) between the ecosphere and the technosphere. Those exchanges, which are responsible for environmental impacts, are called elementary flows.

To enhance the comparability of LCA applied to products and organisations, the European Commission has proposed the Environmental Footprint (EC, 2013a).

Figure 3. Life Cycle Assessment basic principles of accounting resource and emissions along supply chains, modelling each step of production and consumption of goods.

LCA is based on four main steps (Figure 4): 1) goal and scope, 2) life cycle inventory, 3) life cycle impact assessment, and 4) interpretation of results. In the current study, LCA is used as reference methodology for quantifying and monitoring progress towards sustainable production and consumption in EU. This entails:

i) defining goal and scope of the study;

ii) building the life cycle inventory of emissions and resources related to consumption, based on different modelling principles;

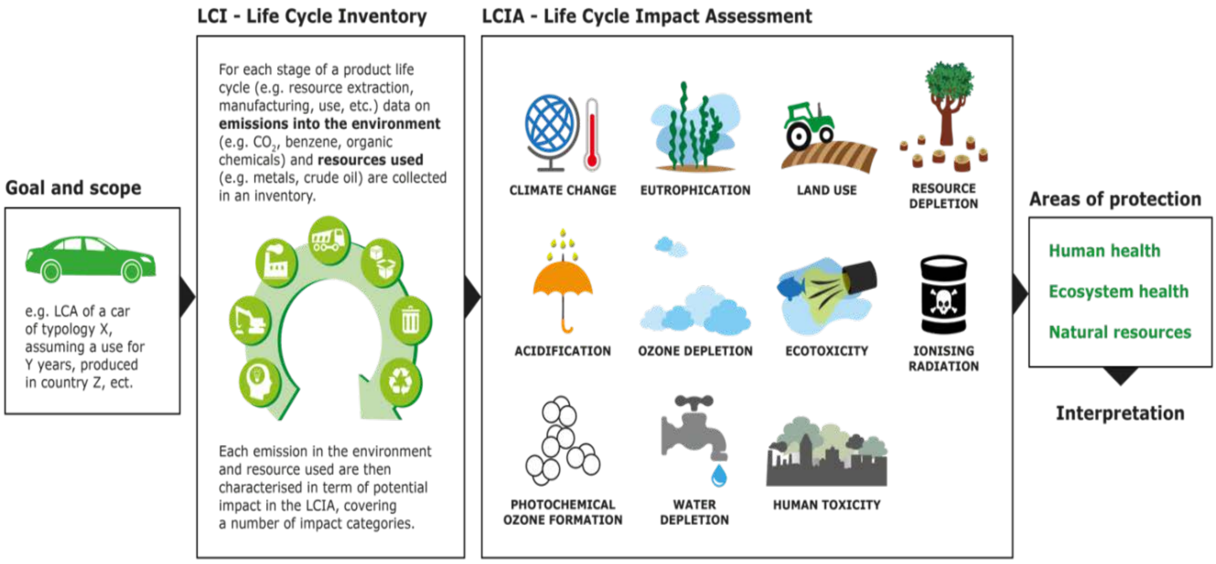
iii) assessing potential impacts in the life cycle impact assessment step, characterising the inventories with the life cycle impact assessment method developed in the context of the Environmental Footprint (EC, 2017) where 16 impact categories can be modelled;

iv) normalising the results against normalisation factors either at the EU (Sala et al., 2015) or at the global (Crenna et al., 2019a) scale. This entails reporting the results against reference values to understand the magnitude of the impacts;

v) weighting normalised results to obtain a weighted score (Sala et al., 2018).

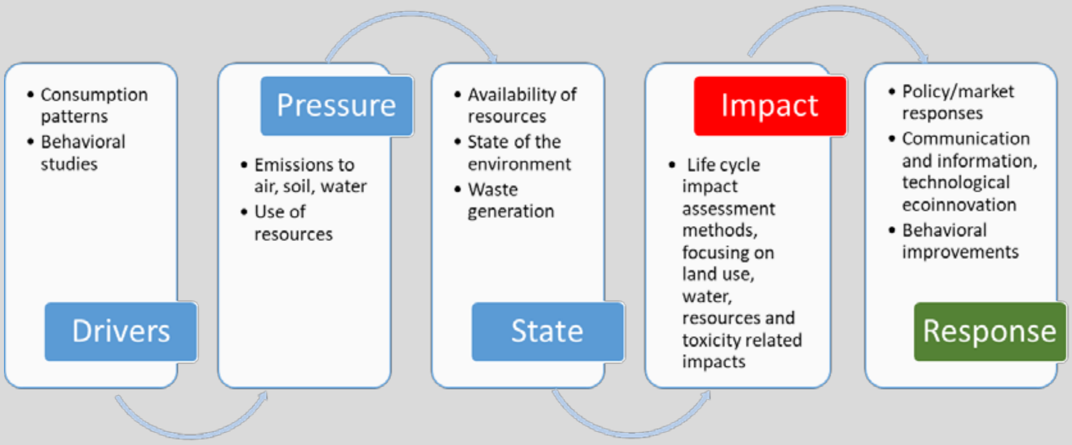
Moreover, results of the LCA could be expressed in terms of impacts at the level of areas of protection (e.g. human health and ecosystem health/biodiversity) as well as compared over Planetary Boundaries.

Figure 4. Life Cycle Assessment steps: goal and scope definition, life cycle inventory, life cycle impact assessment, and interpretation.



Box 2. Overview of LCA and the "Driver Pressure State Impact Response" framework (DPSIR)

The underpinning logic of LCA could be linked with frameworks such as the "Drivers, Pressure, State, Impact and Response" (DPSIR) (Smeets and Weterings, 1999), which represents a way to conduct systems analysis. Social and economic drivers exert pressure on the environment and, as a consequence, the state of the environment changes. In the context of the DPSIR framework (see figure below) it can be observed that the Life Cycle Inventory of elementary flows (resource extraction, emissions) is basically the way in which the environmental pressures are accounted for, whereas the potential impacts, calculated as LCA results, correspond to "impact indicators" in DPSIR terms. It has to be noted that LCA characterization models assess potential changes in the state of the environment, not necessarily actual impacts. The "driving forces" leading to the impacts quantified by Consumption Footprint and the Consumer Footprint are therefore those activities, which are directly or indirectly responsible for the generated impacts. The response part of the DPSIR framework is indirectly addressed by the indicator framework presented in this report since monitoring the progress of environmental performance gives indications on the impact of policies or interventions (or of the absence thereof) and where to prioritize efforts.



2.2 General method description of Consumption and Consumer Footprint

Figure 5 illustrates the steps of LCA and the way those have been applied to assess the environmental impact of consumption. In this report, the term Footprint is used both to refer to results of impact characterization (pressure * impact score) for 16 impact categories and of weighting (pressure * impact score * weighting factor), expressed as single score.

2.2.1 Goal and scope: two indicators, different accounting perspectives

In the Goal and scope definition step, the aims of the study are defined. This step entails also the definition of the unit of analysis (functional unit), the identification of the system boundaries, and the choice of the Life Cycle Impact Assessment (LCIA) models used. **The indicators Consumption Footprint and Consumer Footprint have the same goal, but different scopes** (Figure 5). The goal of the two indicators is to assess the environmental impacts of EU consumption, and to assess the level of decoupling of environmental impacts from economic growth. Considering the complexity of the exercise of modelling EU consumption, different scopes were considered for the two indicators, which allowed on one side to analyse the impacts of EU consumption from different angles, and, on the other, to highlight potential complementarities of the results obtained.

The scopes of the two indicators differ on: the objective of the analysis, the geographical scope, and the accounting approach adopted.

The **Consumption Footprint refers to the environmental impacts exerted by the whole economy,** including all the economic activities, whereas the **Consumer Footprint focuses on the environmental impacts associated to the consumption of an average EU citizen**. The Consumption Footprint is assessed both for the entire EU and at Member State level, whereas the Consumer Footprint is referred to an average EU citizen and to the whole EU population.

Both indicators might be calculated adopting a bottom-up approach, based on LCT. In the case of Consumption Footprint, the indicator is also calculated as well adopting a top-down approach, based on multi-regional input-output. The inventory of the Consumption Footprint is composed by the inventory of domestic impacts (as elementary flows representing resources extracted and substances emitted in EU) combined either with the inventory of imports and exports, calculated through:

- a process-based LCA applied to a selection of traded representative products (bottom-up) or;
- a multi-regional input-output data for the trade (top-down).

The inventory of the Consumer Footprint is fully process-based, with LCAs of more than 150 products, which represent household consumption in the EU.

Moreover, a graphical representation of the differences in scope and the level of detail of the two indicators is reported in Figure 6. These differences affect the inventory of the emissions and resources resulting from the adopted modelling approach for assessing the consumption.

Figure 5. Overview of the methodological steps for calculating life cycle-based indicators for assessing the impacts of EU consumption.

	The Consumer Footprint	**The Consumption Footprint**

Goal and scope

The Consumer Footprint: LCA of products representative of the consumption of an average EU citizen

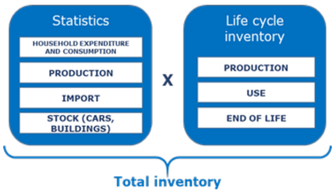
The Consumption Footprint: Economy-wide assessment of apparent consumption in Europe

Life Cycle Inventory

For each stage of a product life cycle, data on resource used (e.g. metals, crude oil) and emissions into the environment (e.g. CO_2, benzene, organic chemicals) are collected in an inventory. The two indicators are based on different modelling approaches to build the inventory.

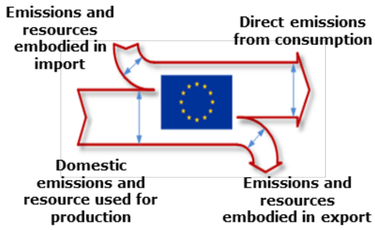
The Consumer Footprint:

- Emissions and resources used due to production and consumption during the entire life cycle of a product in selected areas of consumption (e.g. food, mobility, housing)
- Combining life cycle data (environmental profiles of products) with consumption statistics



The Consumption Footprint:

- Emissions and resources used due to production and consumption in one year in all sectors
- Combination of environmental statistics (domestic) and trade statistics and life cycle inventories of representative products (trade)
- Or though the use of the Environmentally Extended Input-Output Approach



Life Cycle Impact Assessment: potential impact in 16 impact categories linked with SDG's

Each emission to the environment and resource used collected in the inventory is then characterized in terms of potential environmental impacts in the life cycle impact assessment phase, covering the 16 impact categories recommended for the Environmental Footprint. The impact categories are relevant for different SDGs

SDG 3:

- **Human toxicity, cancer**
- **Human toxicity, non-cancer**
- **Particulate matter**
- **Photochemical ozone formation**
- **Ionising radiation**

SDG 6:

- **Impact due to water use**
- **Ecotoxicity**
- **Eutrophication**

SDG 13:

- **Climate chance**
- **Impact due to resource use**

SDG 14:

- **Eutrophication marine and freshwater**
- **Ecotoxicity**

SDG 15:

- **Impact due to land use**
- **Eutrophication terrestrial**
- **Acidification**
- **Impact due to mineral and metal resource use**
- **Ozone depletion**

Normalisation: comparing results with global references

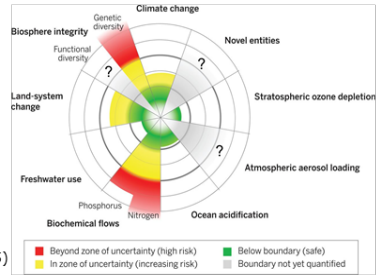
The normalisation helps to understand the relevance of the characterized environmental impacts, compared to the environmental impacts generated at global level.

Weighting: aggregating results in a single score

Weighting allows the identification of the most relevant impact categories, life cycle stages, processes and substances to ensure that the focus is put on those aspects that matter the most. In this study, the weighting set taken as reference is the final set developed for the Environmental Footprint.

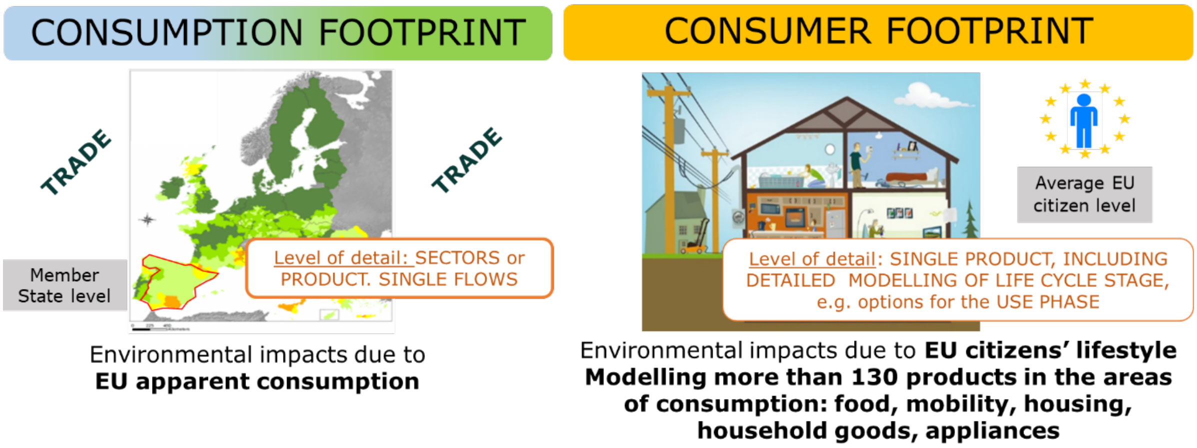
Planetary boundaries

Alternative to normalisation and weighting, the results could be compared with environmental sustainability thresholds, as the planetary boundaries framework provides.



Source: Steffen et al. (2015)

Figure 6. Consumption and Consumer Footprint: main differences in the aims and scopes.



2.2.2 Life Cycle Inventory: different approaches to model consumption

The Life Cycle Inventory (LCI) is the step in which all data on emissions (in air, water, and soil) and resource used (water, land, mineral and metals, fossil fuels) are collected. These data on environmental pressure are the basis for the calculation of impacts in the subsequent life cycle impact assessment step. The life cycle inventories of the two Consumption and Consumer Footprint are based on different perspectives, scales and sources of data, and they have different limitations as well. A general overview of the methodological approaches implemented in this work to develop the inventories for the different elements analysed is reported in Table 3.

Table 3. Accounting perspectives for the estimate of pressures and impacts on the environment in the EU.

Name used in this report	Perspective	Scale / focus of the assessment	Source of data for the estimation	Limitation of the estimation approach
Domestic Footprint	Territorial	Region, country, continental, global	Statistical data, models for emissions estimation	Only local emissions and resource extraction are taken into account.
Consumer Footprint **Trade Footprint Bottom-up**	Consumption-based-PRODUCTS	Products	Representative products and areas of consumption (e.g. food, mobility, housing)	The selection of representative products may lead to incomplete estimation of the overall impacts.
Trade Footprint Top-down **Final Consumption_I/O Footprint** **Household_I/O Footprint**	Consumption-based- SECTORS	Sectors	Based on extended environmental input-output (EEIO)	The sector-based approach is usually associated with a relatively limited coverage of emissions and resources.
Consumption Footprint Bottom-up **Consumption Footprint Top-down**	Territorial and consumption-based	Apparent consumption	Territorial for domestic and product-based / sector-based for trade	The uncertainties deriving by merging a (domestic) statistically based inventory with an LCA inventory may be high. There is a discrepancy related to the coverage of emissions and resources. The number of products that could be modelled is limited.

2.2.3 Life Cycle Impact Assessment: potential environmental impacts in 16 impact categories, normalisation, and weighting

The Life cycle impact assessment step encompasses:

- the **classification** and **characterization of the impacts** at midpoint level (i.e. in 16 impact categories) or endpoint level (i.e. in different areas of protection);
- the **normalisation against a reference system**;
- the **weighting to calculate a weighted score**.

2.2.3.1 Characterisation: from pressure to impacts

The characterization of results consists in the calculation of the potential impacts generated by environmental pressures identified in the inventory (LCI) (e.g. emissions and use of resource) after being classified into relevant impact categories. The **inventory of emissions and resources (LCI) is multiplied by characterisation factors**, namely coefficients of impacts that assign to each emission and resource a level of potential impact **based on environmental impact models**.

The LCIA models firstly classify emissions into impact categories and secondly characterize them to common units to allow comparison (e.g. CO_2 and CH_4 emissions are both expressed in CO_2 equivalent emissions by using their global warming potential). Example of impact categories are: climate change, acidification or resource depletion. Impacts may be calculated at midpoint (e.g. for climate change as global warming potential, in kg CO_2 eq.) or at the endpoint (biodiversity impact due to climate change). Midpoint impact categories usually cover three areas of protection at the endpoint level: human health, ecosystem quality (biodiversity), and natural resources.

For the calculation of the consumption and consumer footprint, **the Environmental Footprint LCIA (EF 2017) recommendations have been followed** (EC, 2017). The 16 impact categories, the underpinning models, the indicators units, and the robustness of the models are reported in Table 4. These impact categories of the EF2017 method are related to different SDGs covering aspects of human health and ecosystems quality (Figure 5). The selection of impact categories and the recommendation of the impact assessment models and factors was performed in the context of the Environmental Footprint based on an analysis of a wide range of existing methods and models used in LCIA, towards those which are internationally recognized and more robust (see e.g. Sala et al., 2019b). It has to be noted that the present study adopted characterization models and factors of the Environmental Footprint method reference package 2.0 (EF package 2.0). Details on the models and the factors are reported in EC-JRC (2018) and Fazio et al. (2018).

The 16 impact categories of the EF 2017 are here introduced and detailed in Annex 1:

- **Climate Change**: Global impact due to changes induced to the climate, including increased average global temperatures and sudden regional climatic changes, as a consequence of the emissions to the atmosphere of the so-called greenhouse gases, such as CO_2, CH_4, and N_2O;
- **Stratospheric Ozone Depletion**: Global impact related to the broken-down of stratospheric O_3, including increased skin cancer cases in humans and damage to plants, as a consequence of man-made emissions of halocarbons (as CFCs and HCFCs), halons, and other long-lived gases containing chloride and bromine;
- **Particulate matter**: Impact on human health due to the increased ambient concentrations of particulate matter (PM) due to the emissions of primary and secondary particulates (i.e. precursors, NO_x, SO_2);
- **Ionising radiation, human health effects**: Impact to human health due to the exposure to ionising radiation (radioactivity) under normal operating conditions (i.e. excluding accidents in nuclear plants);

- **Photochemical Ozone Formation**: Local and regional impact to the environment and human health related to the formation of tropospheric ozone resulting from the oxidation of solvents and other volatile organic compounds (VOCs) released to the atmosphere that affects organic compounds in animals and plants and can increase the frequency of respiratory problems;
- **Acidification**: Regional impact to the environment regarding the modification of acidity of soils, as consequences of emission and deposition of acids (and compounds that can be converted to acids) into the environment;
- **Eutrophication (terrestrial)**: Local and regional impact on the terrestrial ecosystems due to substances containing nitrogen (N) or phosphorus (P) which leads to the disappearance of ecosystems that are poor in nutrients;
- **Eutrophication (freshwater)**: Local and regional impact on the freshwater ecosystems due to substances containing phosphorus (P) which leads to the reduced oxygen availability consequent from increased algal growth;
- **Eutrophication (marine)**: Local and regional impact on the marine ecosystems due to substances containing nitrogen (N) which leads to reduced oxygen availability consequent from increased algal growth;
- **Freshwater ecotoxicity**: Local and regional impact to freshwater ecosystem due to the release of toxic substances that can accumulate and affect individual species as well as the functioning of the entire ecosystem;
- **Human Toxicity (non-cancer effects)**: Local and regional impact to humans due to the exposure (i.e. due to inhalation of air, drinking water, etc.) to toxic substances emitted in the environment and responsible for diseases (e.g. respiratory disease) other than cancer;
- **Human Toxicity (cancer effects)**: Local and regional impact to humans due to the exposure to toxic substances emitted in the environmental and responsible for cancer effects;
- **Land use**: Impacts due to the effects of occupation and transformation of land in terms of reduction of soil qualities (e.g. modification in the organic matter content of soil, or loss of the soil itself (erosion));
- **Water use**: Impact related to the consumption of freshwater (lakes, rivers or groundwater);
- **Resource use (fossil)**: Global impact related to the decreased availability and the potential scarcity for future generations of the total reserve of fossil resources;
- **Resource use (minerals and metals)**: Global impact related to the decreased availability and the potential scarcity for future generations of the total reserve of mineral and metal resources.

Besides these 16 midpoint indicators, in this study, the damages effects that can be generated on the areas of protection **ecosystems quality (biodiversity)** and **human health** are directly addressed as well. In section 7.3, the impact of consumption are reported at the endpoint adopting the method Recipe 2016 (Huijbregts et al., 2017). These areas of protection are affected by different midpoint indicators and linked to diverse SDGs:

- **Ecosystems quality (biodiversity)**: area of protection affected by the midpoint impact categories land use, climate change, acidification, water use, photochemical ozone formation, eutrophication (terrestrial, freshwater, marine) and ecotoxicity. This area of protection is primarily linked to SDG 13 (climate action), 14 (life below water) and 15 (life on land);
- **Human health**: area of protection affected by the midpoint impact categories climate change, particulate matter, human toxicity (cancer, non-cancer), water use, photochemical ozone formation and ozone depletion potential. This area of protection is

primarily linked to SDG 3 (good health and well-being), 7 (affordable and clean energy) and 13 (climate action).

2.2.3.2 The 16 environmental impact categories and their link with sustainable development goals

The above-mentioned 16 impact categories aim to model environmental impacts and environmentally-driven human health impacts. Those impacts are among the priority areas of national and international environmental policies and are linked with several sustainable development goals. In order to assess the extent to which production and consumption in EU is contributing to SDGs, the impact categories used in EF method of life cycle impact assessment have been mapped against the relevant SDGs they refer to, as follows:

- SDG 3 – good health and well-being. The impact categories human toxicity-cancer, human toxicity- non cancer, particulate matter, photochemical ozone formation, and ionising radiations are all linked to potential impacts on human health and may represent a good proxy of the environmentally-driven impacts on human health related to consumption;
- SDG 6 – clean water and sanitation. The impact categories directly affecting water availability and water quality (impact due to water use, ecotoxicity, freshwater eutrophication) are linked with the SDG 6;
- SDG 13 – climate action. The impact category climate change is clearly related to the climate action. However, the impacts due to resource use (fossil fuels) and those related to ozone depletion (since several ozone depleting substance are as well exerting impacts on climate change) are linked to SDG 13;
- SDG 14 – life below water. The impact category related to impacts on potential impairment of water ecosystems (freshwater and marine eutrophication, and ecotoxicity) are linked with the SDG 14;
- SDG 15 – life on land. The impact category related to impacts on potential impairment of terrestrial ecosystems (impact due to land use, terrestrial eutrophication, acidification, impact due to mineral and metal resource use, ozone depletion) are linked with the SDG 15.

It has to be noted that this mapping is just illustrative of the potential link between impact categories and SDGs, as many more implications and linkages/interlinkages could be found. For example, the ozone depletion is as well linked to environmentally-driven human health concerns (e.g. due to the link with increase skin cancer). Moreover, some impact categories may be linked with more than one SDG, e.g. ecotoxicity which is not only linked with clean water and sanitation (SDG 6) but as well with the life below water (SDG14).

2.2.3.3 Normalisation: comparing results with global and EU references

The normalisation step is an optional step in LCA, according to ISO (2006b). Normalisation allows comparing results of characterisation against a reference (e.g. the global impacts) to highlight which are the most relevant impact categories in terms of magnitude of the impacts. When analysing the impacts of EU consumption at country level, the normalisation can be done by using the environmental impacts of the EU as internal normalisation reference (Annex 3 for more details).

The **normalisation** of the characterized results was performed by dividing the impacts of EU consumption **by the environmental impacts generated at global level**, calculated as described in Crenna et al. (2019a), for all the 16 impact categories of the EF 2017 method mentioned in Table 4. Additionally, a normalisation at the EU level was carried out, by means of the Domestic Footprint results (see Annex 3 for the complete set of factors).

2.2.3.4 Weighting: aggregating results in a weighted score and developing a single headline indicator

The weighting is an optional step in LCIA, according to ISO (2006b). Weighting allows expressing results as a single final score, resulting from assigning a weight to each impact category based on the relative importance of an impact compared to another. Throughout the report, results are presented both per impact category and as “weighted score”. The weighted score is calculated multiplying normalised results by weighting factors (WF) and the weighting factors are dimensionless and expressed as points. In literature, there are different options to weight the results hence different weighting sets may be available and could be used (Pizzol et al., 2017). Weighting sets could be the result of surveys, panels, expert judgment, distance to target-based, etc. There are advantages and disadvantages inherently in any weighting scheme, first of all the possibility of compensating the impact in one impact category with a better performance in another.

With regards to the Consumer Footprint and the Consumption Footprint indicators several weighting factors may be selected based on the scope of the analysis and acknowledging that no one size fits all solution exists. In this report, the **weighting factors developed in the context of the Environmental Footprint** are adopted (Sala et al., 2018). With the aim of evaluating the relevance of the selection of alternative weighting factors, in this report another weighting set has been applied, namely, a **"reversibility"-based weighting** factors set resulting from an expert-based weighting set developed in the EF context as well. Both sets are reported in Table 4. The colour code from red to green indicates the ranking according to the decreasing relative importance of the impact categories with respect to the overall environmental impact. More variability is shown within the reversibility-based weighting set, especially when considering the most relevant impact categories. Along the report, the weighted score is calculated according to the EF weighting set. A sensitivity analysis presenting the results with the reversibility set is reported in section 7.2.

Results from LCI and LCIA are then interpreted in accordance to the stated goal and scope. The interpretation step includes completeness, sensitivity, and consistency checks (Sala et al., 2016b). Uncertainty and accuracy of obtained results are also addressed.

Table 4. Impact categories, underpinning models, units, and robustness of the impact assessment models as defined in the Environmental Footprint guidelines (EC, 2017). Weighting factors (WF) and reversibility-based weighting factors (WFr) for the Environmental Footprint (EF).

Impact category	Abbreviation	Unit	Model adopted as in EF	Model robustness*	EU normalisation factors**	Global normalisation factors (EF)[b]	Weighting factors (WFef)[c]	Weighting factors reversibility (WFr)[c]	Planetary boundaries[h]
Climate change	CC	kg CO_2 eq	IPCC, 2013	I	4.82E+12	5.55E+13	21.06	6.01	6.81E+12 [d]
Ozone depletion	ODP	kg CFC-11 eq	World Meteorological Organisation (WMO), 2014	I	9.18E+06	3.33E+08	6.31	2.87	5.39E+08 [d]
Human toxicity, non-cancer	HTOX_nc	CTUh	USEtox (Rosenbaum et al., 2008)	II/III	1.03E+05	2.66E+05	2.13	7.87	4.10E+06 [e]
Human toxicity, cancer	HTOX_c	CTUh	USEtox (Rosenbaum et al., 2008)	II/III	1.24E+04	3.27E+06	1.84	9.72	9.62E+05 [e]
Particulate matter	PM	Disease incidence	Fantke et al., 2016	I	4.97E+05	4.11E+06	8.96	7.61	5.16E+05 [e]
Ionising radiation	IR	kBq U-235 eq	Frischknecht et al., 2000	II	6.01E+11	9.54E+11	5.01	10.03	5.27E+14 [e]
Photochemical ozone formation	POF	kg NMVOC eq	Van Zelm et al., 2008, as applied in ReCiPe 2008	II	1.59E+10	2.80E+11	4.78	7.59	4.07E+11 [f]
Acidification	AC	mol H^+ eq	Posch et al., 2008	II	2.45E+10	3.83E+11	6.20	4.55	1.00E+12 [f]
Eutrophication, terrestrial	TEU	mol N eq	Posch et al., 2008	II	9.15E+10	1.22E+12	3.71	1.45	6.13E+12 [f]
Eutrophication, freshwater	FEU	kg P eq	Struijs et al., 2009	II	5.22E+08	1.11E+10	2.80	1.45	5.81E+09 [d]
Eutrophication, marine	MEU	kg N eq	Struijs et al., 2009	II	8.56E+09	1.35E+11	2.96	1.45	2.01E+11[d]
Land use	LU	Pt	based on Bos et al. (2016)	III	4.57E+14	1.54E+16	7.94	7.54	-
		kg soil loss	LANCA CF version 2.5 (Horn and Meier, 2018)		1.04E+13[a]	7.82E+14			1.27E+13 [d]
Ecotoxicity freshwater	ECOTOX	CTUe	USEtox (Rosenbaum et al., 2008)	II/III	4.15E+12	8.15E+13	1.92	4.87	1.31E+14 [d]
Water use	WU	m^3 water eq	AWARE 100 (based on) (UNEP 2016; Boulay et al. 2018a)	III	3.83E+12	7.91E+13	8.51	7.37	1.82E+14 [f]
Resource use, fossils	FRD	MJ	ADP fossils (van Oers et al., 2002)	III	2.71E+13	4.48E+14	8.32	10.69	2.24E+14 [g]
Resource use, minerals and metals	MRD	kg Sb eq	ADP ultimate reserve (van Oers et al., 2002)	III	8.21E+06	4.39E+08	7.55	8.93	2.19E+08 [g]

*This corresponds to the classification of recommended methods in the EF 2017 (EC, 2017). **This corresponds to the results of Domestic Footprint EU-28 in 2010.
Source: [a]Inventory from Faragò et al. (2019); [b]Crenna et al. (2019a) for the year 2010; [c]Sala et al. (2018); [d]Bjørn & Hauschild (2015), land use regarding soil erosion only; [e]Vargas-Gonzalez et al. (2019); [f]recalculated following Bjørn (2017); [g]JRC calculation based on the "factor 2" concept (Bringezu, 2015; Buczko et al., 2016), [h]PBs units reported in the third column.

2.2.4 Assessing impacts against SDGs and Planetary Boundaries

The results, characterised at midpoint (as for section 2.2.3.1), could be linked to specific SDGs (3, 6, 12, 13, 14, 15) as well as related to planetary boundaries, namely the quantitative estimation of the Earth carrying capacity (Figure 7). This is in line with the “live well within the limits of the planet” concept of the 7th EAP (EU, 2013). The Planetary Boundaries (PBs) framework (Steffen et al., 2015) accounts for nine Earth system processes, which embrace the Sustainable Development Goals (UN, 2015). Hence, **connecting the impact indicators with SDG and PBs helps answering the question whether the consumption in the EU is environmentally sustainable.** This means the quantification of the environmental performance of the EU consumption with respect to the Earth system capacity as an absolute term of comparison. Building on a very well-known ecological concept of carrying capacity, the Planetary Boundaries concept provides a science-based global normalisation reference of the risk that human actions will substantially alter the Earth system (Steffen et al., 2015). The currently available Planetary Boundaries with the associated ecological thresholds are shown in Table 5.

The Planetary Boundaries, as they are, cannot be applied directly for comparing the LCIA results against them. They need to be translated into the metrics of the midpoint indicators, being coherent with the impact assessment modelling adopted for the different impact categories. Based on literature (e.g. Bjørn & Hauschild, 2015; Vargas-Gonzalez et al., 2019), Planetary Boundaries applicable to Consumption and Consumer Footprint have been calculated for the EF 2017 method (Table 6). Six of them are directly taken from the literature from Bjørn & Hauschild (2015) (namely freshwater ecotoxicity, climate change, ozone depletion, marine and freshwater eutrophication, land use), while the remaining ones have been recently recalculated or adapted by EC-JRC. Notwithstanding uncertainties exist in the calculation of the Planetary Boundaries since they are based on complex ecological thresholds, they may help screening the relevance of impacts.

Four Planetary Boundaries, namely photochemical ozone formation, water use, terrestrial eutrophication and acidification, were recalculated following the procedure suggested by Bjørn (2017). This procedure builds on a conversion factor, calculated as weighted average of the ratios between the characterization factors applied in Bjørn & Hauschild (2015) and the ones recommended in the EF 2017 for the substances underpinning each interested impact category. The weight is given by the contribution of each substance to the related global normalisation factor, according to the calculation by means of the EF 2017 method.

The three Planetary Boundaries for both human toxicity categories and ionising radiation were calculated by converting the “acceptable burden” values proposed in Vargas-Gonzalez et al. (2019, submitted) from DALY to the EF 2017 metrics, by using the conversion factor proposed by the same authors. In a similar way, the ”acceptable burden” underpinning the planetary boundary of particulate matter was converted from Disability-Adjusted Life Year (DALY) to Disease incidence according to the conversion factor in Fantke et al. (2016). Alternative calculations of the planetary boundary for particulate matter have been explored, showing the uncertainties behind this value.

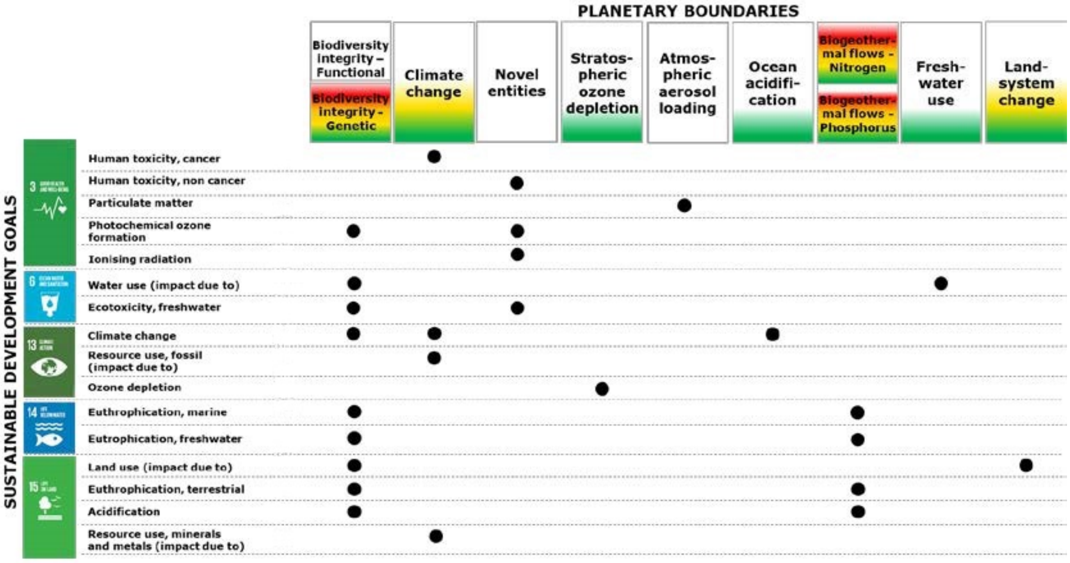
Finally, the two Planetary Boundaries for the resource use categories were calculated by applying the concept of Factor 2 to the global inventory for resources (Sala et al., 2017). In fact, according to Buczko et al. (2016) and Bringezu (2015), a reduction in material consumption by a factor 2 (namely 50%) at the global level is needed to achieve environmental sustainability.

Table 5. Currently available Planetary Boundaries, as proposed by Rockström et al. (2009) and updated by Steffen et al. (2015).

Earth system process	Control variable	PB threshold	PB zone of uncertainty	Nature of limit	Current value	Unit
Climate change	Atmospheric carbon dioxide (CO_2) concentration	350	350-450	Upper	398.5	ppm CO_2
	Change in radiative forcing	1	1-1.5	Upper	2.3	W/m^2
Change in biosphere integrity	Genetic diversity: extinction rate	10	10-100	Upper	100-1000	E/MSY (extinctions per million species-year)
	Functional diversity: Biodiversity intactness index	90	90-30	Lower	84	%
Stratospheric ozone depletion	Stratospheric ozone (O_3) concentration	275.5	275.5-261	Lower	283	DU (Dobson unit)
Ocean acidification	Carbonate ion concentration, average global surface ocean saturation state with respect to aragonite	80	80-70	Lower	84	% of the pre-industrial aragonite saturation state, including natural diel and seasonal variability
Biogeochemical flows (N and P cycles)	Nitrogen (N) global: industrial and intentional biological fixation of N	62	62-82	Upper	150	Tg N/year
	Phosphorus (P) global: P flow from fresh water systems into the ocean	11	11-100	Upper	22	Tg P/year
	Phosphorus (P) regional: P flow from fertilizers to erodible soil	6.2	6.2-11.2	Upper	14	Tg P/year
Land-system change	Global: area of forested land as % of original forest cover	75	75-54	Lower	62	%
	Biome: area of forested land as % potential forest	50	50-30	Lower	-	%
Fresh water use	Global: maximum amount of consumptive blue water use	4000	4000-6000	Upper	2600	km^3/year
	Basin: blue water withdrawal as % of mean monthly river flows	30	30-60	Upper	-	%
Atmospheric aerosol loading	Global: Aerosol Optical Depth (AOD)	-	-	-	-	AOD
	Regional: AOD as a seasonal average over a region	0.25	0.25-0.50	Upper	0.30	AOD
Introduction of novel entities	Not defined yet	-	-	-	-	-

The colour code for the current value of the control variable indicates its status: green=below the PB ("safe"), orange=within the zone of uncertainty of the PB ("increasing risk"), red=beyond the zone of uncertainty of the PB ("high risk"). The planetary boundary itself lies at the intersection of the ecological threshold with the uncertainty zone.

Figure 7. Overview of the link between the EF midpoint impact categories adopted in Life Cycle Impact Assessment, the Sustainable Development Goals and the Planetary Boundaries.



Note: some impact categories may fall into more than one SDG. For the sake of simplicity, each impact category has been listed once. For the complete overview, please refer to Box 1 in section 1. The colour code indicates the status of the planetary boundary: green=below the PB, within the safe operating space; orange=within the zone of uncertainty of the PB; red=beyond the zone of uncertainty of the PB, in a high risk area.

Table 6. Planetary Boundaries as adapted for their application in the LCIA context, according to the impact categories available in the EF method.

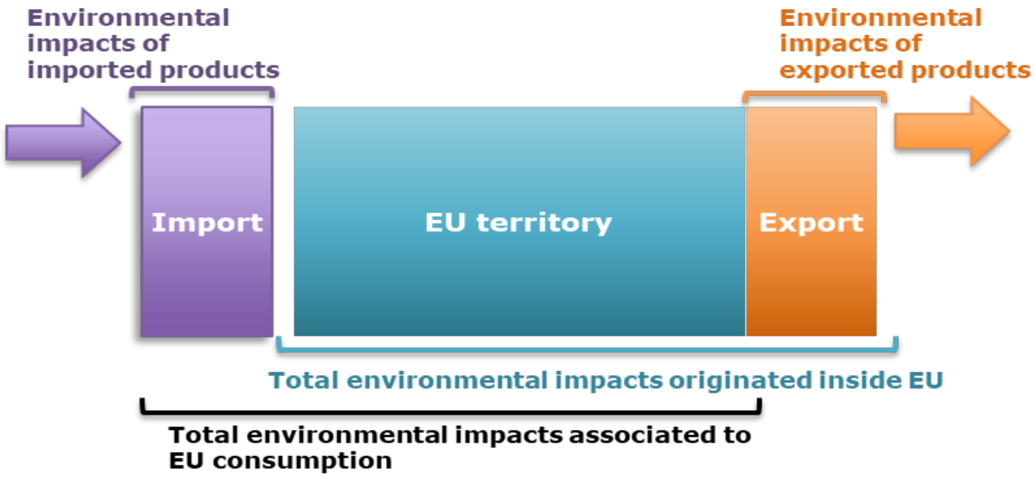
Impact category	**Abbreviation**	**Unit**	**PB**	**PB per capita***	**Sources**
Climate change	CC	kg CO_2 eq	6.81E+12	9.85E+02	Bjørn & Hauschild (2015)
Ozone depletion	ODP	kg CFC-11 eq	5.39E+08	7.80E-02	Bjørn & Hauschild (2015)
Eutrophication, marine	MEU	kg N eq	2.01E+11	2.90E+01	Bjørn & Hauschild (2015)
Eutrophication, freshwater	FEU	kg P eq	5.81E+09	8.40E-01	Bjørn & Hauschild (2015)
Eutrophication, terrestrial	TEU	molc N eq	6.13E+12	8.87E+02	recalculated by Bjørn (personal communication)
Acidification	AC	molc H^+ eq	1.00E+12	1.45E+02	recalculated by Bjørn (personal communication)
Land use	LU	kg soil loss	1.27E+13	1.84E+03	Bjørn & Hauschild (2015)
Water use	WU	m^3 world eq	1.82E+14	2.63E+04	based on recalculation by Bjørn (personal communication)
Particulate matter	PM	Disease incidence	5.16E+05	7.47E-05	based on Vargas-Gonzalez et al. (2019)
Photochemical ozone formation, human health	POF	kg NMVOC eq	4.07E+11	5.88E+01	recalculated by Bjørn (personal communication)
Human toxicity, cancer	HTOX_c	CTUh	9.62E+05	1.39E-04	based on Vargas-Gonzalez et al. (2019)
Human toxicity, non-cancer	HTOX_nc	CTUh	4.10E+06	5.93E-04	based on Vargas-Gonzalez et al. (2019)
Ecotoxicity, freshwater	ECOTOX	CTUe	1.31E+14	1.90E+04	Bjørn & Hauschild (2015)
Ionising radiation, human health	IR	kBq U^{235} eq	5.27E+14	7.62E+04	based on Vargas-Gonzalez et al. (2019)
Resource use, fossils	FRD	MJ	2.24E+14	3.24E+04	JRC calculation based on factor 2 concept (Bringezu, 2015; Buczko et al., 2016)
Resource use, mineral and metals	MRD	kg Sb eq	2.19E+08	3.18E-02	JRC calculation based on factor 2 concept (Bringezu, 2015; Buczko et al., 2016)

*Global population in 2010: 6,916,183,482, as from Bjørn & Hauschild (2015). Planetary Boundaries order presented in accordance with Table 5.

2.3 The Consumption Footprint

The Consumption Footprint takes into account both the burdens associated with domestic activities (within the domestic boundaries of EU) and those due to trade. In order to do so, **three different accounting components are quantified: domestic, import, and export**. The sum of environmental impacts occurring within the domestic boundaries of the EU, with impacts associated with imports minus those associated with exports, leads to the quantification of the environmental impacts associated with EU apparent consumption (the EU Consumption Footprint; Figure 8). In order to support a comprehensive interpretation of the results, those are reported by impact categories as well as weighted score.

Figure 8. Environmental impact associated with EU consumption (the "Consumption Footprint").



The following equation is applied:

Consumption Footprint = **Import Footprint** (impacts due to Imports) **+ Domestic Footprint** (impacts due to activities occurring within the EU boundary) **– Export Footprint** (impacts due to Exports).

The three components building the Consumption Footprint are estimated through different accounting perspectives, as reported in Table 3. On the one hand, the Domestic Footprint is calculated from a territorial (producer) perspective. On the other hand, **impacts allocated to trade are quantified** with a consumption-based perspective, implemented with a resolution of either final products (**bottom-up approach**) or economic sectors (**top-down approach**).

The Domestic Footprint

The Domestic Footprint (that is, the 'domestic' component of the Consumption Footprint) accounts for the environmental impacts associated to emissions and resource extraction occurring within a Member State boundary (or the whole EU boundary). Such impacts stem from both production and consumption activities taking place within the Member State's domestic territory. This means that environmental impacts due to those activities comprised under economic sectors such as industry, agriculture, energy, mining, and service, are accounted for as 'domestic' component. Similarly, environmental impacts stemming from households and government's activities such as transport, heating, etc. are included as well in the 'domestic' component as they occur within the Member State boundary. Details about data sources and elaboration are reported in section 3.1, more extensively detailed in Beylot et al. (2019).

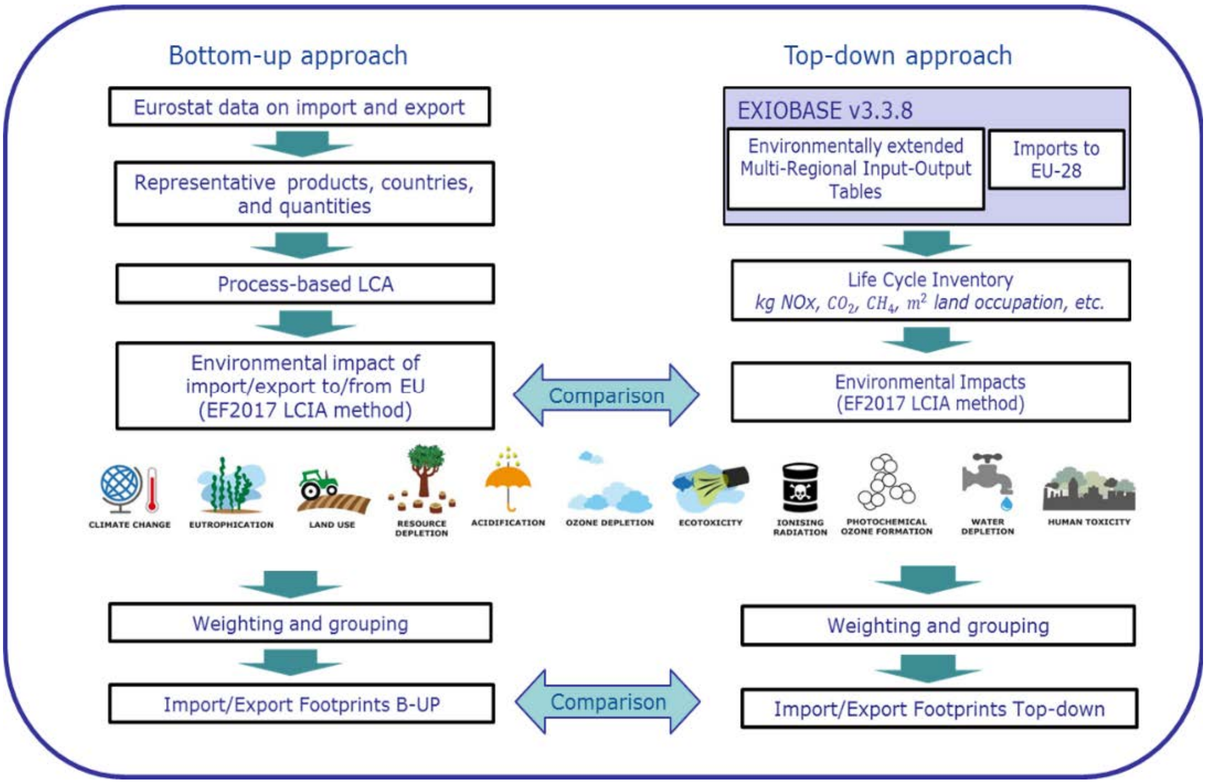
The Trade Footprint: Bottom-up and Top-down approaches

The import and export components account for environmental impacts associated to product's stages of the supply chains happening outside EU borders. For instance, the production of a car imported in one of the Member States requires several production steps, which imply the use of resources such as fossil fuels, metals and minerals as well as the emission of a number of pollutants, leading to environmental impacts. Such impacts are allocated to the car according to the LCA method and represent the environmental burden associated with the production of a car. The sum of all of the environmental burdens associated to the entire volume of imported, or exported, goods leads to the total environmental impact associated with import, or respective export, of an economy.

The trade component of the Consumption Footprint capturing the impacts that are added on top of the Domestic Footprint due to imports and the respective impacts deducted due to exports of goods **can be calculated in two ways** (Figure 9).

1. **Top-down Trade Footprint:** trade impacts calculated using sectorial-based Multi-Regional Input-Output Tables (MRIOTs), considering the EXIOBASE database version 3. The impacts are calculated for the entire trade, at the level of **product categories**;
2. **Bottom-up Trade Footprint**: trade impacts are calculated based on the LCA of 40 selected **representative products**[5] which are imported and exported in EU. The selection has been based on criteria of mass and economic values.

Figure 9. Schematic representation of the two approaches adopted to assess and compare the environmental burdens of trade.



[5] Representative products modelled in the Consumption Footprint bottom-up (40 representative products of most traded goods) differ from those representative products modelled in the Consumer Footprint (150 representative products of most consumed goods in the EU).

2.4 The Consumer Footprint

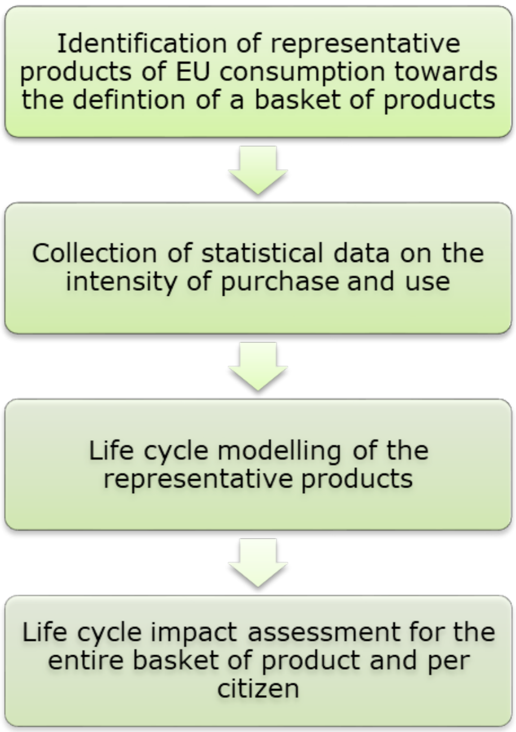
The **Consumer Footprint** aims to assess the potential **environmental impact of EU consumption** calculated by means **of representative products**. The Consumer Footprint is based on the results of the Life Cycle Assessment (LCA) of more than 130 representative products purchased and used in one year 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)**. The sum of the five key areas considered gives a comprehensive picture of the overall impact of household consumption in EU, as well as an indication of the impact generated by an average EU citizen during one year which is a macro level consumption impact indicator.

The **Consumer Footprint** (Figure 10) is a bottom-up approach and **bridges the assessment levels from micro level (product level), to meso level (consumption areas) and to macro level (average Consumer Footprint per reference year)**. For each area of consumption, a respective Basket of representative Products (BoP) is built, based on statistics on consumption and stock of products. For each of the five BoPs, a baseline scenario is calculated, taking as reference the consumption of an average EU citizen.

The developed footprints (LCAs) are in line with the International Life Cycle Data system (ILCD) guidelines and follow, to the extent it is possible and relevant, the Environmental Footprint methods as published in the Communication "Building the Single Market for Green Products" (EC, 2013b). The models are built with a **parametric approach**. This structure allows for building a **baseline scenario** as well as **modelling scenarios** to test the effect of technological improvements or changes in behaviours (as illustrated in section 8) and for periodical updates of the indicators. 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 (see section 4.2).

Figure 10. Consumer Footprint: modelling approach.



The baseline models of the five BoPs allow identifying the environmental hotspots along the products lifecycle and within the consumption area of each specific BoP. Then, results of the hotspot analysis are 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 them. For each of the actions, a scenario can be developed, by acting on the baseline model and simulating the changes associated to the specific intervention. The LCA results of each scenario can be then compared to the results of the baseline, to identify potential benefits or impacts coming from the implementation of the solution tested, as well as to unveil possible trade-offs.

To calculate the Consumer Footprint in the EU, the five BoPs are added together. When doing this, it has to be considered that there are activities that may be part of the life cycle of more than one BoP (for instance, the electricity used for the laundry machine is included in the use phase of the BoP Appliances, but also in the use phase of the BoP Housing, which includes all energy uses that happen in the house). This is not a problem when considering each BoP separately, but can lead to double counting when summing all BoPs. Therefore, for the calculation of the overall Consumer Footprint in the EU overlapping activities were identified, and taken into account only once (generally, in the BoP which has a larger scope, i.e., in the previous example, in the BoP housing).

Moreover, it has to be considered that the BoPs that are built using representative products (namely Food, Household goods and Appliances), do not include 100% of the products consumed in the three areas of consumption described. Therefore, to take into account, to the maximum extent possible, the total consumption in the sector under investigation, quantities of representative products in BoP Food, BoP Household goods and BoP Appliances have been up-scaled to enlarge the representativeness of these two baskets in the assessment of the Consumer Footprint in EU.

2.5 Temporal and geographical scope of Consumption and Consumer Footprint

Given differences in data sources, the Consumption Footprint top-down and bottom-up, and the Consumer Footprint have different temporal and geographical coverage, as well as a different number of indicators that could be calculated, as reported in Table 7**.**

Table 7. Temporal and geographical scope of the different indicators.

	Domestic Footprint	Consumption Footprint Top-down	Consumption Footprint Bottom-up	Consumer Footprint
Time frame	2000-2014	2000-2014 (for EU) 2000-2011 (for single Member States)	4 years: 2000, 2005, 2010, 2014	2 years: 2010 and 2015
Number of indicators	16	14 (emission affecting ionising radiation and ozone depletion are missing in EXIOBASE 3)	16	16
Geographical scope	EU and single countries	EU and single countries	EU 28 as a whole	EU as a whole, no country specification

3 Consumption Footprint in EU and at country scale

By adopting a macro scale perspective, it is possible to calculate the Consumption Footprint of the EU as a whole and at Member State level. Key features of the Consumption Footprint indicator are the life cycle perspective, the quantification of the environmental impacts due to territorial activities and the accounting for the impacts due to trade activities (i.e. import and export). According to the different modelling options for building the inventory of the emissions into air, water and soil and the extracted resource, a production and territorial based perspective could complement the calculation of the apparent consumption with the inventory associated to the trade. This chapter presents the methodological specifications for each approach and the results of such a macro-scale assessment of the Consumption Footprint in the EU, including the Domestic Footprint (territorial approach) and the Consumption Footprint (consumption-based approach) Top-down and Bottom-up. The type of analysis (e.g. contribution, trend) and level of detail of the results (from the EU as a whole to flow contribution) are detailed in Table 8.

Table 8. Type of analysis and level of detail for the Domestic Footprint (section 3.1), Consumption Footprint Top-down (section 3.3) and Consumption Footprint Bottom-up (section 3.4).

	Domestic Footprint	**Consumption Footprint (Top-down)**	**Consumption Footprint (Bottom-up)**
Trend of weighted score EU Footprint (decoupling)	● (2000-2014)	● (2004-2014)	● (2000-2014)
Trend of impact categories for EU (decoupling)	● (2000-2014)	● (2004-2014)	● (2005-2014)
Variation by country and impact category	● (2000-2014)	● (2004-2011)	*Not available*
Variation by country, per person and per area	● (2000-2014)	● (2004-2011)	*Not available*
Country ranking per citizen by impact category	● (2010)	● (2011)	*Not available*
Flow contribution by impact category	● (2010)	● (2010)	*Not available*

3.1 Domestic Footprint at EU and Member States level

Box 3. Key messages from the findings of the Domestic Footprint assessment

— The Domestic Footprint aims at calculating the impacts due to resource extraction, and emissions in 2000-2014 in the EU territory in order to monitor the efforts of EU Member States to decouple economic growth from environmental impacts.

— Trends of environmental impacts (as total EU) and GDP indicate that decoupling is taking place. An absolute decoupling occurs according to most of the indicators.

— In particular, France, United Kingdom, and Belgium register a general decrease associated to almost every indicator, despite an increase in the GDP.

— Considering the impact related to an average citizen in each Member State, countries with a high GDP per citizen frequently present high impact per citizen (e.g. for climate change, marine eutrophication and fossil resource use).

— Main sources of environmental pressures are (i) energy sector (electricity, heating and mobility), (ii) manure, fertilizer and pesticide application in agricultural management or industrial activities, and (iii) nuclear energy production.

— The most influencing substances registered for the EU Domestic Footprint in 2010 frequently are the same appearing in a similar analysis conducted at global level. The main exception is resource use (minerals and metals) indicator.

— Country-specific data have not the same level of coverage and completeness, potentially hampering the analysis. Despite the attempts made for increasing coverage and robustness of the Domestic Footprint, current estimations still present limitations linked to the completeness of the inventories and to the methodological choices. Additionally, the completeness and robustness of the impact assessment and the overall consistency between the previous mentioned aspects may play a role as well in determining strengths and weaknesses of the results.

The objective of the Domestic Footprint is **assessing the overall environmental impact of the European Union (EU) and ultimately of each Member State adopting a production-based and territorial-based perspective.** This evaluation accounts for emissions to air, water and soil, as well as resource extraction occurring in the territory of EU. For this reason, it could be identified as a territorial footprint, representing the "domestic" part of the Consumption Footprint indicator.

The focus of this component of the Consumption Footprint is to **monitor the efforts of EU Member States to decouple economic growth from environmental impact**. In the following sections, the results are reported at EU level and at country level (ISO 2-digits codes identify the countries) (Annex 7) with the aim of assessing if and to which extent decoupling is taking place: if absolute (i.e. economic development increases while the environmental impact is stable or decreasing) or relative (i.e. the environmental impact increases but at a lower rate with regard to economic development).

3.1.1 Methodology for building the domestic inventory

The Domestic Footprint builds upon an **extensive data collection of detailed information (i.e. LCI data) on resource extraction and emissions in EU territory**, which allows calculating the overall environmental impact for 16 impact categories and as weighted score, by taking into consideration a number of environmental pressures (i.e. elementary flows). The LCI construction started from the work by Sala et al. (2014; 2015), which is focused on 1990-2010 timeframe and geographically circumscribed to EU-27. This inventory has been improved in the present work, in terms of both time and geographic coverage by including data on Croatia (as latest Member of EU) and data related to the time period 2011-2014.

The inventory consists of data gathered from different sources: official statistics and emission models. Statistics are retrieved from official reports and databases hosted by international, European and national bodies, for instance, the United Nations Convention on Climate Change (UNFCCC), Eurostat, the European Environmental Agency (EEA), the Food and Agricultural Organization of the United Nations (FAO), the Organisation for Economic Co-operation and Development (OECD), the British Geological Survey (BGS). Even if, from a general point of view, the domestic inventory does not capture the information at the economic sector, some of the data sources adopted provide data at this level or even related to the specific economic activity. Generally speaking, the inventory consists of: (i) raw data, as provided by third parties (e.g. greenhouse gas emissions in UNFCCC reports); (ii) estimated data, as calculated applying scientific literature (e.g. total nitrogen and phosphorus emissions to water from wastewater treatment plants); and (iii) extrapolated data, as estimated to fill the gaps in the original data sources (e.g. data on water withdrawal). Table 9 illustrates the data sources for the domestic inventory according to each impact indicator of EF 2017, referring to 2000-2014 timeframe, which constitutes the focus of the present analysis. Specific details on the data collection and the extrapolation strategies are reported in Annex 2.

Taking into account the possible limitations, the above-mentioned differences in the origin of the data may introduce some uncertainties, and the hierarchical approach applied in case of multiple sources for the same type of data plays a role as well. Additionally, not all the Member States provided the same set of data. The variability in country-specific data was not associated to a precise factor, for instance the entry year in the EU, but more often occurred for data referred to most recent years (i.e. 2011-2014) or to small countries (e.g.

Malta, Luxembourg data on GHGs other than CO_2 and methane). These aspects have an important role in determining the overall robustness, leading to different levels of robustness according not only to the data sources but also to the country.

Table 9. Data sources of the EU domestic inventory 2000-2014 for all the EF 2017 impact categories.

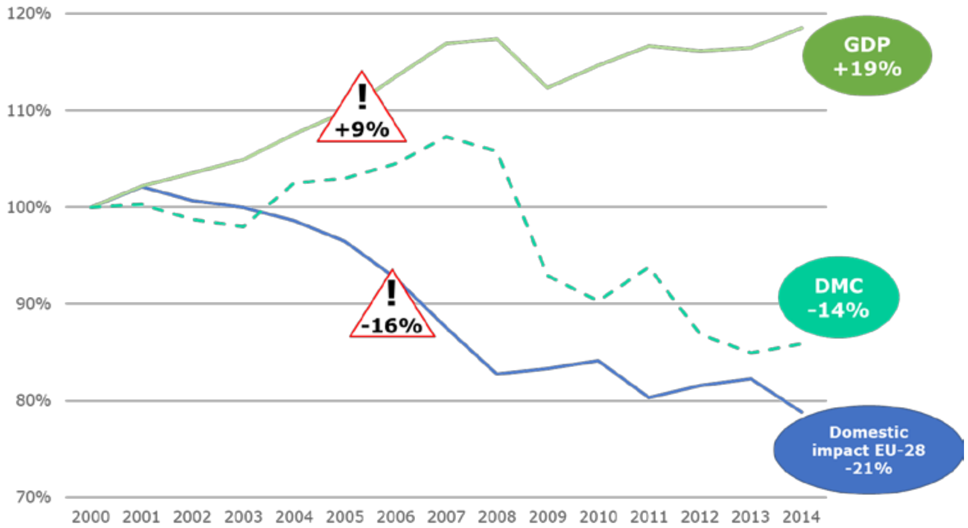
Impact category	Substance groups	Data sources
Climate change (CC)	GHGs both from direct emissions and those associated to LULUCF (land use, land-use change and forestry); PCFs; HFCs; SF_6	- UNFCCC (2017)
	CFCs; HCFCs	- Linear extrapolation based on 2000-2010, from Sala et al. (2014)
Ozone depletion (ODP)	CFCs; HCFCs	- Linear extrapolation based on 2000-2010, from Sala et al. (2014)
Human toxicity cancer (HTOX_c), Human toxicity, non-cancer (HTOX_nc) and Ecotoxicity freshwater (ECOTOX)	Air emissions: Heavy metals (HMs) Organics non-NMVOC (non-methane volatile organic compounds), dioxins, PAH, HCB, etc. Releases in water: Industrial releases of HMs + organics Urban wastewater treatment plants (HMs + organics) Releases in soil: Industrial releases (HMs, POPs) Sewage sludge (containing organics and metals) Manure Pesticides: Active ingredients (AI) breakdown (i.e. disaggregated into EU countries and major types of crops) combined with dosage statistics.	- Leclerc et al., 2019
Particulate matter (PM)	NOx; NH_3; SO_2; PM_{10}; $PM_{2.5}$; CO	- EMEP/CEIP (2017)
Ionising radiation (IR)	Emissions of radionuclides: -to air and water from electricity generation from nuclear sources, i.e. uranium mining and milling, nuclear power plants, coal, natural gas and oil combustion, geothermal energy extraction	- UNSCEAR, 2016
	-to air and water from nuclear spent-fuel reprocessing	- RADD (2017); UNSCEAR (2016)
	-from crude oil in the energy mix supply	- EF dataset (EC-JRC, 2017)
Photochemical ozone formation (POF)	NMVOC as aggregated; NO_X, CH_4; CO	- EMEP/CEIP (2017)
	NMVOC breakdown	- Laurent & Hauschild (2014)
Acidification (AC)	NO_X; SO_2; NH_3	- EMEP/CEIP (2017)
Eutrophication, terrestrial (TEU)	NO_X; NH_3	- EMEP/CEIP (2017)
Eutrophication, freshwater (FEU)	Phosphorous (total) to soil and water, from agriculture	- Eurostat (2017a) for phosphorous input and output data; UNFCCC (2017) for nitrogen input; FAOstat (2013) for cultivated cereal surfaces - Bouwman et al. (2009) 10% loss of P to water as global average
	Phosphorous (total) to soil and water, from sewages	- Van Drecht et al (2009) for removal efficiency of P - (RPA 2006) Use of laundry and dishwater detergents and Fraction of P-free laundry detergent - OECD (2013), Eurostat (2017b) for % of people connected to wastewater treatment plants (WWTP)
Eutrophication, marine (MEU)	NO_x; NH_3	- EMEP/CEIP (2017)
	Nitrogen (total) to water, from agriculture	- UNFCCC (2017) for Ntot input data, losses to water and to air, synthetic fertilizers manure - N output based on ratios (by country, by year) between Input and Output by Eurostat (2017a), multiplied to Inputs from UNFCCC (2017)
	Nitrogen (total) to soil and water, from sewages	- protein intake, FAOstat (2018) - Van Drecht et al. (2009)removal efficiency of Nitrogen - OECD (2013), Eurostat (2017b) % of people connected to WWTP
Land use (LU)	"Land occupation" and "land transformation": forest, cropland, grassland, settlements, wetlands, unspecified	- UNFCCC (2017)
Water use (WU)	Gross freshwater abstraction & Gross water consumption	-FAO-Aquastat (2018); Eurostat (2018a); OECD (2016) -WaterGAP (Müller Schmied et al., 2014; Flörke et al., 2013; Aus der Beek et al., 2010)
Resource use	Minerals and metals (MRD)	-BGS (2017); USGS (2011; 2012; 2013; 2014); World Mining Data (Reichl et al., (2017).
	Fossils (FRD)	-Eurostat (2017c; 2017d; 2017e; 2017f; 2017g)

Based on the developed inventory, emissions and resources extracted in EU have been characterised with the EF 2017 impact assessment method (EC, 2017) to calculate potential impact in 16 impact categories. This operation could introduce other aspects playing a role in defining the strengths and the weaknesses of the Domestic Footprint. Key features are (i) the level of robustness of the impact assessment method, and (ii) the consistency between the level of detail for both the inventory and the characterization factors underpinning the calculation (Sala et al., 2015; Benini and Sala, 2016).

3.1.2 Domestic Footprint: trends of environmental impacts over time (2000-2014)

The Domestic Footprint time-trend calculated as a weighted score over the period 2000-2014 is reported in Figure 11. To assess the decoupling of environmental impacts from both economic growth and resource consumption, the trend of the environmental impact is compared with the Gross Domestic Product (GDP) as well with the Domestic Material Consumption (DMC), both measured as total for EU (Eurostat, 2018b; 2018c).

Figure 11. Domestic Footprint weighted score: overall variation between 2000 and 2014, compared with GDP and DMC.



Note: Results for 2000 are reported as 100%, and results for the other years are rescaled accordingly. Data source for GDP and DMC: Eurostat (2018b; 2018c).

The decoupling is quite evident. Actually, the relative change between 2000 and 2014 of **the EU environmental impact as a weighted score is a general decrease** (-21%) **whereas the GDP shows a general increase for the same period** (+19%), which is specular in the extent to the Domestic Footprint reduction. 2004 marks the beginning of an absolute decoupling phase (2004-2008): despite the continuous growth of GDP (ca.+9%), a substantial decrease in the environmental impact is observed (i.e. -16%).

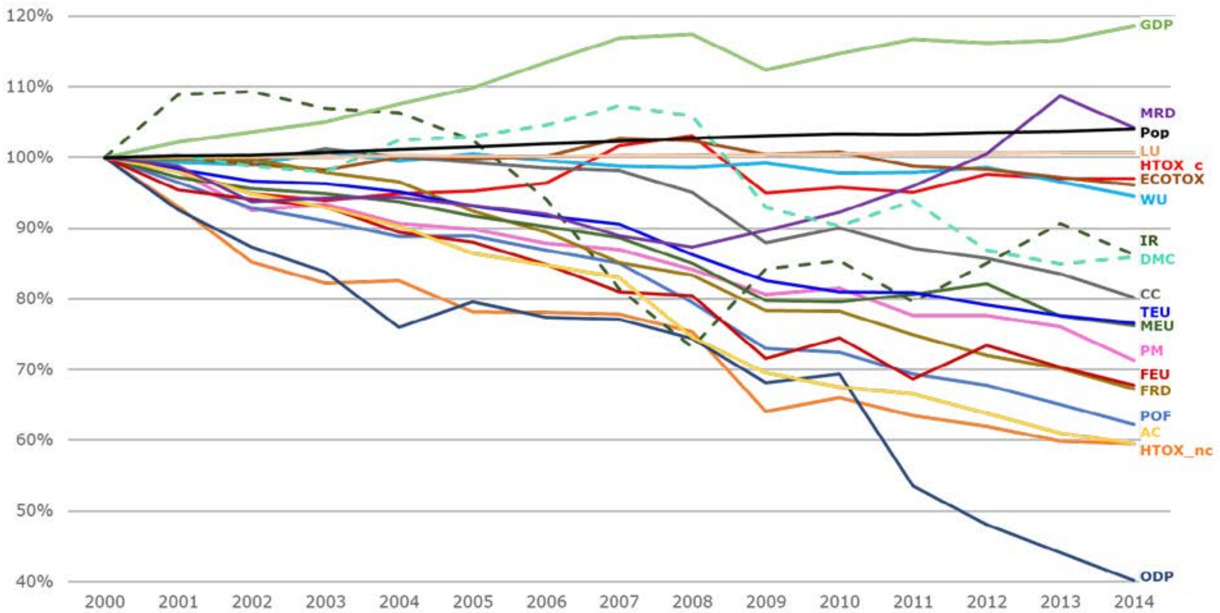
When all the indicators are plotted against their value in the year 2000 set as starting point (Figure 12), it is possible to notice that most of them register a break in the link between the economic growth and the environmental impacts in 2000-2014. Furthermore, an absolute decoupling occurs in the majority of cases, starting from year 2000. Only three indicators present a relative decoupling: for ionising radiation, land use and resource use (mineral and metals), the impact score increases (at different rate according to each indicator) but without exceeding the GDP growth. The population trend (Eurostat, 2018d) is included as a term of comparison, showing no significant variation in the timeframe. Considering that GDP grew by 19% in 2000-2014, the decoupling is more evident in 2000-2014 for ozone depletion (-60%), resource use-fossils (-33%), human toxicity-non cancer, photochemical ozone formation and acidification (all around -40%).

The linear extrapolation of some missing data for the most recent years could affect the reduced trend registered in some impact categories. For instance, HCFCs and CFCs emissions lead the ozone depletion impact and 2011-2014 data for these flows were linearly extrapolated based on the decreasing trend of previous years (2000-2010).

Regarding ionising radiation, the very peculiar trend observed depends mainly on nuclear energy production in United Kingdom and France. For both countries, radioactive emissions come principally from nuclear power plants and reprocessing activities. Actually, the nuclear electricity generation increased in 2000-2003 in United Kingdom and in 2000-2014 in France (IAEA-PRIS, 2017), by increasing the emissions as well. In particular, radioactive emissions stemming from the nuclear technology most diffused in United Kingdom, i.e. gas-cooled reactors (IAEA-PRIS, 2017), are characterized by a high content of C-14 (UNSCEAR, 2016) which is leading the EU impact score in ionising radiation.

In spite of the general decreasing trend of EU impacts for all the analysed indicators, **not all the Member States may have the same rate of emission reduction or resource efficiency.** Therefore, Table 10 gives an easy indication on the potential difference in the evolution of the impacts in 2000-2014 for each country and each indicator compared to GDP. The picture is globally showing an enhancement in saving emissions and resource extraction. In particular, France, United Kingdom and Belgium show very good results. Despite an increase in the GDP, these countries register a general decrease associated to almost every indicator and significant reduction (namely between -70% and -100%) for at least one of them. The table includes also the variation in the weighted score, calculated by means of a global reference (Crenna et al., 2019a) or of the EU total impact in the normalisation step. When using the global normalisation references, the ionising radiation acquires the greatest importance, returning a very high contribution to the weighted score. This happens because, when comparing the EU impacts to the global ones, the ionising radiation shows a very high ratio: about 60% of the global score (Crenna et al., 2019a). In order to avoid this kind of influence, the EU normalisation approach is introduced in the comparisons among the Member States.

Figure 12. Domestic Footprint: indicators overview per impact category, overall variation between 2000 and 2014.



Note: Comparison of the results of 16 EF 2017 indicators with GDP, DMC, and population. Results for 2000 are reported as 100%, and results for the other years are rescaled accordingly. GDP, DMC and population data source: Eurostat (2018b; 2018c; 2018d). Acronyms explained: CC = climate change; ODP = ozone depletion; HTOX_nc = human toxicity, non-cancer; HTOX_c = human toxicity, cancer; PM = particulate matter; IR = ionising radiation; POF = photochemical ozone formation; AC = acidification; TEU = eutrophication, terrestrial; FEU = eutrophication, freshwater; MEU = eutrophication, marine; LU = land use; ECOTOX = ecotoxicity freshwater; WU = water use; FRD = resource use, fossils; MRD = resource use, minerals and metals.

Table 10. Domestic Footprint: EU and country-specific percentage variation in the environmental impacts between 2000 and 2014.

	CC	ODP	Htox_nc	Htox_c	PM	IR	POF	AC	TEU	FEU	MEU	ECOTOX	LU	WU	FRU	MRU	Single GLO	Single EU	GDP	POP	DMC
AT	8%	-27%	28%	-9%	-23%	-33%	-33%	-14%	-11%	-36%	-35%	6%	-1%	-5%	-28%	-35%	-10%	18%	22%	6%	-11%
BE	-25%	-39%	-47%	-17%	-41%	-29%	-49%	-45%	-32%	-26%	-9%	-8%	2%	-33%	-30%	-81%	-33%	-8%	22%	9%	-12%
BG	-3%	-66%	-57%	8%	-32%	-10%	-26%	-68%	-25%	-4%	-4%	-22%	0%	-12%	4%	98%	-19%	14%	63%	-12%	52%
CY	0%	43%	-43%	-67%	-67%	n.a.	-27%	-49%	-20%	4%	-23%	-32%	2%	11%	n.a.	-41%	-30%	-1%	22%	24%	-42%
CZ	-15%	39%	-12%	125%	-39%	124%	-20%	-42%	-38%	-27%	-34%	-2%	0%	-14%	-13%	n.a.	-17%	8%	41%	2%	-13%
DE	-13%	2%	-42%	-30%	-24%	-44%	-39%	-18%	-14%	-33%	-32%	-3%	2%	-26%	-36%	181%	-21%	9%	17%	-2%	-5%
DK	-31%	-56%	-36%	-21%	-22%	11%	-47%	-32%	-31%	-7%	-33%	1%	0%	2%	-52%	36%	-32%	-9%	12%	6%	-14%
EE	31%	-94%	17%	19%	-47%	103%	-21%	-39%	2%	-28%	6%	8%	0%	15%	-20%	n.a.	-19%	9%	62%	-6%	73%
EL	-20%	-39%	12%	-13%	-6%	-50%	-38%	-51%	-25%	-64%	-15%	-11%	-1%	0%	-24%	22%	-17%	4%	-2%	1%	-10%
ES	-18%	-45%	-58%	22%	-38%	-10%	-41%	-48%	-23%	-25%	-55%	14%	1%	-10%	-31%	-60%	-27%	-8%	19%	15%	-51%
FI	-37%	-80%	-24%	-22%	-36%	-13%	-39%	-27%	-21%	-25%	64%	0%	1%	0%	16%	93%	-8%	25%	18%	5%	-8%
FR	-22%	-47%	-57%	-44%	-42%	41%	-61%	-32%	-24%	-48%	-26%	-6%	2%	-11%	1%	-59%	8%	5%	17%	9%	-19%
HR	-8%	-50%	-81%	-71%	-42%	-36%	-32%	-48%	-36%	-2%	-22%	-11%	0%	-6%	-20%		-32%	-8%	24%	-6%	21%
HU	-26%	206%	-43%	225%	-18%	11%	9%	-65%	-15%	13%	-16%	-8%	0%	7%	-25%	24%	-19%	7%	30%	-3%	9%
IE	-17%	-59%	-29%	-2%	-32%	294%	-49%	-35%	-16%	-28%	-23%	5%	0%	-14%	-29%	-21%	-24%	-6%	54%	23%	-38%
IT	-28%	-47%	-41%	38%	-26%	31%	-49%	-43%	-29%	-41%	-31%	-5%	0%	18%	-35%	-20%	-24%	2%	-1%	7%	-53%
LT	20%	46%	18%	162%	-1%	-100%	95%	-13%	9%	-30%	28%	-18%	1%	-89%	-95%	4%	-13%	19%	80%	-16%	78%
LU	15%	-34%	-24%	24%	-23%	205%	-37%	-28%	-28%	-5%	-27%	4%	1%	-23%	n.a.	n.a.	-9%	21%	46%	27%	-16%
LV	203%	10%	-88%	88%	-15%	n.a.	-4%	2%	24%	36%	30%	1%	0%	17%	-93%	n.a.	13%	43%	67%	-16%	41%
MT	8%	-35%	-89%	-72%	-55%	n.a.	-65%	-70%	-42%	-4%	-44%	-6%	1%	69%	n.a.	n.a.	-38%	-17%	44%	10%	29%
NL	-15%	-22%	22%	-8%	-39%	5%	-47%	-33%	-32%	-59%	-37%	1%	1%	35%	-4%	-6%	-18%	17%	16%	6%	-17%
PL	-3%	197%	4%	60%	-22%	279%	51%	-36%	-16%	-33%	-5%	-7%	0%	-7%	-22%	12%	-10%	17%	64%	-1%	22%
PT	-26%	10%	-40%	-20%	-40%	-23%	-47%	-55%	-31%	-30%	-34%	-7%	1%	-14%	n.a.	14%	-27%	12%	1%	2%	-24%
RO	-17%	1485%	-63%	89%	8%	112%	94%	-52%	-21%	8%	-3%	-11%	0%	-21%	-16%	-75%	-1%	13%	67%	-11%	194%
SE	-66%	-47%	-12%	-19%	-25%	14%	-35%	-24%	-22%	-19%	-34%	9%	0%	-1%	13%	1%	-9%	2%	31%	9%	15%
SI	-17%	-19%	-82%	-76%	-20%	34%	-36%	-55%	-12%	-36%	-16%	-20%	2%	11%	7%	12%	-20%	2%	30%	4%	-24%
SK	-14%	8%	-57%	-10%	10%	-90%	-20%	-35%	-12%	-32%	0%	-19%	0%	-52%	-14%	92%	-54%	0%	76%	0%	25%
UK	-34%	-78%	-29%	-23%	-32%	-36%	-58%	-50%	-34%	-28%	-37%	-2%	0%	-35%	-63%	-75%	-39%	-28%	26%	9%	-27%
EU28	-20%	-59%	-40%	-2%	-28%	-14%	-38%	-40%	-23%	-32%	-24%	-5%	1%	-6%	-33%	4%	-21%	n.a.	19%	4%	-14%

Note: Domestic Footprint relative change between year 2000 and year 2014, according to 16 indicators. GDP, DMC and population data source: Eurostat (2018b; 2018c; 2018d). Weighted score with both global and EU normalisation references is included. Traffic light colours identify the rate of variation: significant increase (orange: 51% to 100%), slight increase (yellow; 0% to 50%), decrease (light green;-1% to -69%) and remarkable decrease (dark green; -70% to -100%). Dark red cells identify outliers (i.e. more than 2 times increase). Not available data are reported as “na”. Details on all the outliers are presented in Annex 3. Acronyms mentioned in Figure 12 are used to identify all the impact categories. Greece results in human toxicity (cancer and non-cancer) and ecotoxicity could be underestimated due to high uncertainties related to the underpinning inventory.

Table 11. Domestic Footprint: EU and country-specific environmental impacts in 2010 – absolute values.

	CC	ODP	HTOX_nc	HTOX_c	PM	IR	POF	AC	TEU	FEU	MEU	ECOTOX	LU	WU	FRD	MRD
AT	8.37E+10	4.45E+04	1.43E+03	1.79E+02	6.48E+03	6.87E+06	3.06E+08	3.55E+08	1.66E+09	7.03E+06	1.49E+08	7.60E+10	8.43E+12	2.15E+10	9.47E+10	6.38E+03
BE	1.38E+11	4.22E+05	2.39E+03	3.17E+02	1.06E+04	4.58E+09	3.07E+08	4.58E+08	1.86E+09	7.37E+06	1.49E+08	8.51E+10	3.92E+12	5.38E+10	5.18E+11	4.18E+04
BG	5.49E+10	5.27E+04	1.69E+03	1.50E+02	1.09E+04	1.36E+09	2.39E+08	7.68E+08	1.30E+09	9.69E+06	1.49E+08	4.73E+10	1.16E+13	1.78E+11	3.75E+11	6.63E+05
CY	9.70E+09	3.75E+03	4.26E+02	1.24E+01	8.54E+02	0.00E+00	2.54E+07	5.71E+07	1.41E+08	7.39E+05	1.58E+07	4.81E+09	1.07E+12	5.68E+09	0.00E+00	3.56E+03
CZ	1.40E+11	4.60E+04	3.92E+03	1.70E+02	1.01E+04	2.52E+09	3.85E+08	6.08E+08	1.95E+09	7.09E+06	2.11E+08	5.32E+10	8.77E+12	3.27E+10	1.19E+12	0.00E+00
DE	9.58E+11	1.73E+05	1.36E+04	1.66E+03	4.79E+04	1.38E+10	2.18E+09	3.63E+09	1.48E+10	4.82E+07	7.52E+08	6.55E+11	4.00E+13	2.09E+11	4.01E+12	9.43E+05
DK	6.65E+10	2.91E+03	8.93E+02	1.50E+02	8.11E+03	9.04E+07	2.18E+08	3.45E+08	1.59E+09	8.69E+06	2.13E+08	7.04E+10	5.38E+12	1.18E+10	8.11E+11	6.27E+02
EE	2.00E+10	2.68E+03	1.20E+03	8.39E+01	4.25E+03	0.00E+00	7.41E+07	1.65E+08	2.81E+08	1.14E+06	2.74E+07	8.60E+09	4.32E+12	2.02E+09	7.36E+09	0.00E+00
GR	1.20E+11	2.61E+03	2.61E+03	4.79E+02	1.72E+04	1.49E+07	5.01E+08	7.76E+08	2.23E+09	1.07E+07	2.48E+08	6.32E+10	1.36E+13	3.45E+11	3.11E+11	1.49E+05
ES	3.34E+11	3.42E+05	9.51E+03	1.27E+03	4.67E+04	6.75E+09	1.52E+09	2.65E+09	1.02E+10	7.09E+07	8.75E+08	3.96E+11	5.22E+13	9.96E+11	8.15E+11	4.16E+05
FI	5.24E+10	8.17E+04	1.58E+03	2.03E+02	1.13E+04	6.18E+06	2.81E+08	3.23E+08	1.21E+09	5.69E+06	4.62E+08	3.92E+10	2.76E+13	2.99E+10	3.98E+11	6.31E+05
FR	5.23E+11	1.26E+06	7.68E+03	1.22E+03	6.48E+04	2.17E+11	2.05E+09	3.16E+09	1.37E+10	8.52E+07	1.29E+09	8.22E+11	6.76E+13	3.54E+11	4.69E+12	3.32E+05
HR	2.23E+10	1.62E+04	6.77E+02	6.33E+01	8.51E+03	3.93E+06	1.25E+08	2.11E+08	7.97E+08	4.77E+06	7.70E+07	2.34E+10	5.69E+12	2.26E+10	1.19E+11	7.26E-04
HU	6.89E+10	2.75E+05	1.55E+03	2.59E+02	1.39E+04	1.40E+09	2.56E+08	3.52E+08	1.53E+09	8.48E+06	2.20E+08	7.86E+10	1.05E+13	5.59E+10	3.61E+11	1.40E+02
IE	7.25E+10	5.37E+04	8.69E+02	2.38E+02	6.46E+03	2.11E+07	1.21E+08	4.13E+08	1.76E+09	1.42E+07	7.70E+07	5.96E+10	6.65E+12	4.86E+09	9.16E+10	4.37E+05
IT	5.14E+11	8.94E+05	1.31E+04	2.05E+03	5.65E+04	4.81E+07	1.81E+09	2.13E+09	9.21E+09	2.18E+07	7.47E+08	3.85E+11	3.22E+13	9.19E+11	5.06E+11	1.95E+05
LT	1.29E+10	1.23E+03	3.37E+02	9.09E+01	5.89E+03	3.84E+05	1.20E+08	1.82E+08	6.43E+08	4.65E+06	7.88E+07	1.98E+10	6.64E+12	2.61E+09	5.62E+09	1.42E+04
LU	1.23E+10	2.65E+02	1.51E+02	3.59E+01	7.53E+02	3.08E+06	4.01E+07	4.23E+07	2.08E+08	4.99E+05	2.06E+07	3.91E+09	2.77E+11	4.85E+08	0.00E+00	0.00E+00
LV	1.62E+10	3.52E+04	2.00E+03	2.06E+02	4.73E+03	0.00E+00	9.37E+07	8.17E+07	3.78E+08	2.34E+06	3.89E+07	1.47E+10	5.99E+12	4.14E+09	2.00E+08	0.00E+00
MT	3.14E+09	9.90E+02	7.01E+01	6.88E+00	2.90E+02	0.00E+00	1.19E+07	2.13E+07	5.54E+07	7.97E+05	5.83E+06	2.93E+09	4.65E+10	1.49E+09	0.00E+00	0.00E+00
NL	2.33E+11	4.59E+05	3.04E+03	4.44E+02	6.87E+03	3.72E+08	4.30E+08	6.34E+08	2.92E+09	1.03E+07	2.10E+08	1.39E+11	4.61E+12	7.17E+10	2.74E+12	1.90E+05
PL	4.07E+11	5.51E+05	1.59E+04	8.77E+02	4.96E+04	6.48E+06	1.59E+09	2.73E+09	7.33E+09	4.96E+07	8.31E+08	3.66E+11	3.38E+13	7.24E+10	2.49E+12	2.59E+06
PT	7.22E+10	6.46E+05	2.28E+03	4.41E+02	1.25E+04	5.58E+06	3.39E+08	3.79E+08	1.49E+09	1.43E+07	1.50E+08	7.51E+10	9.42E+12	2.16E+11	0.00E+00	1.34E+05
RO	1.23E+11	4.30E+05	3.06E+03	5.09E+02	3.52E+04	7.52E+09	6.30E+08	1.13E+09	3.08E+09	2.89E+07	2.95E+08	1.45E+11	2.54E+13	1.01E+11	9.17E+11	6.04E+04
SE	4.30E+10	1.62E+04	2.04E+03	9.81E+01	7.59E+03	1.28E+09	1.46E+08	2.31E+08	7.09E+08	4.33E+06	7.98E+07	3.78E+10	4.96E+12	1.43E+10	1.90E+11	2.88E+04
SI	1.45E+10	2.63E+04	3.25E+02	4.57E+01	3.76E+03	5.11E+08	7.75E+07	9.94E+07	4.26E+08	2.05E+06	3.88E+07	1.41E+10	1.89E+12	1.78E+10	1.11E+11	4.38E-02
SK	2.05E+10	7.52E+04	1.48E+03	1.58E+02	7.48E+03	1.23E+10	3.11E+08	3.41E+08	1.47E+09	5.21E+06	1.23E+08	8.27E+10	3.82E+13	3.43E+10	6.44E+11	1.34E+06
GB	6.89E+11	3.26E+06	8.95E+03	1.01E+03	3.79E+04	3.32E+11	1.71E+09	2.21E+09	8.56E+09	8.76E+07	1.03E+09	3.80E+11	2.68E+13	5.59E+10	5.66E+12	3.92E+04
EU-28	4.82E+12	9.18E+06	1.03E+05	1.24E+04	4.97E+05	6.01E+11	1.59E+10	2.45E+10	9.15E+10	5.22E+08	8.56E+09	4.15E+12	4.57E+14	3.83E+12	2.71E+13	8.21E+06

Note: Acronyms mentioned in Figure 12 are used to identify all the impact categories. Units for the impact categories are the following: CC in kg CO_2 eq, ODP in kg CFC-11 eq, HTOX_nc in CTUh, HTOX_c in CTUh, PM in Disease incidence, IR in kg U235 eq, POF in kg NMVOC eq, AC in molc H^+ eq, TEU in molc N eq, FEU in kg P eq, MEU in kg N eq, ECOTOX in CTUe, LU in pt, WU in m^3 world eq, FRD in MJ, MRD in kg Sb eq.

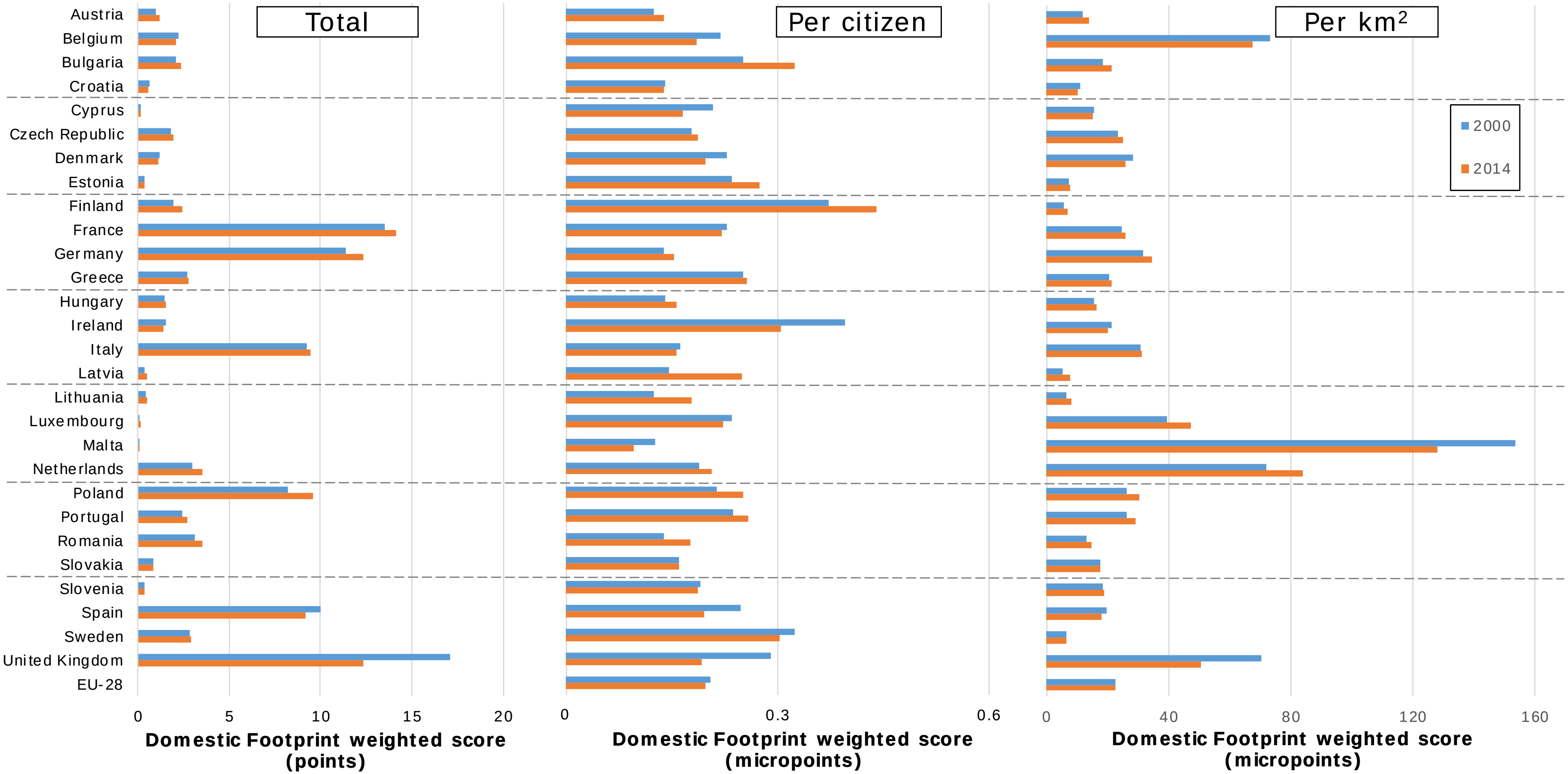
In Figure 13, a number of comparisons among Member States is presented. For these comparisons, results for each country have been normalised to the total EU impact.

When plotting results as total for each country (Figure 13), **a pattern of decrease emerges for some countries** (i.e. 8 out of 28). Some of them remarkably reduce their impact; for instance, United Kingdom (-28%) and Malta (-17%). On the other hand, most of Member States register an impact increase (mostly between +2%, as Slovenia and Italy, and +18%, as Austria). For a few cases, the increase is more significant, namely for Latvia and Finland (+43% and +25%, respectively), but this could be related to economic growth (see Table 10), as for other eastern Member States (i.e. Lithuania and Romania). Finally, in other cases, the impact is not really increasing nor decreasing, as for Slovakia.

When results per citizen are analysed (Figure 13), a variable outcome is observed. Most of countries present a reduction in the total environmental impact. Out of 28 Member States, almost half is below the impact of an average EU citizen. France, Italy and Luxembourg present a decrease (by 3%) in the average impact per citizen despite a general impact increase, thus suggesting more efficiency in the resource use. Significant decrease is registered for United Kingdom (-34%), Malta (-25%), Spain (-20%), and Ireland (-23%). As in the previous comparison, an impact increase occurs in eastern countries (i.e. Latvia, Lithuania and Romania) where an economic growth is taking place (see Table 10).

Results comparison among countries is carried out also considering the country area (Figure 13). Here the picture remarkably changes: some of the smallest Member States (e.g. Luxembourg, Malta and Belgium) register higher impacts with regard to EU because of their very limited surface area. Most of Member States register an increase in the impact in 2014 and only a few Member States reduce it significantly (i.e. United Kingdom, Malta, Belgium, Denmark and Ireland). On the other hand, Latvia reports a significant increase in the average impact per km^2 (namely, +43%), followed by Finland (+25%), Luxembourg and Austria (respectively, +20% and +18%).

Figure 13. Domestic Footprint weighted score in the EU Member States (2000 and 2014): total per country, impact per average citizen and impact per km^2.



Note: Results are presented as weighted score, normalised against EU total impact.

3.1.3 Domestic Footprint: analysis of the relative contribution of countries and emission to the total impact

In this section, an in-depth analysis is carried out specifically for year 2010. This year was deemed more robust in terms of inventory data and is the reference year for the Consumer Footprint as well. In Table 12, the overall results of the EU Domestic Footprint are presented as characterized with EF 2017, together with normalised values (by means of global references) and weighted score.

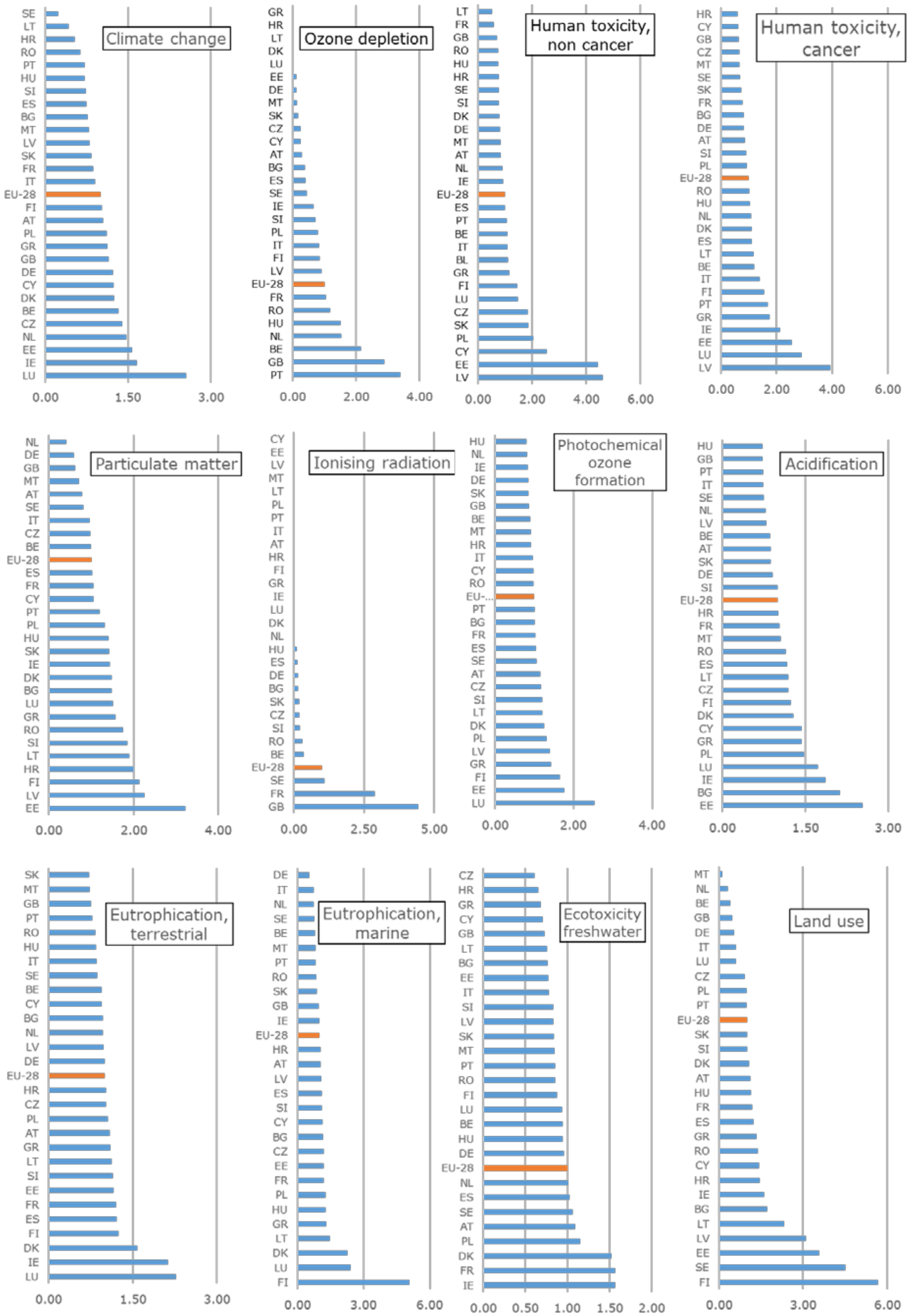
Table 12. Domestic impacts in 2010: characterized, normalised, and weighted total values for each impact indicator at EU scale.

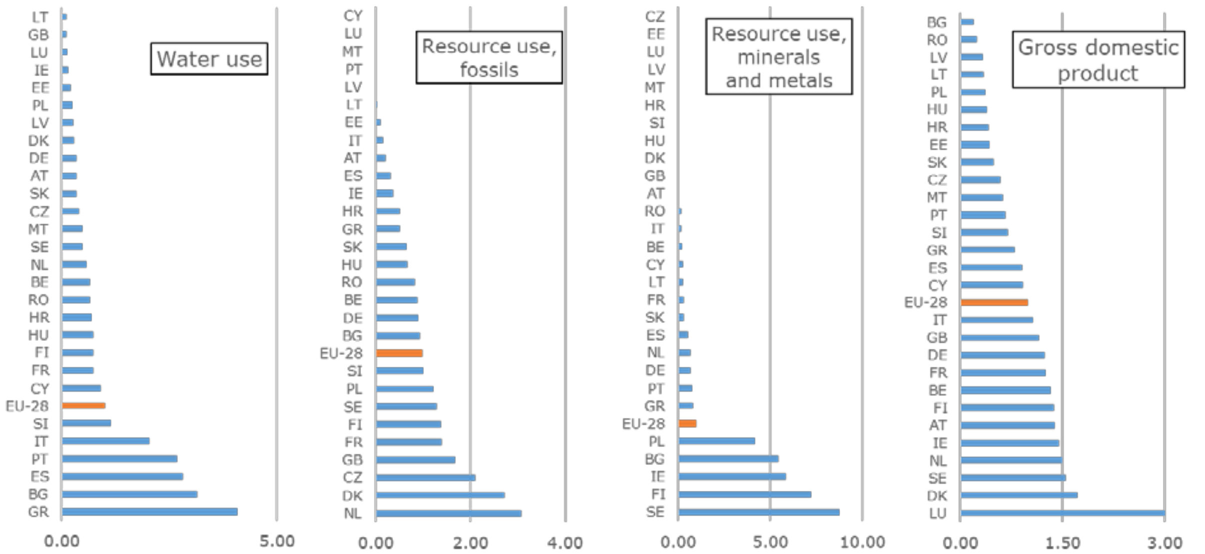
Impact category	Unit	Characterized	Normalised	Weighted score
Climate change	kg CO_2 eq	4.82E+12	8.70E-02	1.83E+00
Ozone depletion	kg CFC-11 eq	9.18E+06	2.75E-02	1.74E-01
Human toxicity, non-cancer	CTUh	1.02E+05	3.14E-02	5.77E-02
Human toxicity, cancer	CTUh	1.23E+04	4.68E-02	9.96E-02
Particulate matter	Disease incidence	4.97E+05	1.21E-01	1.09E+00
Ionising radiation	kBq U^{235} eq	6.01E+11	6.30E-01	3.16E+00
Photochemical ozone formation	kg NMVOC eq	1.59E+10	5.67E-02	2.71E-01
Acidification	molc H^+ eq	2.45E+10	6.39E-02	3.96E-01
Eutrophication, terrestrial	molc N eq	9.15E+10	7.51E-02	2.79E-01
Eutrophication freshwater	kg P eq	5.22E+08	4.69E-02	1.31E-01
Eutrophication, marine	kg N eq	8.56E+09	6.35E-02	1.88E-01
Land Use	Pt	4.57E+14	2.97E-02	2.36E-01
Ecotoxicity freshwater	CTUe	4.14E+12	5.09E-02	9.78E-02
Water use	m^3 world eq	3.83E+12	4.85E-02	4.12E-01
Resource use, fossils	MJ	2.71E+13	6.04E-02	5.02E-01
Resource use, minerals and metals	kg Sb eq	8.21E+06	1.87E-02	1.41E-01

Note: The numbers reported as characterized results are the figures used in the normalisation step when the EU reference is taken. When the normalisation is carried out on the entire time frame, the EU impact for each year is taken as normalisation factor for that specific year.

As already discussed, Member States differently contribute to the overall Domestic Footprint. In order to understand which Member States are mainly playing a role - and to what extent - the impact of an average citizen in each Member State is reported in Figure 14. The picture varies for different indicators, however some general patterns could be identified. **When resource depletion is considered, most of countries are below the EU average, since only few countries have a significant domestic extraction of resources, whereas for the indicators led by air emissions, countries are more equally distributed above and below the average EU.** Member States with a high GDP per citizen frequently present high impact per citizen (e.g. for climate change, marine eutrophication and fossil resource use).

Figure 14. Domestic Footprint per citizen in 2010: ranking of EU Member States in perspective with EU and GDP, considering all 16 impact categories.





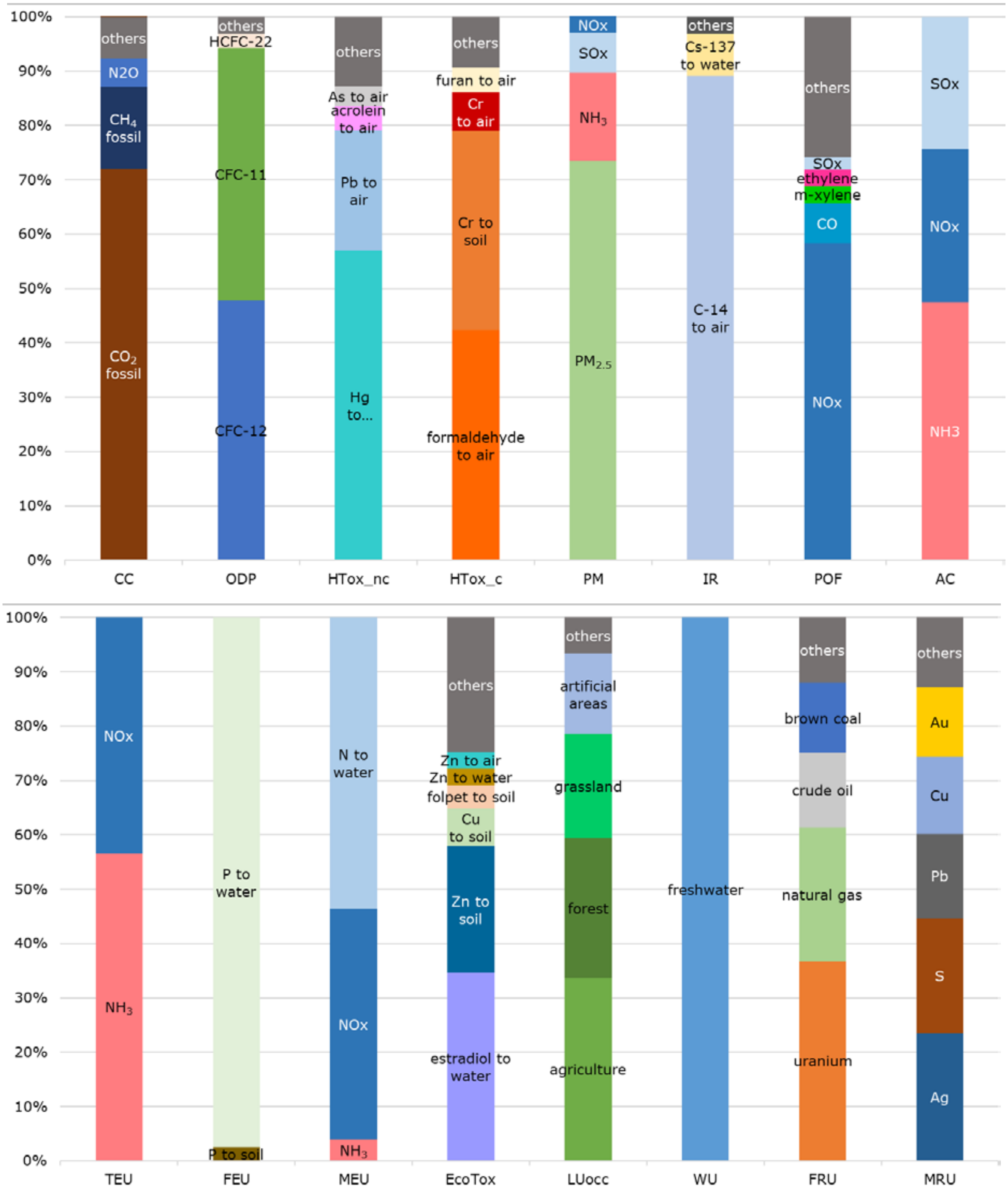
Note: The presented values correspond to the ratio between the impact in the country over the impact in EU (therefore, the value for EU is 1).

Finally, to identify the key environmental pressures determining the impacts for the EU, the indicators used to monitor EU environmental impact are decomposed in their elementary flows (i.e. substances and resources contributing to the total impact) in Figure 15. For several impact categories, a limited number of substances lead the results. In most of cases, one flow is contributing more than 50% (e.g. climate change, human toxicity-non cancer, particulate matter, photochemical ozone formation), and even up to more than 80% (e.g. C-14 for ionising radiation).

It is possible to notice that in many cases just a limited number of substances lead the results. In most of the cases, one flow is contributing more than 50% (e.g. climate change, human toxicity-non cancer, particulate matter, photochemical ozone formation), and even up to more than 80% (e.g. C-14 for ionising radiation). At the domestic scale, sector or product level is not investigated, but some considerations about the main sources of pressures and impacts could be performed. For example, in the previous section, it has already been highlighted the nuclear energy production leading the ionising radiation. Additionally, based on existing studies, database and statistics (EEA, 2016; 2017b), it is clear that certain air emissions (e.g. CO_2, $PM_{2.5}$ and NO_x) derive from the energy sector (electricity, heating and mobility). Likewise, most of the substances considerably contributing to toxicity-related indicators come from manure, fertilizer and pesticide application in agricultural management or from industrial activities. Moreover, the agricultural systems are also the main source of phosphorus and nitrogen to water.

It is worthy to say that the most influencing substances registered for the Domestic Footprint of EU in 2010 frequently are the same appearing in a similar analysis conducted at global level for the same year (Crenna et al., 2019a), especially for climate change and ionising radiation. On the other hand, the category resource use (minerals and metals) presents different impact drivers due to the relatively limited activities of mining of these resources in the EU.

Figure 15. Domestic Footprint in EU: key emissions and resource driving the overall impacts.



Note: Reference year: 2010. Geographical reference: EU. For the acronyms explanation, refer to Figure 12.

3.2 Consumption Footprint at EU and Member States level

The EU Consumption Footprint could be calculated by means of two approaches, related to the way trade impacts are accounted for:

Consumption Footprint Top-down: where the **Domestic Footprint is combined with trade impacts** calculated using **sectorial-based Multi-Regional Input-Output Tables (MRIOTs)**, considering the EXIOBASE database version 3. Geographical coverage is EU and the single Member States, temporal coverage is: 2000-2014 for EU, 2000-2011 for Member States.

<u>Consumption Footprint Bottom-up</u>: where the **Domestic Footprint is combined with trade impacts** calculated based on the **LCA of 40 selected representative products** which are imported to and exported from the EU. The selection has been based on criteria of mass and economic values. Geographical coverage is EU as a whole, temporal coverage is 4 distinct years: 2000, 2005, 2010, and 2014.

3.3 Consumption Footprint Top-down

Box 4. Key messages on the Consumption Footprint Top-down

— EU GDP increased by around 10% from 2004 to 2014. In the meantime, the EU Consumption Footprint Top-down was stable (-1%), yet with a decrease from 2004 to 2009 (-9%) and a similar increase (+8%) from 2009 to 2014 (limited absolute decoupling).

— Import Footprint and Export Footprint Top-down increased from 2004 to 2014 (+30% for exports, +24% for imports).

— Regarding 8 impact categories out of the 14 under study (in particular, e.g. climate change, particulate matter, acidification, terrestrial eutrophication), impacts induced by apparent consumption were 7 to 25% lower in 2014 than in 2000, in a context of an increase of the GDP (+19%).

— The six countries ranking first in EU in terms of GDP (respectively, Germany, France, the United Kingdom, Italy, Spain, and the Netherlands) are observed to be the main contributors to the total EU Consumption Footprint (2/3 of the total Footprint).

— EU countries with the lowest values of Human Development Index globally show the largest Consumption Footprint per million euro of GDP, and the largest decrease in Consumption Footprint per million euro of GDP (from 2004 to 2011).

— Products with limited supply-chains are observed as the main contributors to the impacts induced by imports: i) food products (in particular products of meat) and food-related services regarding acidification, terrestrial eutrophication, freshwater eutrophication, marine eutrophication, land use, and water use; ii) basic and intermediate products (in particular basic iron and steel, and rubber and plastic products) regarding human toxicity-cancer, human toxicity- non-cancer, ecotoxicity, particulate matter, photochemical ozone formation, and climate change; and iii) raw materials (metals, ores and concentrates on the one hand, and fossil fuels on the other hand) regarding mineral and metal resource use and fossil resource use.

— A larger contribution of manufactured products is observed regarding the total impacts of exports from EU, both when compared to the contribution of other products and services exported and when compared to the share of manufactured products in the total impacts of imports.

As mentioned in section 3.2, the Consumption Footprint Top-down is based on the combination of the Domestic Footprint with trade impacts calculated using sectorial-based Multi-Regional Input-Output Tables (MRIOTs), considering the EXIOBASE database version 3. Geographical and temporal coverage: 2000-2014 for EU, 2000-2011 for single Member States.

Firstly, the trend in apparent consumption is analysed on the one hand as a weighted score, and on the other hand considering the trend of 14 impact categories used to characterize environmental impacts in this study. Among the 16 EF 2017 indicators used to characterize the impacts relative to the Domestic Footprint, two are excluded regarding the analysis of the Consumption Footprint Top-down, due to missing elementary flows: ionising radiation and ozone depletion (Beylot et al., 2019b). Moreover, a contribution analysis is performed, with respect to EU Member States, products and substances.

It is noteworthy that the time series presented in the following do not consider the same time span whether at the level of EU or at the level of single countries. The decision on the time span covered was a balance between two (in some cases conflicting) considerations: on the one hand, covering the largest time span possible, and on the other hand, ensuring a good robustness of the presented results and of the subsequent interpretations and conclusions.

Regarding the EU, the evolution of the (weighted score[6]) Consumption Footprint is presented for the period 2004-2014. It has to be reminded that EU Consumption Footprint has also been calculated regarding years 2000 to 2003, but the latter are excluded from the present section due to a number of outliers observed. Results for 2012-2014 have been calculated by extrapolation, considering the trend of emissions and resource consumption induced by EU trade for the period 2000-2011 (Annex 4). In addition, the evolution of the Consumption Footprint by impact category is presented for the period 2000-2014, accordingly including the time span 2000-2003 which appears robust and informative in many cases of impact categories.

On the contrary, at the level of several EU countries, no trend was observed for the impacts of imports and exports for the period 2000-2011, rendering impossible any attempt of extrapolation (see Annex 4). Therefore, time series and corresponding variations for EU countries are presented for the period 2004-2011, excluding both results for years 2000-2003 (due to a number of outliers observed) and any extrapolated results for the time period 2011-2014 (due to the absence of trends in the previous years).

Finally, **it should be noted that the contribution analysis of substances is presented considering the year 2010** (as in the case of the Domestic Footprint), while the contribution of product groups to the Trade Footprints of EU is presented considering the year 2011 (as the last year for which EXIOBASE 3 data were available for this study).

3.3.1 Methodology for calculating the Consumption Footprint Top-down

The inventory of emissions and resource extraction relative to the Consumption Footprint Top-down, at EU and Member State levels, is built considering both Domestic and Trade inventories. The Domestic inventory is the inventory built for the Domestic Footprint, as presented in section 3.1. The Trade inventory is calculated using sectorial-based MRIOTs. The import and export of goods and services is considered to induce emissions to the environment and resources extraction along these goods and services' supply-chain. Input-Output Analysis enables to allocate the emissions and resource extraction of the production stages to the goods and services imported and exported, through the application of the Leontief inverse equation (Leontief and Ford, 1970).

The hybrid version of EXIOBASE 3 was used in this study to implement Input-Output Analysis. The nomenclature of sectors in EXIOBASE relies on the NACE nomenclature, with further disaggregation regarding some products (in particular agriculture and food products, energy and waste treatment; for further details see supplementary information (SI) document 9 in Stadler et al., 2018). Imports to and exports from the EU differentiate the 28 EU Member States and 113 products and services. Investments are additionally integrated within the IO tables, based on the approach developed in the project FORWAST (Schmidt et al., 2010). All the results presented hereafter therefore account for investments (usually referred to as "capital goods" or "infrastructure" in LCA) whose contribution is attributed to imports and exports. In EXIOBASE 3, MRIO Tables are available for 43 countries, including the 28 EU countries under focus in this study, plus five rest-of-world regions. The environmental extensions distinguish 164 sectors with respect to 48 countries and regions, and report coefficients relative to 78 elementary flows: 36 mineral, metal and energy resources, 5 types of land occupation, 3 types of water consumption, and 29 substances emitted to air, 2 to water and 3 to soil. The results on Consumption Footprint are based on EXIOBASE time series available for years 2000 to 2011, extended to 2014 considering a linear extrapolation.

[6] As explained in section 2.2.3, the weighted score was calculated based on selecting weighting factors for the impact categories.

Up to now, existing studies based on EE-MRIO databases have primarily limited their analysis to a reduced set of flows, in most cases without any quantification of the corresponding impacts these flows induce on the environment. A key aspect of this study relies on the mapping between the inventory of elementary flows as calculated from the application of EXIOBASE 3, and the corresponding characterization factors available in up-to-date impact assessment methods, which enable to calculate the potential impacts these flows induce on the environment. Fourteen impact categories, out of the 16 implemented to the Domestic Footprint, are considered with applying the EF 2017 LCIA method (EC, 2017). Impacts in terms of ionizing radiation and ozone depletion are excluded from calculations performed with EXIOBASE 3, due to the absence of the corresponding contributing elementary flows in EXIOBASE environmental extensions. The impact characterization required a systematic classification to the EF 2017 nomenclature more extensively detailed in Beylot et al. (2019). To comprehensively assess the potential impacts of consumption, and the decoupling of economic growth from environmental impacts, there are still limitations that should be systematically presented and addressed in future development. Hence, the current limitations in using EXIOBASE 3 for environmental impact assessment are also mentioned along this report, with specific attention to EXIOBASE environmental extensions and to the case study on EU consumption.

3.3.2 Consumption Footprint Top-down: trends of environmental impacts over time (2000-2014)

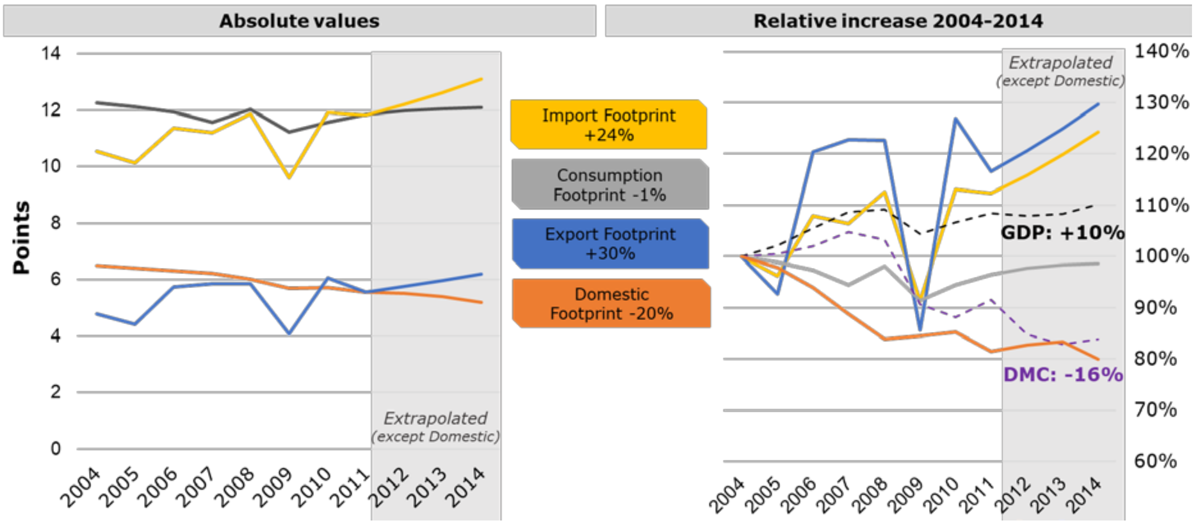
The evolution of the EU Consumption Footprint Top-down from 2004 to 2014 is presented in Figure 16. **The EU Consumption Footprint Top-down weighted score is globally observed to be stable from 2004 to 2014 (-1%), yet with a decrease from 2004 to 2009 (-9%) and a similar increase (+8%) from 2009 to 2014** (reminding that the scope of the EU Consumption Footprint is limited to the impact categories listed in Table 4, the overall impact on biodiversity and impacts due to marine littering are excluded from the calculated indicator; see section 7.3 for details on the link between midpoint indicators and biodiversity). In the meantime, EU GDP increased by around 10% from 2004 to 2014, so that (limited) absolute decoupling of GDP from impacts of apparent consumption was observed in the EU during this period. Whatever the year, four impact categories, out of the 14 used to calculate the Consumption Footprint Top-down weighted score, contribute mostly to the total footprint: climate change, minerals and metals resource use, fossil resource use and particulate matter (in total representing from 63% to 70% of the total footprint). In addition, impacts on acidification, land use and water use also have contributions superior to 5% regarding most years in the time series. While the EU Domestic Footprint steadily decreased from 2004 to 2014, as described in section 3.1.2, imports and exports footprints on the contrary increased from 2004 to 2014 (+30% for exports, +24% for imports), yet with a drop in 2009 (-14% compared to 2004 regarding exports, -9% regarding imports). The globally stable trend in Consumption Footprint is the result of the combination of the trends of the three parameters, namely: the decreasing of Domestic Footprint and increasing imports and exports footprints. It is noteworthy to mention that considering EU footprints and GDP growth from 2004 to 2014, we therefore observe: *i)* absolute decoupling regarding the EU Domestic Footprint (see section 3.1), *ii)* absolute decoupling regarding Consumption Footprint Top-down, yet close to relative decoupling (stable evolution of the Consumption Footprint from 2004 to 2014), and *iii)* no decoupling regarding international trade (that transits through EU and is therefore “hidden” in the EU Consumption Footprint).

Impacts on climate change and particulate matter are key contributors to the total Domestic Footprint of EU (representing approximately 50-51% of the total, from 2004 to 2014), while impacts related to fossil resource and minerals and metals resource have limited contributions[7] (respectively, mainly less than 9% and less than 3% of the total footprint). On the contrary, regarding imports and exports footprints, these four impact

[7] This is referring to the resource extraction in EU only

categories represent from 68 to 78% of the total footprint, depending on the year. The impact on minerals and metals resource use in particular stands from 25 to 45% of the total footprints of imports and exports.

Figure 16. Consumption Footprint Top-down, Domestic Footprint and Trade (import and export) Footprints Top-down: weighted score overall variation between 2004 and 2014, compared with GDP and DMC.



Note: The left graph displays absolute values for the four footprint. The right graph (Relative increase 2004-2014) reports results for 2004 as 100%, and results for the other years are rescaled accordingly. Data source for GDP and DMC: Eurostat (2018b; 2018c).

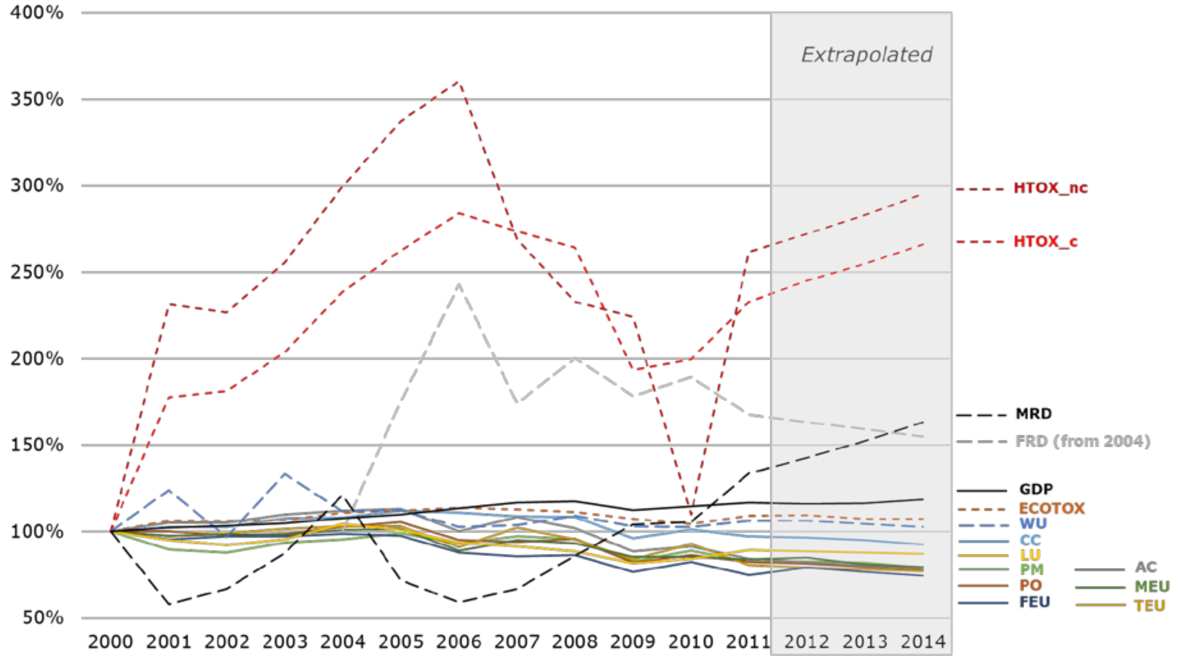
3.3.2.1 Consumption Footprint Top-down: trends by impact category

Regarding eight impact categories out of the 14 under study with respect to the Consumption Footprint Top-down (respectively, climate change, particulate matter, acidification, terrestrial eutrophication, freshwater eutrophication, marine eutrophication, photochemical ozone formation, and land use) **a declining trend is observed from 2000 to 2014** (Figure 17).

Impacts induced by apparent consumption were **7 to 25% lower in 2014 than in 2000, in a context of increase of the GDP (+19%)**. However, it is to be noticed that in most cases of impact categories, the impacts induced by imports and exports increased from 2000 to 2014 (e.g. impacts induced by imports increased by 36 to 40% regarding climate change, acidification and photochemical ozone formation, while corresponding impacts of exports increased by 32 to 53%). Therefore, regarding these eight impact categories, the decrease in impacts of apparent consumption from 2000 to 2014 was the result of the combination of the decrease in domestic impacts and of the increase in impacts from exports, in a context of rising impacts from imports.

On the contrary, **an increase in impacts** induced by apparent consumption is observed **considering the six remaining impact categories**. Over the period 2000-2014 (2004-2014 specifically regarding fossil resource use), this increase is observed to be limited considering freshwater ecotoxicity and water use (respectively 7 and 3%), while impacts manifest a large (55 to 63%) to very large (166 to 195%) increase regarding resource use (fossils and minerals and metals) and human toxicity (cancer and non-cancer), respectively.

Figure 17. Consumption Footprint Top-down: indicators overview, overall variation in 2000-2014.



Note: Comparison of the results of 14 EF 2017 indicators with GDP. Ionising radiation and ozone depletion are not reported due to the absence of elementary flows in EXIOBASE 3. Results for 2000 are reported as 100%, and results for the other years are rescaled accordingly. GDP data source: Eurostat (2018b). Acronyms mentioned in Figure 12 are used to identify all the impact categories.

However, at this stage of development of the environmental extensions of EXIOBASE 3, three of the EXIOBASE 3 features imply that the impact assessment step adds a layer of uncertainty, potentially significant but still unexplored:

— a number of elementary flows are absent from the environmental extensions, so that part (especially regarding human toxicity and ecotoxicity) or even the entirety of impacts (regarding ozone depletion and ionizing radiation) cannot be properly assessed;

— details are missing regarding some properties of emissions (e.g. regarding $PM_{2.5}$ and chromium emissions to air), whereas they may significantly affect the impact assessment step;

— some flows are reported in an aggregated manner compared to their counterpart in impact assessment methods, while largely contributing to impacts (e.g. other industrial minerals with respect to minerals and metals resource use).

In addition to these limits in the impact assessment, the very large variations observed from one year to another regarding several impact categories (human toxicity, ecotoxicity freshwater, fossil and minerals and metals resource use) are most probably the result of uncertainties in the compilation of the EXIOBASE 3 database. These uncertainties not only concern the environmental extensions, but also all the intermediate exchanges considered to calculate the impacts along the supply-chain of imports and exports.

3.3.3 Consumption Footprint Top-down: analysis of the relative contribution of countries and emission to the total impact

A contribution analysis is performed with respect to countries and to elementary flows. When considering the variations of the impacts of apparent consumption for each country, with respect to the 14 impact categories under study (Table 13), the picture is globally showing a decrease for most indicators and countries as in the case of the domestic impacts (Table 10). Considering 11 impact categories out of the 14 under study (namely climate change, human toxicity cancer and non-cancer, particulate matter, photochemical ozone formation, acidification, eutrophication freshwater, terrestrial and marine, ecotoxicity freshwater and land use), an impact decrease is observed from 2004 to 2011 in 17 to 26 EU countries, depending on the impact category. On the contrary, considering water use and resource use (both fossils and minerals and metals), a growth in impact is observed for most EU countries. Moreover, a limited number of countries (namely the Netherlands, Romania, Sweden and Czech Republic) show an increase in impact for most impact categories. Oppositely, France, Portugal, Germany, Croatia, Lithuania, and Slovenia show a decrease in impact for all (or almost all) impact categories.

Overall, a limited set of countries is observed to contribute to a large share of the total EU Consumption Footprint Top-down weighted score. The six countries ranking first in EU regarding GDP (respectively, Germany, France, the United Kingdom, Italy, Spain, and the Netherlands) are observed to be the main contributors to the total EU Consumption Footprint. While these six countries approximately contributed to 3/4 of the total GDP in 2011, they altogether contributed to approximately 2/3 of the total EU Consumption Footprint.

However, considering the Consumption Footprint per million euro of GDP (rather than the total Consumption Footprint as described above), a different picture is observed (Figure 18). Despite some specific cases of countries, which depart from the overall trend, the following general observations can be made:

- countries with the lowest Human Development Index[8] (HDI, as drawn from UNDP; 2012) globally show the largest Consumption Footprint per million euro of GDP. This can be for example observed considering the 12 EU countries with HDI lower than 0.850 (in brown and yellow in Figure 18) as compared to the 16 other EU countries, whether in year 2004 or in year 2011;
- in these countries with the lowest HDIs of the EU zone, the Consumption Footprint per million euro of GDP has decreased in relatively large proportions from 2004 to 2011;
- conversely, in countries with larger HDIs, a limited decrease (or even an increase in several cases) can be observed from 2004 to 2011.

In Figures 19 and 20, a number of comparisons show the difference in the Consumption Footprint Top-down between 2004 and 2011 for each Member State. For these comparisons, results for each country have been normalised to the total EU impact. Considering the total Consumption Footprint Top-down weighted score respectively in 2004 and 2011 (Figure 19), a decrease is observed for most EU countries (16 out of 28). The largest decrease in footprint (ranging between -37 and -40%) is observed in Estonia, Latvia, Lithuania, and Portugal, while the largest increase (ranging between +33 and +68%) is observed in Luxembourg, the Netherlands, Croatia and Germany.

Moreover, when considering the Consumption Footprint per citizen, more than half of EU countries are observed to have an impact superior to the EU average (Figure 20). The largest Consumption Footprint per citizen (in 2011) is observed for Luxembourg, the Netherlands, and Finland (with values 1.8 to 3.7 times larger than the EU average), while the lowest is observed for Poland and Croatia (respectively 53 and 29% lower than the EU average). As in the case of the total Consumption Footprint per country, for most countries (17 out of 28) a decrease in the Consumption Footprint per citizen is observed from 2004 to 2011.

[8] "Human Development Index (HDI): A composite index measuring average achievement in three basic dimensions of human development—a long and healthy life, knowledge and a decent standard of living." (UNDP, 2012)

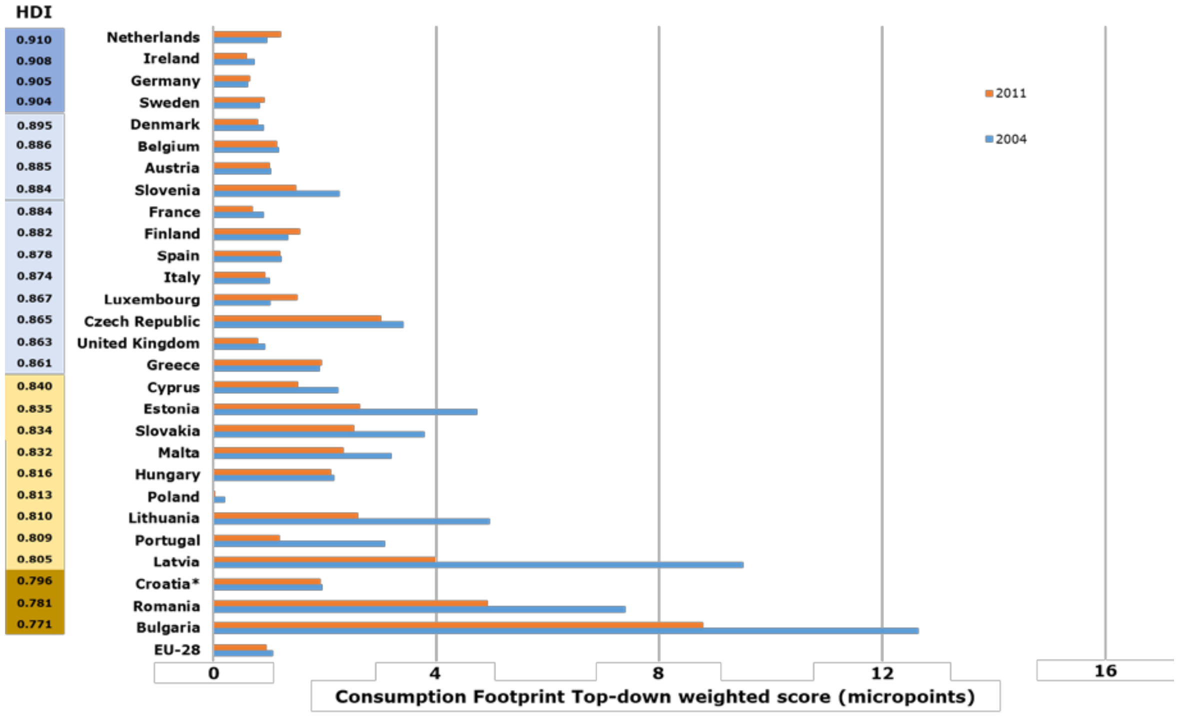
Table 13. Consumption Footprint Top-down: EU and country-specific variation in the environmental impacts between 2004 and 2011.

	CC	HTOX_nc	HTOX_c	PM	POF	AC	TEU	FEU	MEU	ECOTOX	LU	WU	FRD	MRD	Single GLO	Single EU	GDP	POP	DMC
AT	11%	-18%	-17%	9%	-1%	-8%	-27%	-42%	-26%	2%	-29%	11%	32%	41%	9%	6%	12%	3%	-9%
BE	0%	-22%	-11%	-5%	3%	-10%	-5%	-25%	23%	-6%	-32%	24%	6%	56%	9%	2%	12%	6%	7%
BG	8%	27%	0%	-6%	-26%	-32%	-21%	-24%	-14%	-2%	-41%	-25%	18%	-13%	-10%	-7%	30%	-5%	12%
CY	-15%	-39%	-48%	-68%	-34%	-52%	-38%	-17%	-20%	-24%	-11%	-19%	99%	20%	-20%	-16%	18%	16%	8%
CZ	6%	2%	55%	1%	15%	-4%	-20%	-15%	-20%	0%	8%	-1%	37%	9%	8%	7%	22%	3%	-9%
DE	-12%	-31%	-15%	-23%	-21%	-28%	-25%	-19%	-24%	-3%	-10%	-6%	-135%	38%	18%	33%	11%	-3%	4%
DK	-17%	0%	4%	-22%	-25%	-57%	-75%	-15%	-46%	-1%	-8%	34%	32%	10%	-8%	-8%	5%	3%	-9%
EE	-15%	-13%	-15%	-3%	-19%	-58%	-60%	-50%	-68%	-5%	-83%	-51%	103%	7%	-36%	-40%	15%	-3%	24%
GR	-21%	-30%	-32%	-31%	-48%	-58%	-32%	-23%	-35%	-12%	15%	-9%	19%	55%	-8%	-10%	-10%	2%	-13%
ES	-16%	-36%	-10%	-22%	-23%	-33%	-31%	-59%	-35%	2%	-19%	-21%	3%	213%	6%	-7%	8%	10%	-43%
FI	-6%	-40%	-17%	-9%	-14%	-7%	1%	-5%	78%	-2%	-27%	20%	46%	141%	27%	16%	10%	3%	-4%
FR	-13%	-6%	-11%	-23%	-35%	-26%	-31%	-33%	-23%	-2%	-17%	-14%	-12%	-4%	-16%	-15%	8%	4%	-12%
HR[1]	-22%	-55%	-57%	-30%	-74%	-35%	-28%	-16%	-13%	-21%	-49%	-8%	-16%	760%	32%	34%	-2%	-1%	-24%
HU	-17%	-19%	70%	12%	11%	-26%	-30%	-8%	-16%	-7%	-20%	10%	16%	31%	2%	2%	5%	-1%	-36%
IE	-19%	-20%	-13%	-31%	-31%	-126%	65%	-76%	38%	-3%	-26%	6%	51%	62%	-8%	-14%	13%	13%	-45%
IT	-14%	-20%	2%	-13%	-20%	-22%	-19%	-24%	-20%	-2%	-15%	1%	24%	1%	-8%	-3%	0%	3%	-23%
LT	-33%	-29%	2%	-20%	-67%	-58%	-48%	-17%	-28%	-13%	-64%	-47%	-37%	-31%	-37%	-37%	21%	-10%	18%
LU	32%	-179%	424%	4%	-22%	-4%	-9%	-8%	-10%	58%	14%	2%	-381%	192%	76%	68%	19%	13%	-21%
LV	-13%	-64%	-49%	-33%	-38%	-51%	-53%	-6%	-41%	-16%	-60%	16%	6%	-80%	-52%	-39%	15%	-9%	17%
MT	-14%	-36%	-12%	-30%	-24%	-46%	-52%	-53%	-46%	25%	-77%	-38%	-671%	93%	-15%	-18%	16%	4%	-10%
NL	22%	62%	63%	28%	29%	50%	86%	67%	76%	17%	35%	52%	193%	13%	40%	54%	11%	2%	-2%
PL	15%	15%	53%	-1%	83%	-23%	-27%	-9%	-11%	-4%	2%	31%	30%	20%	-80%	21%	37%	0%	47%
PT	-27%	-33%	-26%	-22%	-32%	-37%	-31%	-38%	-31%	-13%	-37%	-4%	-19%	-98%	-61%	-39%	2%	1%	-8%
RO	0%	72%	273%	9%	94%	-34%	9%	10%	4%	3%	51%	53%	50%	-50%	-19%	4%	22%	-6%	56%
SE	6%	44%	52%	4%	1%	-4%	-9%	-7%	-9%	6%	1%	8%	12%	97%	25%	15%	14%	5%	9%
SI	-20%	-42%	-21%	-19%	-13%	-49%	-54%	-56%	-53%	-12%	-38%	-32%	8%	-17%	-25%	-23%	14%	3%	-25%
SK	-5%	-57%	-68%	7%	2%	6%	5%	-44%	9%	-22%	-56%	4%	15%	0%	-8%	-8%	38%	0%	5%
GB	-21%	-23%	-20%	-19%	-34%	-30%	-29%	-20%	-29%	-8%	-14%	-25%	45%	21%	-8%	-9%	6%	5%	-27%
EU28	-10%	-12%	-3%	-13%	-18%	-25%	-21%	-24%	-17%	-2%	-14%	-5%	68%	11%	-3%	na	8%	2%	-8%

Note: Consumption Footprint Top-down relative change between year 2004 and year 2011, according to 14 indicators. GDP, DMC and population data source: Eurostat (2018b; 2018c; 2018d). Weighted score with both global and EU normalisation references included. Traffic light colours identify the rate of variation: significant increase (orange: 51% to 100% and red: over 100%), slight increase (yellow; 0% to 50%), decrease (light green;-1% to -69%) and remarkable decrease (dark green; respectively -70% to -100% and over -100%). Dark red cells identify outliers (i.e. more than 2 times increase). Details on all the outliers are presented in Annex 5. Acronyms mentioned in Figure 12 are used to identify all the impact categories.

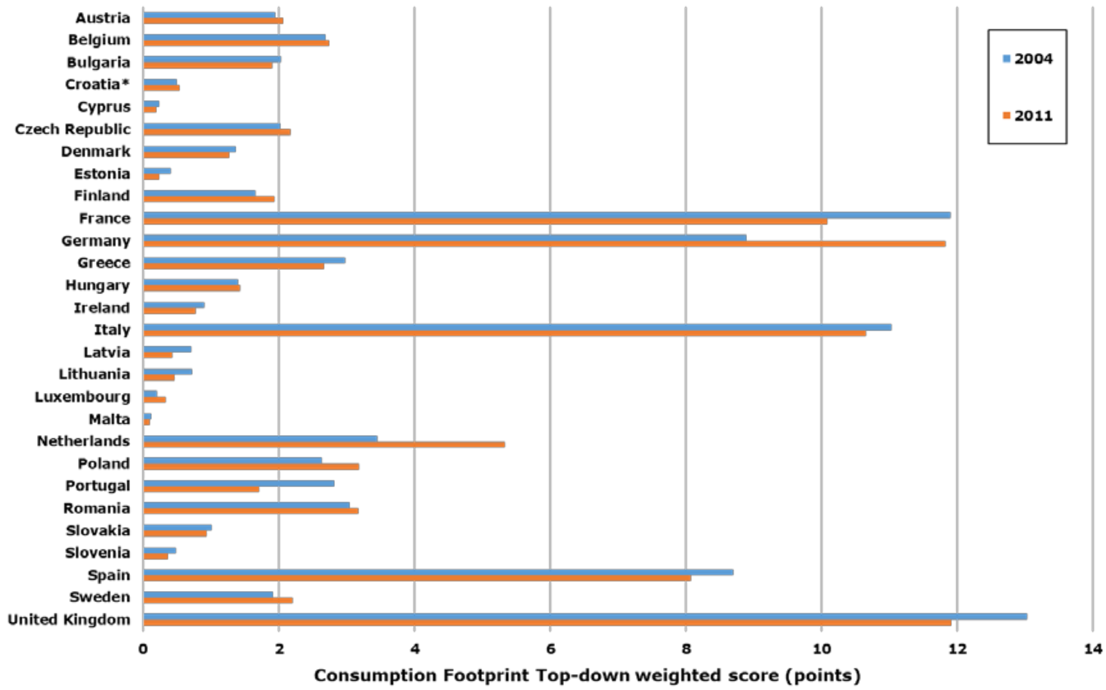
[1]Apparent consumption, Import and Export % variation is calculated for the timeframe 2006-2011, no data available before 2006 in EXIOBASE for HR.

Figure 18. EU Consumption Footprint Top-down weighted score per million euro of GDP in the 28 EU countries (years 2004-2011) put in perspective with countries' Human Development Index (HDI) in year 2011.



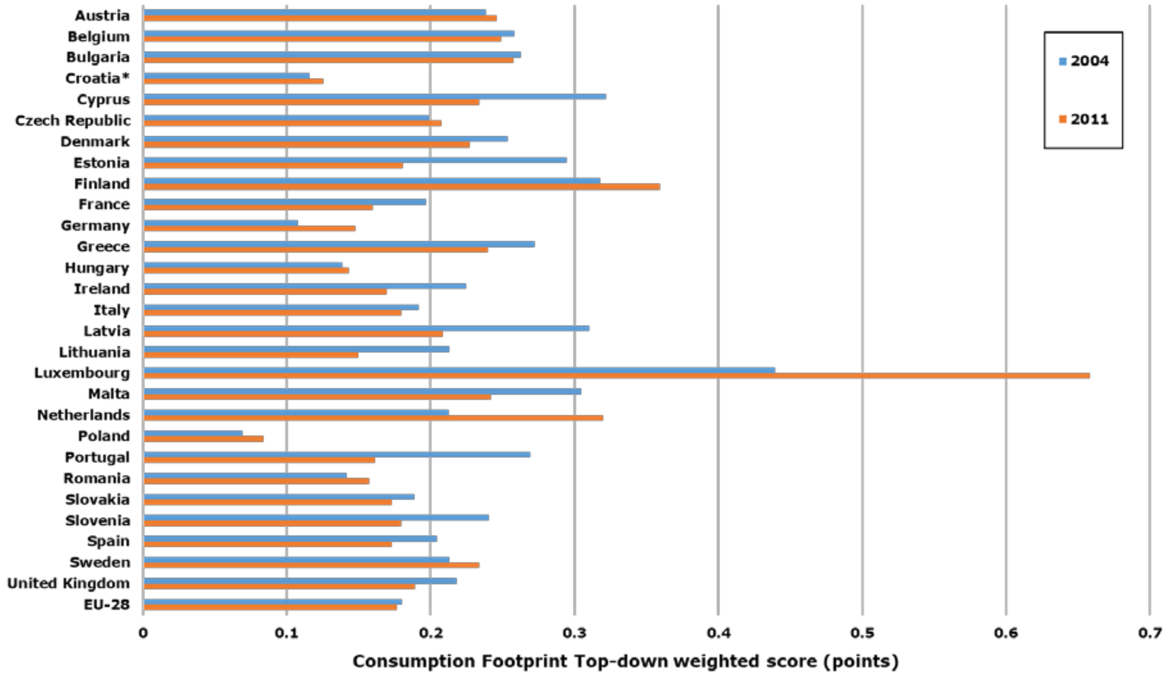
*Regarding Croatia, the value for 2006 is used instead of that for year 2004 (impacts of apparent consumption cannot be calculated from EXIOBASE 3 for years prior to 2006).

Figure 19. Consumption Footprint Top-down weighted score in the EU Member States (2004 and 2011).



Note: Results are presented as weighted score, normalised against EU total impact. Regarding Croatia, the value for 2006 is used instead of that for year 2004 (impacts of apparent consumption cannot be calculated from EXIOBASE 3 for years prior to 2006)

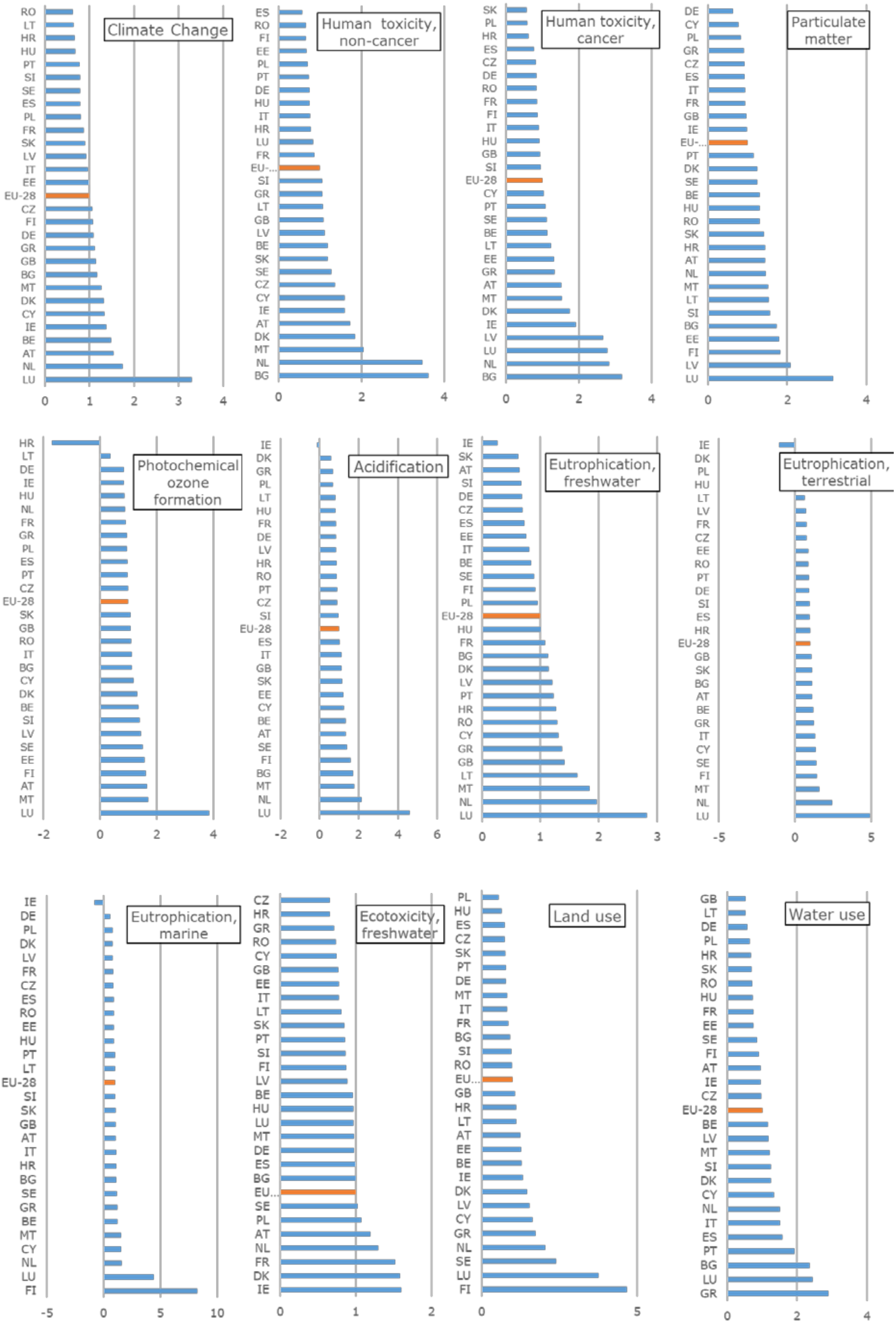
Figure 20. Consumption Footprint Top-down weighted score of an average citizen in each Member State and in EU (2004 and 2011).

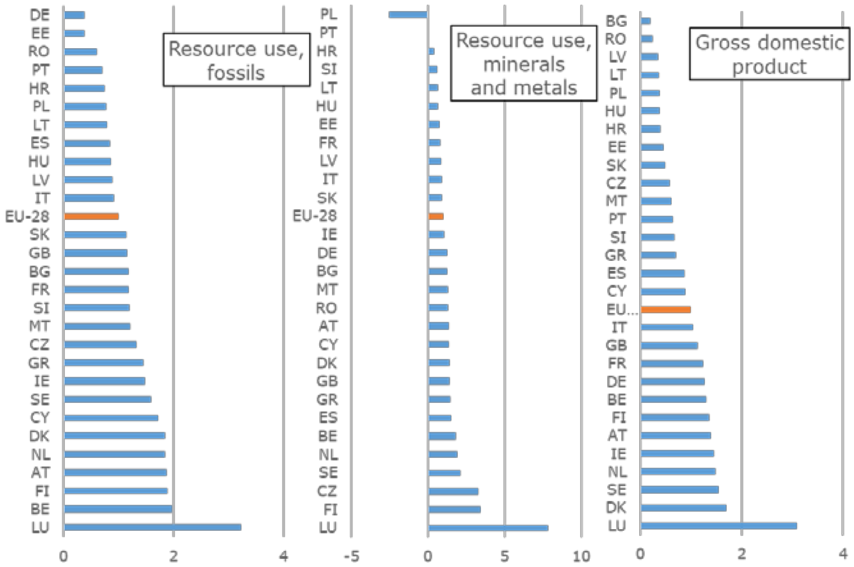


Note: Results are presented as weighted score, normalised against EU total impact. Source for population in 2004 and 2011: Eurostat (2018d). Regarding Croatia, the value for 2006 is used instead of that for year 2004 (impacts of apparent consumption cannot be calculated from EXIOBASE 3 for years prior to 2006)

The Consumption Footprint Top-down per citizen can be compared between EU Member States not only considering weighted score but also midpoint impact categories (Figure 21). In several cases of countries (in particular Austria, Belgium, Finland, Luxembourg, and Netherlands), relatively large GDP per citizen and large impacts per citizen compared to the EU average are simultaneously observed for most impact categories. On the contrary, in several cases of countries with limited GDP per citizen compared to the EU average (in particular Croatia, Lithuania, and Hungary), limited impacts per citizen compared to the EU average are observed. This correlation between the rankings in terms of GDP per citizen and midpoint impacts per citizen is however not valid for all countries. In particular, the GDP per citizen in Bulgaria and Malta is inferior to that of the EU average, while the corresponding Consumption Footprint per citizen is among the largest for most impact categories.

Figure 21. Consumption Footprint Top-down per citizen in 2011: ranking of EU Member States in perspective with EU and GDP, considering 14 impact categories.





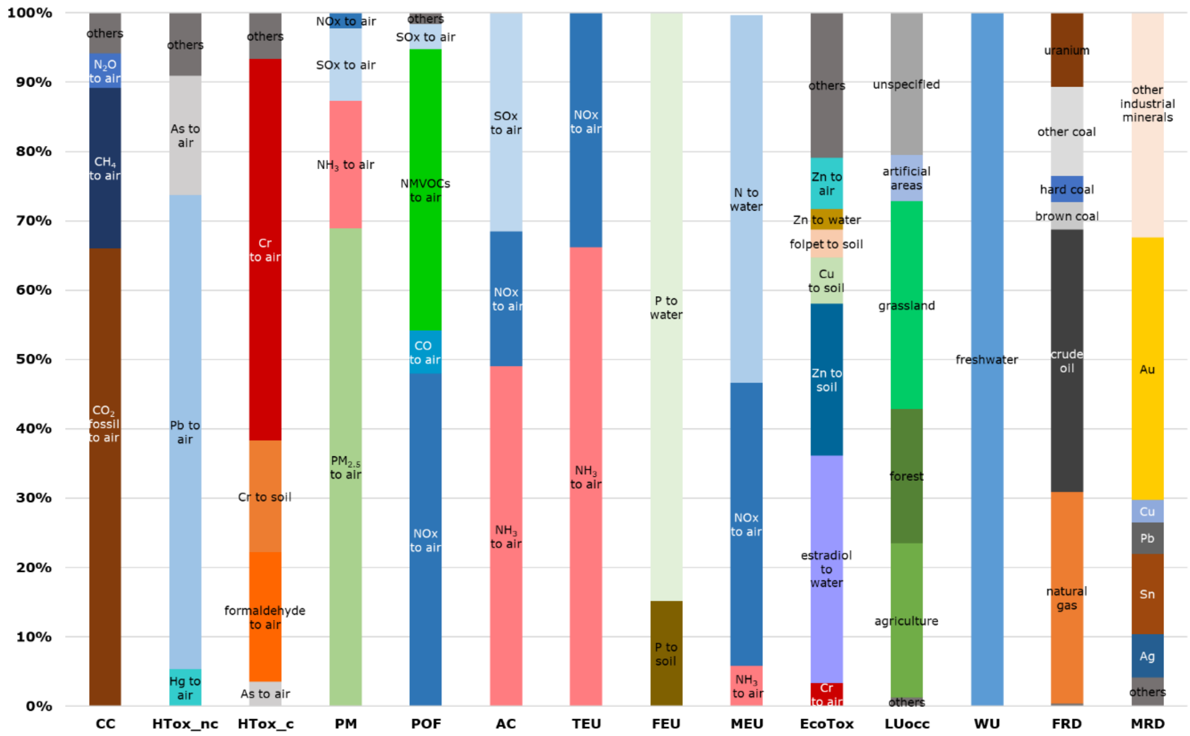
Note: The presented values correspond to the ratio between the impact in the country over the impact in EU (therefore, the value for EU is 1). Negative values are outliers due to modelling issues which may lead to export with higher values than import.

Regarding each impact category, a limited set of elementary flows (that is, of emissions to the environment and of resources extracted) contribute to a major share of the impacts induced by EU apparent consumption (Figure 22). By definition of apparent consumption, the contribution of a given elementary flow to the total impact is the result of the contribution of this flow to the impact occurring within the domestic boundaries of the EU, and of the impact allocated to trade. It is to be reminded that these two “components” of apparent consumption are obtained thanks to two different approaches (respectively bottom-up and top-down), using different modelling, in particular as to the coverage of elementary flows.

On the one hand, regarding the majority of impact categories (climate change, acidification, eutrophication freshwater, terrestrial and marine, fossil resource use, land use, photochemical ozone formation, particulate matter and water use), the set of most contributing elementary flows is the same considering both the domestic component and the trade one, despite slight differences in terms of impact contribution. In particular, it can be observed that ammonia (NH_3) is the most contributing substance to impacts on acidification and terrestrial eutrophication, respectively representing 49 and 66% of the total impact of EU apparent consumption. Moreover, sulphur oxides (SO_x) and nitrogen oxides (NO_x) emissions to air are the second contributors to impacts respectively on acidification (32% of the total impact) and terrestrial eutrophication (34%). NO_x emissions to air additionally represent the second contribution in terms of marine eutrophication (41%), while emissions of nitrogen to water are the most contributing ones (53%). Similarly, the impact on freshwater eutrophication is induced by emissions of respectively phosphorus (P) to soil (15%) and to water (85%). Finally, the impact on climate change is mainly induced by emissions of fossil carbon dioxide (CO_2) (66%) and methane (CH_4) (23%) to air.

On the other hand, regarding toxicity-related indicators and mineral resource use, relatively large differences appear when comparing the elementary flows mainly contributing to the Domestic Footprint with those contributing to the Trade Footprint. In particular, in the case of ecotoxicity, the contribution of estradiol (active ingredient of pharmaceuticals) emitted to water, of folpet (fungicide) to soil, of copper to soil and of zinc to water, which appear as the major contributors to the total Consumption Footprint, are in fact entirely embodied in the Domestic Footprint (as they are not accounted for in EXIOBASE 3 and subsequently neither in the Trade Footprint). Similarly, in the case of minerals and metals resource use, the contribution of other industrial minerals is entirely due to trade. For these four impact categories, the difference in contributions from Domestic to Trade Footprints is the result of limitations in the modelling (namely differences in the coverage of elementary flows).

Figure 22. Consumption Footprint Top-down in EU (2010): key emissions and resource driving the overall impact.



Note: Acronyms mentioned in Figure 12 are used to identify all the impact categories.

3.3.4 The Trade Footprint Top-down: contribution analysis of products

In the modelling, EU imports and exports are divided into 113 categories of products and services, considering the EXIOBASE nomenclature. Yet, a restricted set of "key" products and services is identified on the basis of their "large" contribution to several impact categories ("large" to be understood here as "in comparison with other products and services"). In particular, the 10 products and services which represent the largest contributions to the impacts (so-called Top10, specific to each impact category) stand for 55 to 85% of the total impacts of imports (depending on the impact category under study), and from 51 to 82% of the impacts of exports. In the following, the analysis of key products and services focuses on these Top10 contributors (see Annex 6 for the full list of these Top10 products and services, by impact category).

Regarding the impacts of imports on acidification, eutrophication (terrestrial, freshwater and marine eutrophication), land use and water use, food products and food-related services appear as key contributors (Figure 23). Hotels and restaurants services stand for 14 to 29% of the total impact allocated to import[9]. Moreover, while food products represent a relatively large share of impacts (e.g. 22% in terms of terrestrial eutrophication, when only considering food products from the 10 most contributing categories of products and services), it can be specifically noted that meat products represent a relatively important

[9] It is noteworthy that international trade of services covers trade between residents and non-residents of an economy, and services delivered through enterprises that are locally established but foreign-controlled (UN, 2011). In particular, regarding the accommodation industry, export transactions account for the expenditures of non-residents tourists and business travellers for their accommodation in the domestic territory (Leurs and Ouradou, 2018).

contribution regarding eutrophication (terrestrial, marine, and freshwater) and land use. In addition to food products, agriculture products also appear as important contributors in the case of water use, for which wheat, cereal grains and crops not elsewhere classified (nec) altogether contribute to 22% of the total impacts allocated to imports. Moreover, several intermediate products (e.g. chemicals nec and basic iron and steel, and products of forestry, wood and products of wood in the specific case of land use) are part of the Top10 contributors for several impact categories. Finally, manufactured products (e.g. motor vehicles, trailers and semi-trailers) represent a relatively important contribution only in the case of acidification. The main difference in the contribution analysis with respect to imports as opposed to exports is observed considering intermediate and manufactured products. The contribution of intermediate products to the total impacts of exports is very limited, except regarding land use for which pulp and paper contribute up to 16% of the total. On the contrary, the contribution of manufactured products (e.g. machinery and equipment nec and motor vehicles) is important: in particular, the manufactured products which are part of the Top10 contributors stand for 19 to 25% of the total impacts regarding acidification, land use and water use.

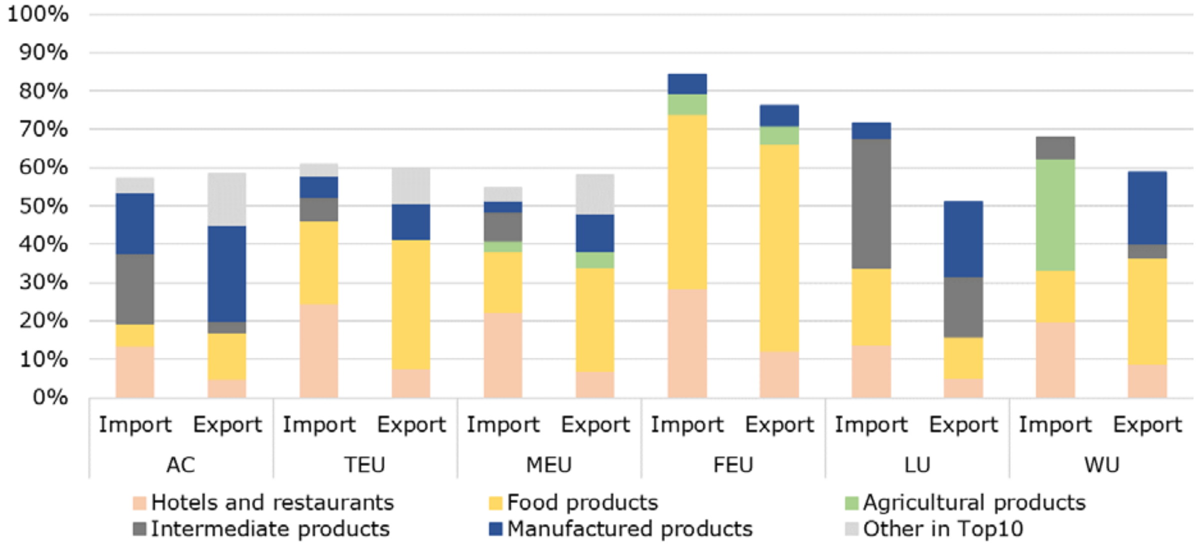
Secondly, approximately half of the impacts of imports on toxicity-related categories stem from the import of basic iron and steel, while manufactured products (machinery and equipment nec, motor vehicles, etc.) appear as the second category of most contributing products (Figure 24). On the contrary, in the case of exports, manufactured products stand for the major share of the total impacts: the eight categories of manufactured products, which appear in the Top10 stand for 69-71% of the impacts.

Thirdly, considering impacts of imports on particulate matter, photochemical ozone formation and climate change, basic and intermediate products (in particular basic iron and steel, and rubber and plastic products) stand for the main contribution within the Top 10 products (representing 21-23% of the total impacts), while manufactured products represent a lower contribution.

On the contrary, regarding the impacts of exports, manufactured products (once again machinery and equipment nec, motor vehicles, etc.) represent a major contribution, ranging from 24 to 36% of the total impacts when considering only manufactured products which are part of the Top10.

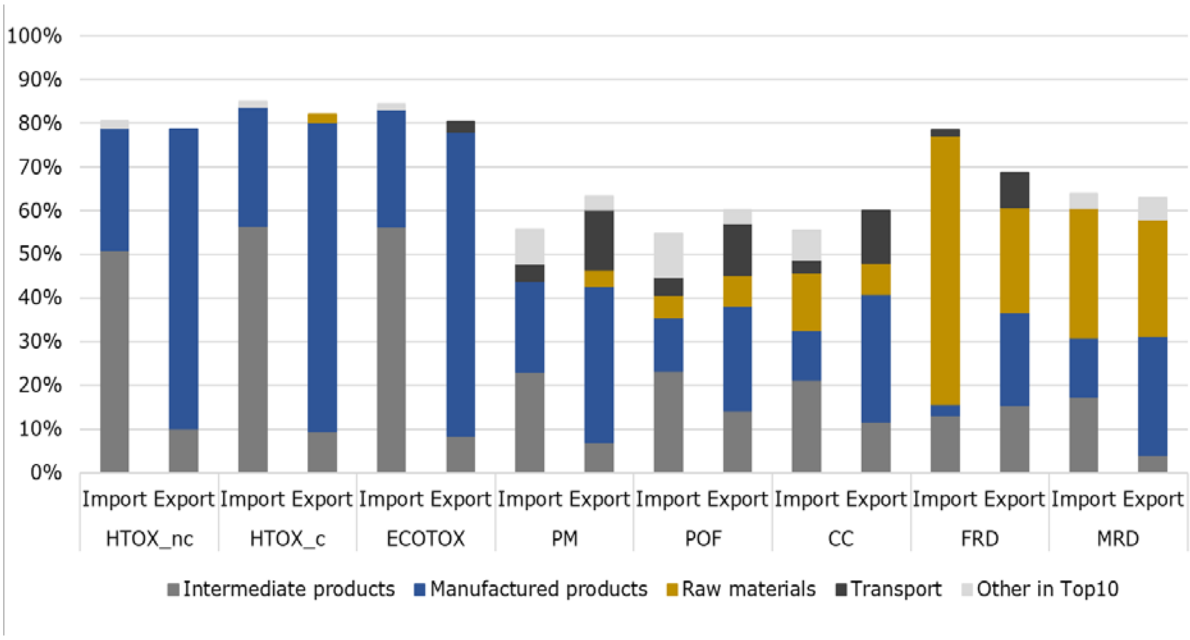
Finally, considering impacts of imports on resource use (both fossil and mineral resource), raw materials are observed to induce a major contribution, on the one hand due to metals, ores and concentrates (minerals and metals resource use), and on the other hand due to fossil fuels (fossils resource use). Regarding exports, in both cases of impact categories, manufactured products induce a larger contribution than in the case of imports (standing for 21-27% of the total when only considering manufactured products that rank in the Top10), while a lower contribution of raw materials is observed.

Figure 23. The Trade Footprint Top-down of EU: contribution analysis of products, with focus on six impact categories and the 10 products and services which represent the largest contributions to these impacts.



Note: The 10 products and services which represent the largest contributions to the impacts are gathered into six categories (Food products, Intermediate products, etc.). Their contribution does not sum up to 100%: only the Top10 contributors (in EXIOBASE nomenclature) are represented here.

Figure 24. The Trade Footprint Top-down of EU: contribution analysis of products, with focus on eight impact categories and the 10 products and services which represent the largest contributions to these impacts.



Note: The 10 products and services which represent the largest contributions to the impacts are gathered into six categories (Food products, Intermediate products, etc.). Their contribution does not sum up to 100%: only the Top10 contributors (in EXIOBASE nomenclature) are represented here.

3.4 Consumption Footprint Bottom-up

The Consumption Footprint Bottom-up is obtained by adding to the Domestic Footprint (presented in Section 3.1) the impact of net import to EU, namely the difference between Import Footprint Bottom-up and Export Footprint Bottom-up, calculated through a methodology based on process-based LCA.

Box 5. Key messages on the Consumption Footprint Bottom-up

— The impacts of the Consumption Footprint Bottom-up decreased for all the impact categories between 2000 and 2014, while the GDP increased (absolute decoupling).

— The results are mainly correlated with the trends in the mass of imported products.

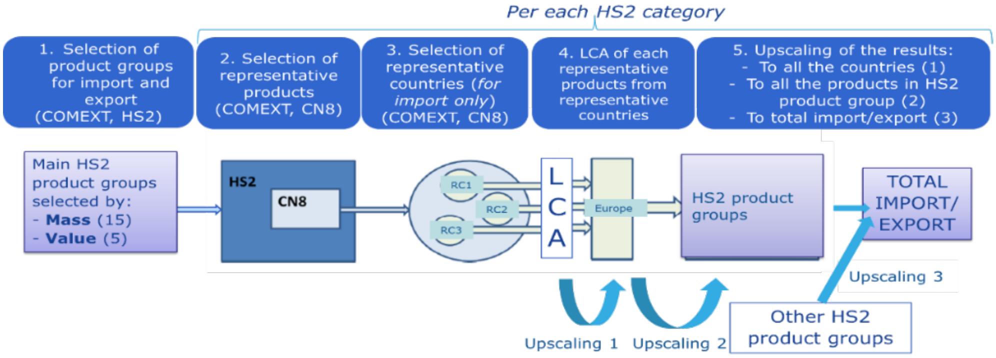
— Environmental impacts are higher for the Import Footprint Bottom-up than for the Export Footprint Bottom-up for almost all the impact categories.

— "Fuels and mineral oils" is the most imported product group as well as the most impacting imported product group for the majority of impact categories.

3.4.1 Methodology of the Consumption Footprint Bottom-up

The Import Footprint Bottom-up and Export Footprint Bottom-up were assessed **on the basis of process-based LCA of 40 products representative of the mostly traded goods (20 products for the Import and 20 products for the Export)** (Corrado et al. 2019). The selection of representative products was based on Comext, the Eurostat's reference database on international trade in goods (Eurostat, 2017h). Firstly, following the two-digits Harmonised System nomenclature (HS2) (Annex 7), 20 product groups were selected respectively for imports and exports, of which 15 were the most important in mass and 5 in value in 2010. Within each product group, the most important product in terms of mass was selected as representative product. The selection of representative products was done following the Combined Nomenclature for classifying goods (CN8), more detailed than the HS2 nomenclature. In case of **import, the three countries producing most of the imported products were selected as representative countries,** taking into account as far as possible country-specific characteristics of production processes, depending on information availability. This was just for import, because the impacts of transport of imported products were allocated to EU consumption, and, coherently with this approach, the impacts of exported products should be allocated to importing countries. An LCA was performed for each representative product and results were up-scaled in order to cover the entire amount of traded goods. A three-steps upscaling was done, encompassing the upscale to all the importing countries (applicable only to import), to all the products in the HS2 category, and, putting together the results for all the product groups, the upscaling to total imports and exports. A summary of the procedure adopted to quantify the impacts of trade with a bottom-up approach is reported in Figure 25. Results were calculated for the years 2000, 2005, 2010, and 2014, and for the intermediate years were interpolated according to the total imported and exported amount of products, as reported in Comext database.

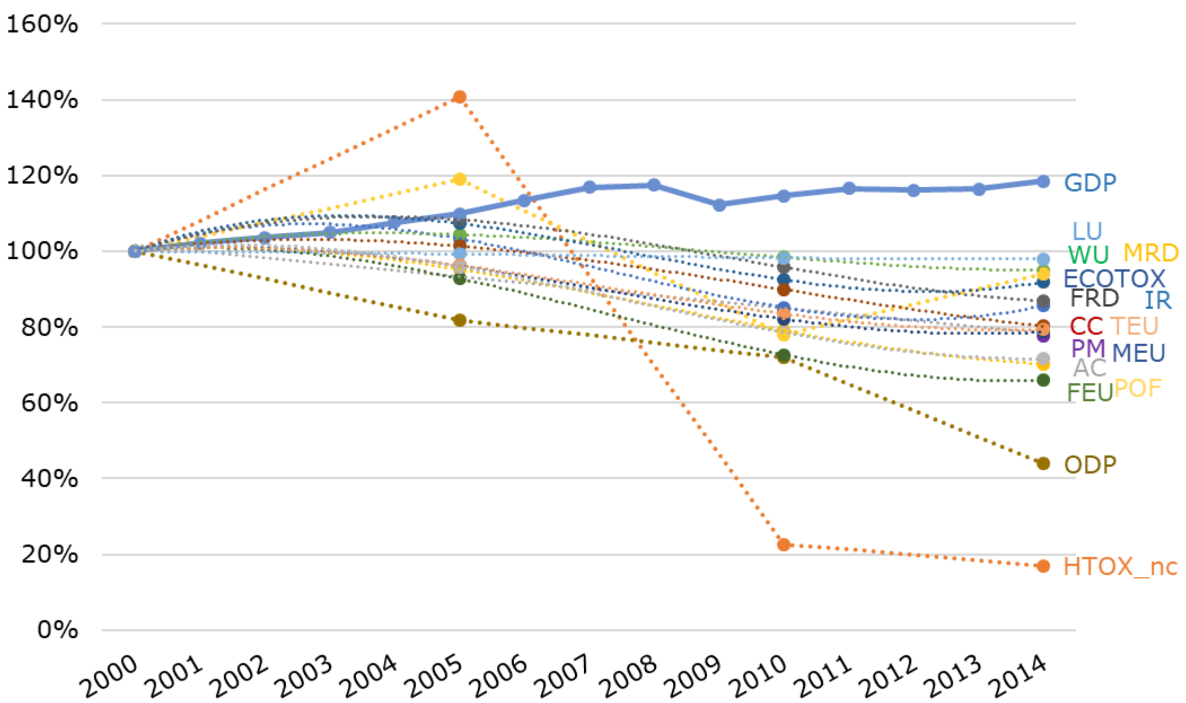
Figure 25. Procedure to quantify the impacts of trade with a bottom-up approach.



3.4.2 Consumption Footprint Bottom-up: trends of environmental impacts overtime (2000-2014)

The analysis of temporal trends for apparent consumption **between 2000 and 2014** highlights an **overall decrease of the impacts for all the impact categories**, despite an initial increase of some impact categories, e.g. human toxicity non-cancer and mineral resource use, between 2000 and 2005 (Figure 26). This decreasing trend is opposite to the one of GDP, which in the same timeframe showed a 19% increase. For eight out of sixteen impact categories (human toxicity non-cancer, particulate matter, photochemical ozone formation, ozone depletion potential, acidification, and marine, freshwater, and terrestrial eutrophication) the reduction of the impacts was higher than 20%. A reduction lower than 5% was observed only for land use. For all the impact categories, the decreasing trend is driven by the reduction of the burdens of domestic activities and the concomitant increase of the impacts of exports. The impacts of imports are increasing, but they did not offset the effects on apparent consumption of the observed trends for domestic and exports.

Figure 26. Impacts of EU apparent consumption and GDP from 2000 to 2014 calculated with a bottom-up approach (base 100% for year 2000).



A more in-depth analysis of the results for the trade calculated with the bottom-up approach is reported in Corrado et al. (2019).

3.4.3 Trade Footprint Bottom-up: contribution analysis of products

The product groups selected to apply the bottom-up approach cover respectively **93% and 80% of the amount of imported and exported goods, and 70% and 76% of the economic value** of imported and exported products. A summary of the names used to refer to the product groups is reported in Annex 7. From the selection of product groups (Figure 27), it is evident that EU imports mainly food products and raw materials and exports finished products, with complex supply chains. This is reflected also in the selection of the representative products: 16 out of 20 product groups were analysed both for import and export, but the representative products had in general a longer supply chain in case of export, except in few cases. This situation leads to a sort of **"export effect"** for some impact categories, e.g. human toxicity cancer and non-cancer, where the **impacts of exports are elevated** (Figure 28) **and play a considerable role in contributing to**

reduce the burdens of the European apparent consumption, while increasing the overall environmental burdens exerted on the global environment. This should be interpreted considering that complex supply chains imply a high number of production processes and the assembly of different components, generally responsible for high impact intensity per unit of product. However, in a globalised economy, it is unlikely that all the production stages take place in the same area and it may be that exported products embed some impacts generated along the supply chain outside EU boundaries.

It has to be highlighted that differences in the approaches adopted to calculate the impacts of the trade components, i.e. imports and exports, and of domestic activities may affect the reliability of the results. To limit this possibility, a thorough review of the flow mapping has been performed to assure consistency in the characterization of elementary flows. However, the lack of detailed information on some of the elementary flows in one or in the other approach may limit the meaningfulness of the results for apparent consumption, particularly for those impact categories in which several flows are significantly contributing to the overall impacts and are characterised by a high degree of uncertainty. This is particularly evident for the impact category human toxicity cancer, for which a negative apparent consumption is obtained, which cannot happen in reality, and is therefore not reported in the results.

The main drivers behind the impacts of the product groups calculated with the bottom-up approach are the amount of traded goods and the emission intensity, namely the impact generated by a unit of mass of product.

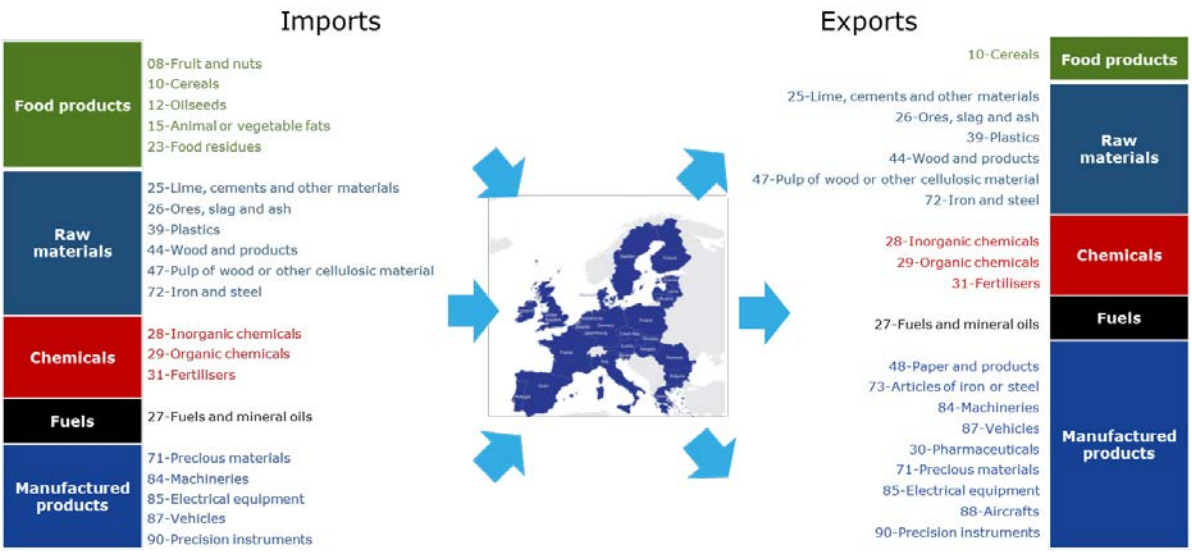
Results for 2010 show that group **"27 - Fuels and mineral oils" is by far the most largely imported product group in terms of mass and contributes to the majority of the impacts of import**, for almost all the impact categories (acidification, human toxicity cancer, climate change, terrestrial eutrophication, ionising radiation, ozone depletion, photochemical ozone formation, fossil resource depletion, particulate matter, and water use), with a share ranging between 36% for human toxicity cancer, and 98% for ozone depletion. Other hotspots due to high impact intensities are represented by "84 – Machineries", for the impact categories human toxicity non–cancer (40%), freshwater eutrophication (45%), and mineral resource use (56%); "23 – Food residues" for ecotoxicity (30%); "47 – Pulp of wood or other cellulosic materials" for land use (26%).

The analysis of the impacts in function of the country of origin shows that **the proportion between the environmental impacts does not always reflect the proportion between the shares of imported quantities from different countries**. Concerning the product group "27 - Fuels and mineral oils", for example, import from Russia represents 57% of the mass of the imported product group, but contributes between 63% and 97% to all the impact categories. On the contrary, the amount of imported products from Norway corresponds to 27% of the total, but contributes from 0% to 21% to all the impact categories. **This may be due to different production processes, and different means of transport and distances. This element highlights the importance of integrating as far as possible country-specific differences in the LCA model.**

The share of product groups to impact categories for 2014 is overall similar to 2010 (Table 14, Table 15). For the majority of the product groups there is a slight reduction of the imported amount ranging from 3% to 37%. A considerable reduction of imports is observed for imports of "10 – Cereals" (-110%), but it has just a small influence on the environmental impact since the product group is contributing to a small extent to all impact categories. Imports of "84 – Machineries" is reduced by 37% but it remains anyway a hotspot for the same impact categories reported for 2010. A small increase in imported amounts, comprised between 3% and 4% is observed for the product groups "23 – Food residues", "26 – Ores, slag and ash", and "27 – Fuels and mineral oils".

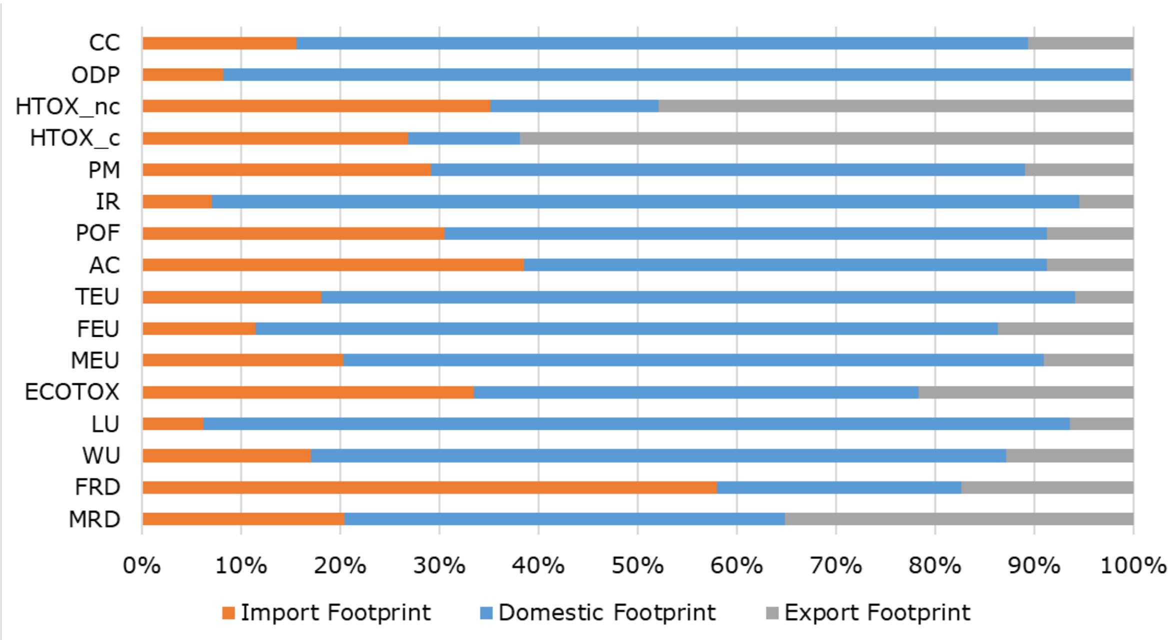
Concerning **exports**, the contribution of different product groups is more varied. **"27 - Fuels and mineral oils"** is the most exported product group, although the relative importance and the share of environmental impact is much lower compared to imports. It is a hotspot for the impact categories climate change, terrestrial eutrophication, photochemical ozone formation, and fossil resource use, to which it contributes respectively by 24%, 19%, 20% and 53%. **"72 – Iron and steel"** contributes by 51% to human toxicity cancer, 38% to ecotoxicity, 20% to ozone depletion, 29% to particulate matter, and 19% to water use due to a combination of quite large exported quantities and quite high emission intensities. **"84 – Machineries"** represents the main hotspot for acidification (20%), freshwater eutrophication (68%), human toxicity non-cancer (52%), and mineral resource use (59%) because of relatively high impact intensities. For the same reason the products groups "**10 - Cereals"**, **"47 – Pulp of wood and other cellulosic material"** and **"87 – Vehicles"** are the main contributors respectively to marine eutrophication (26%), land use (35%), and ionising radiation (22%).

Figure 27. Selected product groups representative of main imports and exports, according to the bottom-up approach.



Note: Numbers before the names of the product groups refer to the HS2 nomenclature classes, described according to abbreviated names (Annex 7).

Figure 28. Share of impacts of imports, domestic activities and exports in 2010.



Note: The impacts of the trade components are calculated according to the bottom-up approach, whereas the impacts of domestic activities are calculated as described in section 3.1.

Table 14. Contribution of product groups to the environmental impacts of imports in the years 2010 and 2014.

Impact category	Year	71-Precious materials	84-Machi-neries	85-Electrical equipment	87-Vehicles	90-Precision instruments	08-Fruit and nuts	10-Cereals	12-Oilseeds	15-Animal or vegetable fats	23-Food residues	25-Lime, cements and other materials	26-Ores, slag and ash	27-Fuels and mineral oils	28-Inorganic chemicals	29-Organic chemicals	31-Ferti-lisers	39-Plastics	44-Wood and products	47-Pulp of wood or other cellulosic material	72-Iron and steel
AC	2010	0%	3%	3%	1%	0%	1%	1%	1%	1%	2%	0%	3%	77%	0%	0%	1%	1%	0%	1%	2%
AC	2014	0%	3%	4%	2%	0%	0%	1%	1%	1%	2%	0%	3%	76%	0%	0%	1%	1%	0%	1%	2%
HTOX_c	2010	0%	27%	12%	12%	1%	0%	1%	1%	1%	3%	0%	1%	36%	0%	0%	1%	1%	0%	1%	2%
HTOX_c	2014	0%	32%	11%	12%	1%	0%	3%	1%	1%	2%	0%	1%	32%	0%	0%	1%	1%	0%	1%	1%
CC	2010	0%	4%	9%	3%	0%	0%	1%	2%	2%	5%	0%	2%	51%	4%	2%	2%	3%	0%	1%	8%
CC	2014	0%	6%	9%	3%	0%	0%	1%	3%	2%	5%	0%	2%	47%	4%	2%	3%	3%	0%	1%	8%
ECOTOX	2010	0%	11%	5%	3%	0%	8%	1%	11%	1%	30%	0%	1%	28%	0%	0%	1%	0%	0%	0%	0%
ECOTOX	2014	0%	13%	4%	3%	0%	7%	2%	16%	1%	25%	0%	0%	25%	0%	0%	1%	0%	0%	0%	0%
FEU	2010	0%	45%	8%	5%	1%	0%	1%	8%	1%	12%	0%	0%	16%	0%	1%	1%	0%	0%	1%	0%
FEU	2014	0%	51%	7%	5%	0%	0%	2%	7%	1%	9%	0%	0%	14%	0%	1%	1%	0%	0%	1%	0%
MEU	2010	0%	2%	3%	1%	0%	2%	5%	9%	4%	12%	0%	7%	45%	1%	1%	1%	1%	0%	2%	3%
MEU	2014	0%	3%	3%	1%	0%	2%	11%	9%	4%	11%	0%	6%	41%	1%	1%	1%	1%	0%	1%	3%
TEU	2010	0%	3%	4%	2%	0%	1%	2%	3%	4%	6%	1%	8%	55%	0%	1%	2%	2%	0%	2%	4%
TEU	2014	0%	4%	4%	2%	0%	1%	4%	4%	4%	6%	1%	7%	52%	0%	1%	2%	2%	0%	2%	4%
IR	2010	0%	8%	6%	7%	1%	0%	0%	0%	2%	1%	0%	1%	64%	3%	1%	1%	0%	1%	2%	1%
IR	2014	0%	11%	6%	8%	1%	0%	1%	0%	2%	1%	0%	1%	61%	3%	1%	2%	0%	2%	2%	1%
LU	2010	0%	1%	1%	0%	0%	1%	6%	24%	5%	24%	0%	0%	12%	0%	0%	0%	0%	1%	26%	0%
LU	2014	0%	1%	1%	0%	0%	1%	12%	20%	5%	22%	0%	0%	12%	0%	0%	0%	0%	1%	23%	0%
HTOX_nc	2010	0%	40%	9%	6%	1%	0%	1%	1%	0%	2%	0%	0%	28%	0%	0%	1%	0%	0%	1%	10%
HTOX_nc	2014	0%	45%	8%	6%	1%	0%	3%	1%	0%	1%	0%	0%	24%	0%	0%	1%	0%	0%	0%	9%
ODP	2010	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	98%	0%	0%	0%	0%	0%	0%	0%
ODP	2014	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	97%	0%	1%	1%	0%	0%	0%	0%
POF	2010	0%	2%	3%	2%	0%	1%	1%	2%	2%	5%	0%	6%	67%	0%	1%	1%	2%	0%	1%	3%
POF	2014	0%	3%	4%	2%	0%	1%	1%	3%	3%	5%	0%	5%	65%	0%	1%	1%	2%	0%	1%	3%
FRD	2010	0%	1%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	89%	1%	1%	1%	1%	0%	0%	1%
FRD	2014	0%	1%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	88%	1%	1%	1%	2%	0%	0%	1%
MRD	2010	0%	56%	25%	9%	1%	0%	0%	0%	1%	1%	0%	0%	4%	0%	0%	2%	0%	0%	1%	0%
MRD	2014	0%	61%	21%	9%	1%	0%	0%	0%	1%	0%	0%	0%	3%	0%	0%	2%	0%	0%	1%	0%
PM	2010	0%	5%	3%	2%	0%	0%	0%	5%	5%	12%	0%	6%	53%	0%	0%	1%	1%	0%	1%	5%
PM	2014	0%	7%	3%	2%	0%	0%	1%	7%	5%	11%	0%	5%	51%	0%	0%	1%	1%	0%	1%	5%
WU	2010	0%	5%	12%	4%	0%	7%	0%	0%	16%	1%	0%	2%	40%	1%	1%	1%	2%	1%	5%	2%
WU	2014	0%	5%	10%	5%	1%	7%	0%	0%	17%	0%	0%	1%	35%	1%	1%	1%	2%	0%	5%	2%

Table 15. Contribution of product groups to the environmental impacts of exports in the years 2010 and 2014.

Impact category	Year	10-Cereals	25-Lime, cements and other materials	26-Ores, slag and ash	27-Fuels and mineral oils	28-Inorganic chemicals	29-Organic chemicals	30-Pharma-ceuticals	31-Ferti-lisers	39-Plastics	44-Wood and products	47-Pulp of wood or other cellulosic material	48-Paper and products	71-Precious materials	72-Iron and steel	73-Articles of iron or steel	84-Machi-neries	85-Electrical equipment	87-Vehicles	88-Aircrafts	90-Precision instruments
AC	2010	5%	2%	0%	18%	7%	2%	1%	1%	5%	0%	3%	5%	0%	13%	3%	20%	1%	13%	0%	1%
AC	2014	7%	2%	0%	17%	7%	1%	1%	1%	4%	1%	3%	4%	0%	12%	2%	20%	1%	15%	0%	1%
HTOX_c	2010	2%	0%	0%	7%	0%	0%	0%	0%	1%	0%	1%	1%	0%	51%	0%	21%	0%	13%	0%	3%
HTOX_c	2014	2%	0%	0%	7%	0%	0%	0%	0%	1%	0%	1%	1%	0%	47%	0%	22%	0%	14%	0%	3%
CC	2010	3%	6%	0%	24%	0%	2%	1%	1%	8%	1%	2%	5%	0%	17%	6%	11%	1%	10%	0%	1%
CC	2014	3%	7%	0%	24%	0%	2%	1%	1%	7%	1%	2%	4%	0%	16%	5%	11%	1%	12%	0%	1%
ECOTOX	2010	4%	0%	0%	5%	0%	0%	1%	0%	1%	0%	1%	2%	0%	38%	0%	31%	0%	12%	0%	3%
ECOTOX	2014	5%	0%	0%	5%	0%	0%	0%	0%	1%	0%	1%	2%	0%	35%	0%	32%	0%	13%	0%	3%
FEU	2010	3%	0%	0%	3%	0%	1%	1%	0%	0%	0%	1%	3%	0%	9%	0%	68%	0%	10%	0%	0%
FEU	2014	4%	0%	0%	3%	0%	0%	0%	0%	0%	0%	1%	2%	0%	8%	0%	69%	0%	11%	0%	0%
MEU	2010	38%	2%	0%	17%	0%	1%	5%	0%	3%	1%	3%	4%	0%	9%	2%	8%	1%	5%	0%	0%
MEU	2014	46%	2%	0%	17%	0%	1%	1%	0%	3%	1%	3%	3%	0%	7%	1%	8%	1%	5%	0%	0%
TEU	2010	13%	4%	0%	19%	1%	2%	1%	1%	5%	1%	5%	6%	0%	15%	3%	14%	1%	9%	0%	1%
TEU	2014	15%	4%	0%	19%	1%	2%	1%	1%	4%	2%	5%	5%	0%	13%	2%	14%	1%	9%	0%	1%
IR	2010	1%	3%	0%	8%	0%	1%	2%	1%	0%	1%	3%	17%	0%	18%	0%	19%	1%	22%	1%	1%
IR	2014	1%	4%	0%	8%	0%	1%	3%	1%	0%	1%	3%	14%	0%	16%	0%	20%	1%	24%	1%	1%
LU	2010	17%	0%	0%	14%	0%	0%	1%	0%	0%	2%	35%	27%	0%	1%	0%	1%	0%	1%	0%	0%
LU	2014	21%	0%	0%	15%	0%	0%	0%	0%	0%	3%	34%	23%	0%	1%	0%	1%	0%	1%	0%	0%
HTOX_nc	2010	1%	1%	0%	7%	0%	0%	0%	0%	0%	0%	1%	2%	0%	23%	0%	52%	0%	11%	0%	1%
HTOX_nc	2014	1%	1%	0%	6%	0%	0%	0%	0%	0%	0%	1%	1%	0%	21%	0%	53%	0%	13%	0%	1%
ODP	2010	4%	5%	0%	0%	1%	4%	2%	4%	0%	0%	5%	10%	0%	20%	1%	18%	12%	14%	0%	1%
ODP	2014	5%	6%	0%	0%	1%	3%	0%	3%	0%	0%	5%	9%	0%	18%	1%	18%	13%	16%	0%	1%
POF	2010	3%	3%	0%	20%	1%	3%	1%	1%	10%	1%	4%	5%	0%	17%	3%	13%	1%	13%	0%	1%
POF	2014	3%	4%	0%	20%	1%	2%	1%	1%	9%	1%	4%	5%	0%	15%	3%	13%	1%	15%	0%	1%
FRD	2010	1%	1%	0%	53%	0%	4%	1%	1%	9%	0%	1%	3%	0%	8%	2%	6%	2%	7%	0%	0%
FRD	2014	1%	1%	0%	54%	0%	4%	1%	1%	9%	0%	1%	3%	0%	8%	2%	6%	2%	7%	0%	0%
MRD	2010	1%	0%	0%	1%	1%	1%	1%	1%	0%	0%	1%	1%	0%	20%	0%	59%	0%	13%	0%	2%
MRD	2014	1%	0%	0%	1%	1%	1%	0%	1%	0%	0%	1%	1%	0%	18%	0%	60%	0%	14%	0%	2%
PM	2010	3%	1%	1%	7%	2%	1%	0%	1%	2%	6%	3%	5%	0%	29%	1%	24%	1%	11%	0%	2%
PM	2014	3%	1%	1%	7%	2%	1%	1%	1%	2%	7%	3%	4%	0%	26%	1%	25%	1%	12%	0%	2%
WU	2010	1%	1%	0%	12%	5%	2%	2%	0%	5%	0%	9%	16%	0%	19%	0%	12%	1%	14%	0%	1%
WU	2014	1%	2%	0%	13%	6%	2%	2%	0%	5%	0%	9%	14%	0%	18%	0%	12%	1%	12%	0%	0%

As for imports, not many differences are observed between exports in 2010 and 2014 in terms of contribution of product groups to different impact categories. The main differences concern ozone depletion and terrestrial eutrophication for which the main hotspots are respectively “84 – Machineries”, and “27 – Fuels and Mineral oils”.

The **food sector** is more important for imports than for exports, both in terms of mass and environmental impacts. Besides being a **hotspot for ecotoxicity**, mainly because of pesticides use, imports of products groups related with the food sector, namely “23 – Food residues”, “15 – Animal or vegetable fats”, “12 – Oilseeds” , “10 – Cereals” and “08 – Fruits and nuts” are the **main responsible of the emissions of ammonia (NH_3) to the atmosphere and nitrates (NO_3^-) to water**. These emissions are respectively responsible for the impacts on terrestrial eutrophication, acidification, and marine eutrophication. The food sector is less represented in exports, with only one representative product group, and this explains the considerably lower absolute impacts on acidification (23% of impacts of imports), terrestrial eutrophication (33% of the impacts of imports), and marine eutrophication (43% of the impacts of imports).

3.5 Comparison of Consumption Footprint Top-down and Bottom-up (2005-2014)

Box 6. Key messages on the comparison between Consumption Footprint Top-down and Bottom-up

— Overall, higher results for top-down approach, in particular due to its broader scope (it includes services) and intrinsic differences in the modelling approaches.

— For both approaches, existence of an “export effect” associated with the important increase of export between 2005 and 2014, with a beneficial effect on the reduction of the Consumption Footprint (while the overall impacts generated increase).

— EU is a “net importer of environmental impacts” according to both approaches, with some exceptions for bottom-up regarding human toxicity, non-cancer, freshwater eutrophication, and land use.

— Further refinements of the methodological approaches needed to have a more robust estimation of the impacts of EU apparent consumption.

The differences between the Consumption Footprints Top-down and Bottom-up results from the approaches adopted to assess the trade components, which are respectively based on EXIOBASE, and process-based LCA (Beylot et al., 2019b; Corrado et al., 2019). The **bottom-up approach** has the advantage of being very often **more precise** than the top-down, as **it allows for higher detail and flexibility**. On the other hand, the **top-down** approach has the advantage of capturing well overall figures at macro-scale. In general, but with relevant exceptions, the top-down approach **covers a broader range of economic activities but less environmental interventions and flows** than the bottom-up approach.

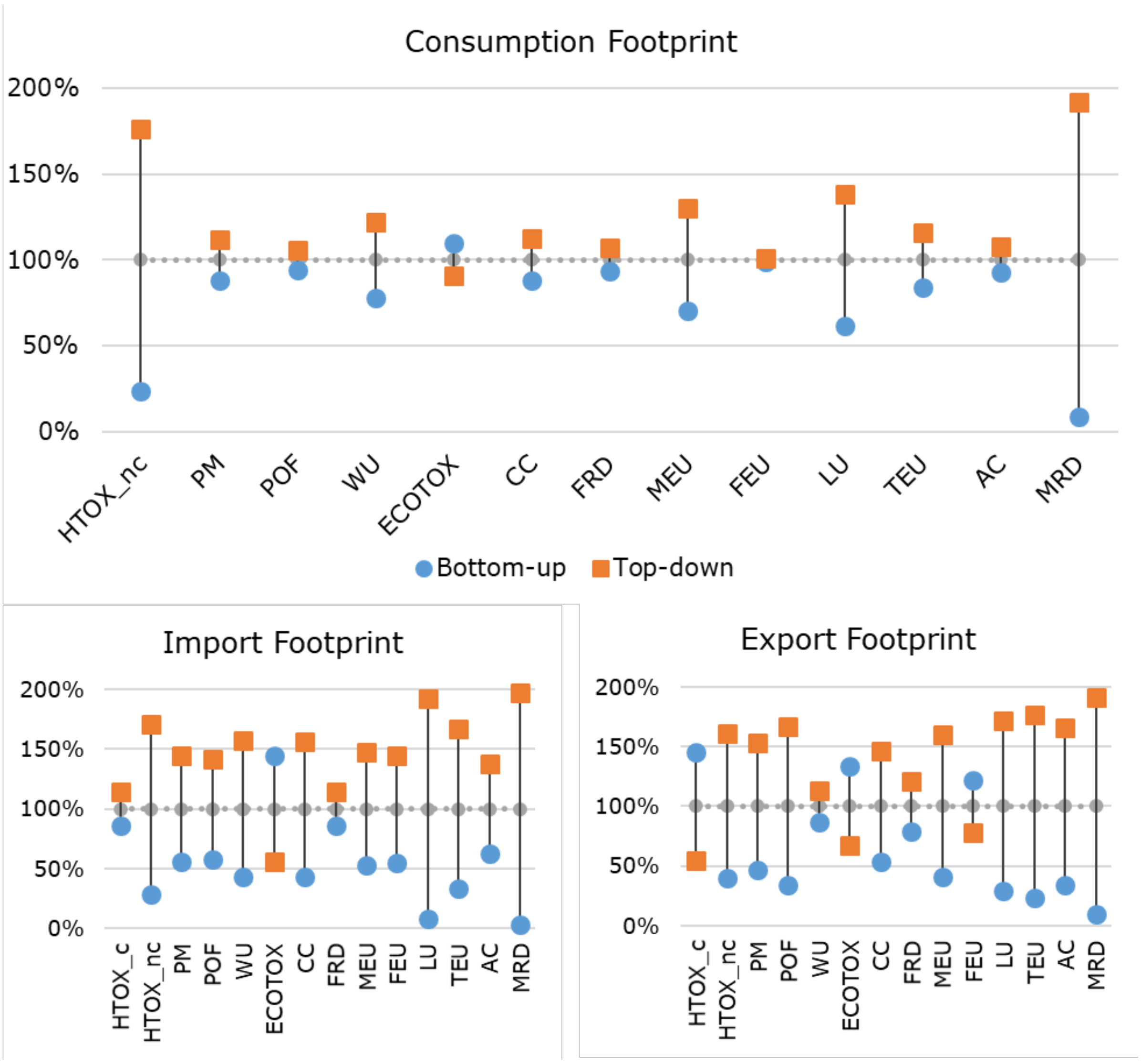
The results obtained with the two approaches are compared both at the level of impact categories considering 2010 as reference year, and temporal trend of Import and Export Footprints, as summarised in the current section. In light of the abovementioned pros and cons of the two approaches, the **comparison** of the results **informs on converging results that may support certain conclusions on trends and drivers of impacts**. Moreover, the comparison may unveil their potential criticalities, as well as highlight complementarities, which may help improving further estimates of impacts.

Overall, the **two approaches converge** in estimating higher impacts for apparent consumption than for domestic, meaning that **EU can be considered a “net importer of environmental impacts”.** The impacts of the Consumption Footprint Top-down are higher than for the Domestic Footprint for all the impact categories (section 3.3), whereas, in case of the Consumption Footprint Bottom-up, some exceptions are found for the impact categories human toxicity non-cancer, freshwater eutrophication, land use, and mineral resource use.

The comparison for the Consumption Footprint of the two approaches highlights that **results per impact category are always comprised between ±100% of the average value** (Figure 29). They are comprised between 6% and 38% of the average for all the impact categories except human toxicity non-cancer, and mineral resource depletion for which higher discrepancies are found (respectively, 77% and 92% of the average).

The impacts of imports and exports calculated with the two approaches present higher differences than results for apparent consumption, as shown in Figure 29. This implies that the overall broad convergence of results for apparent consumption is due to similarities in the difference "impacts of import – impacts of export" calculated with the bottom-up and top-down approaches for all the impact categories, except for the abovementioned ones.

Figure 29. Environmental impacts of Consumption and Trade Footprints in 2010 estimated with the bottom-up and top-down approaches.



Note: The average value is reported 100% and the results for the two approaches are rescaled accordingly. The impact of apparent consumption on human toxicity cancer is not reported because of negative contributions and it is considered not robust enough.

Results obtained with the top-down approach are higher for all the impact categories, except for ecotoxicity, and, only in the case of exports, for freshwater eutrophication and human toxicity cancer. Including the impact of services and governments, the top-down approach has a broader scope, which may reasonably explain the overall greater results. A possible cause of the lower results for ecotoxicity obtained with the top-down approach is the omission of heavy metals emissions to water and pesticides emissions to agricultural soil, which together represent respectively the 86% and 83% of the impact of import and export assessed with the bottom-up approach.

The higher differences between the two approaches are observed for the impact category mineral resource use, which, in case of the top-down approach, may be biased by the calculation of the impacts through the characterisation of the inventory flows, reported in a very aggregated manner, as explained in section 3.3.3. Other values higher than ± 50% of the average for both import and export are for land use, terrestrial eutrophication, and human toxicity non-cancer. On the contrary, results included between ± 50% of the average are for the impact categories human toxicity cancer, ecotoxicity, fossil resource use, and freshwater eutrophication.

Overall, **both approaches** globally show the **larger contribution of manufactured products in the total impacts of exports from** EU, both when compared to the contribution of other products and services exported, and when compared with the share of manufactured products in the total impacts of imports. Some **exceptions** are **for the bottom-up approach**, where **"27 - Fuels and mineral oils"** and **"72 - Iron and steel"** are hotspots for a large share of impact categories, e.g. human toxicity cancer and non-cancer, climate change, fossil resource use. Moreover, in both approaches, **products with shorter supply-chains** are observed as the **main contributors to the impacts induced by imports to EU**. However, the bottom-up approach identifies "27 - Fuels and mineral oils" as the main contributing category of products for almost all impact categories. On the contrary, the top-down approach identifies as main contributing categories: i) food products (in particular products of meat) and food-related services regarding acidification, terrestrial, freshwater and marine eutrophication, land use and water use, ii) basic and intermediate products (in particular basic iron and steel, and rubber and plastic products) regarding human toxicity cancer and non-cancer, ecotoxicity, particulate matter, photochemical ozone formation, and climate change, and iii) raw materials (respectively metals, ores and concentrates on the one hand, and fossil fuels on the other hand) regarding mineral and fossil resource use.

Box 7. Trade Footprint Bottom-up: outlook and perspectives

The Trade Footprint Bottom-up is based on the assessment of the environmental impacts of 20 representative products of both imports and exports, up-scaled to the total traded goods. Upscaling the results implies assuming that a single product is fully representative of an entire product group, and that selected product groups are fully representative of all the imported and exported products. In light of the results of the LC-IND2 project, it was evident that the selection and upscaling procedure are sources of uncertainties for the results. Therefore, some refinements have been identified to foster the robustness of future updates of the Trade Footprint Bottom-up results. They consist of improving the representativeness of product groups to be analysed, as well as of representative products within each of them.

As discussed in previous sections, it is clear that bottom-up and top-down approaches may have a complementary role in assessing the environmental impact of EU consumption. The top-down approach supports efficiently the definition of the broad picture, ensuring consistency at the overall level, but very likely involving less accuracy at a higher level of detail. On the other hand, the bottom-up approach allows an in-depth analysis of single products, but may not capture the interconnections between economic sectors, and the contribution of services. Such complementarities are seen as beneficial for the update and improvement of the Trade Footprint Bottom-up.

The selection of the product groups was originally based on mass and economic value reported in statistics for 2010. The selection of representative products within each product group, instead, was done exclusively on a mass basis, for the same year. As highlighted by Lavers et al. (2017), this approach may underpin two main weaknesses. The first is that mass and economic value are not the only indicators of environmental impact. For example, the analysis of the Trade Footprint Top-down highlighted that there are **products, such as meat and meat-based ones, which are not highly relevant in terms of mass or economic value, but have a considerable environmental impact.** The second is that the contribution of representative products to the EU environmental burden of consumption may change over time. These two limitations can be overcame by capitalizing both on the results obtained with the top-down approach (Trade Footprint Top-down) and on the procedure proposed by Lavers et al. (2017).

Foreseen procedural refinements for the selection of product groups and representative products encompass:

— inclusion of environmental relevance as a selection criterion for both product groups and representative products. Such information can be gathered from the results obtained with the top-down approach (Trade Footprint Top-down), and scientific and grey literature;

— analysis of the trends of mass of traded product groups and representative products over time and exclusion of the ones which are relevant only few years;

— increase in the number of representative products within a product group, ensuring that they cover at least 50% of the overall mass.

To further broaden the meaningfulness of Trade Footprint Bottom-up thanks to future updates, the following interventions have been identified:

— increase the level of breakdown, with the analysis of the environmental impacts of trade at the Member State scale, applying the same methodology developed for EU;

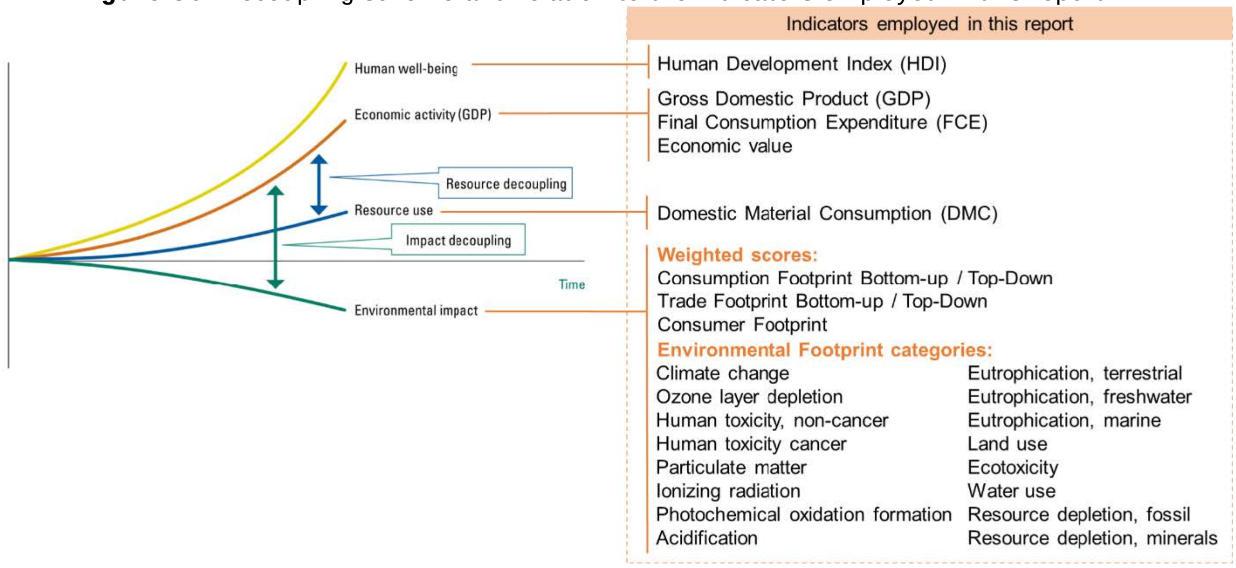
— systematisation of the calculation of the environmental burdens of trade through the development of a modular IT tool for Member States;

— alignment of the LCA models for representative products to the EF framework, ensuring consistency in the modelling, and contributing to the systematization of calculations as discussed in the previous point.

3.6 Assessing the decoupling of economic growth from environmental impacts

Decoupling seeks "using less resources per unit of economic output and reducing the environmental impact of any resources that are used or economic activities that are undertaken" (UNEP, 2011). While the economic growth is commonly measured as the Gross Domestic Product (GDP), different indicators can be used to measure the environmental performance as the decoupling can occur at two levels, differentiating the decoupling from the resource use (resource decoupling) and from the environmental impact (impact decoupling) (UNEP, 2011). The Domestic Material Consumption (DMC) accounts for the 'resource productivity', which is the lead indicator of the Resource Efficiency Roadmap (EC, 2011a), where the economic growth (GDP) over the consumption of materials (DMC) is measured. The Consumption Footprint indicators developed in this project aim at quantifying the environmental impact and enabling the evaluation of decoupling from environmental impacts (Figure 30). Notwithstanding that the decoupling takes place when the economic growth rate is higher than the environmental impact variation, the trend of the environmental impact determines the decoupling grade. When the environmental impact decreases in the context of a growing economy, the decoupling is considered absolute. However, although the environmental impact increases, a relative decoupling takes place when the environmental impact increase rate is lower than the economic growth rate (Ekins et al., 2017; UNEP, 2011). Therefore, assessing the decoupling of economic growth from its environmental impact may indicate the pathway towards sustainable development.

Figure 30. Decoupling scheme and relation to the indicators employed in this report.



Source: Adapted from UNEP (2011).

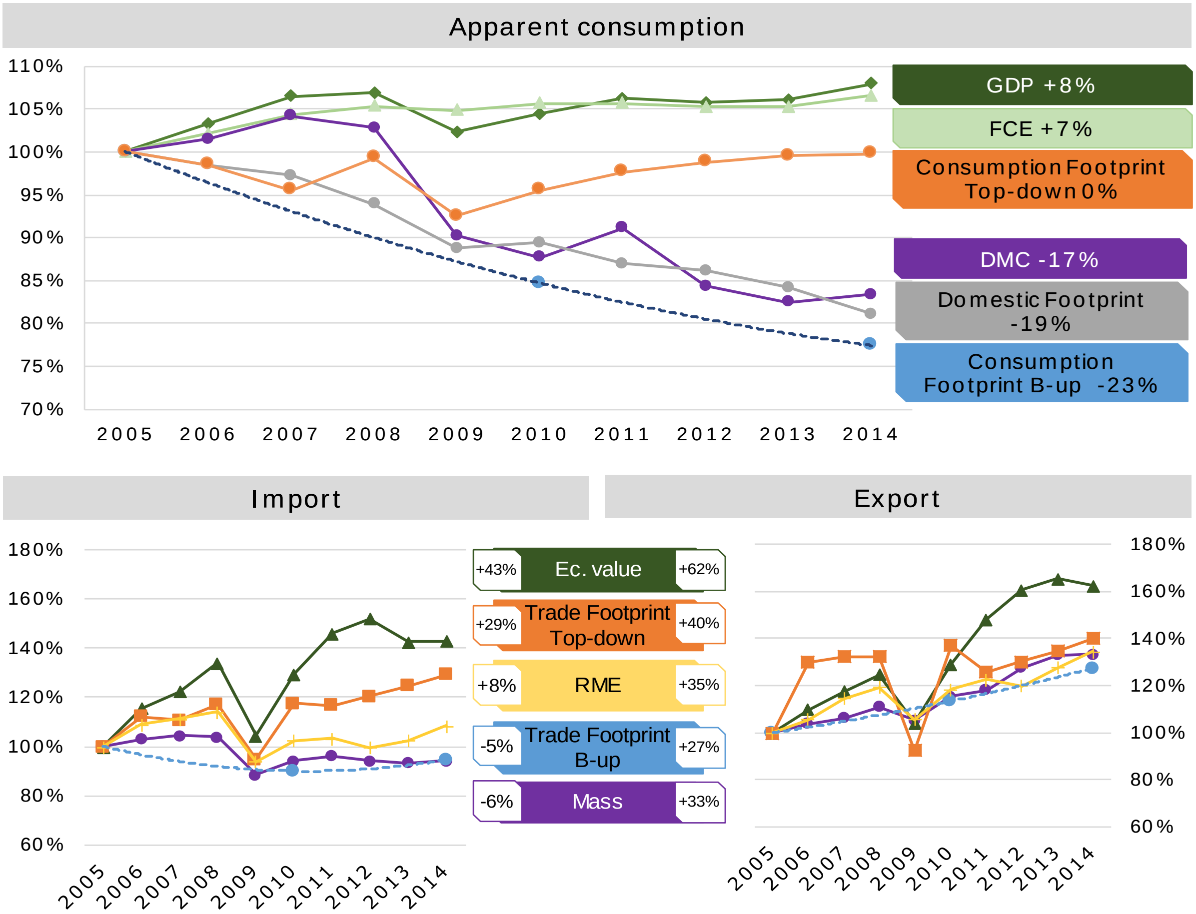
3.6.1 The decoupling of economic growth from environmental impacts of EU consumption

Despite the intrinsic differences of the two approaches, the results converged in the description of an overall absolute decoupling of the Consumption Footprints Top-down and Bottom-up from indicators of economic growth, such as GDP and Final Consumption Expenditure (FCE). However, the extent is different depending on the approach. The Trade Footprints show a deviation from the economic value of imports and exports in both approaches (Figure 31). The comparison between the temporal trends is done considering years between 2005 and 2014 for the reasons explained in section 3.3.1 and because results for the bottom-up approach in 2004 are interpolated (see section 3.4.1).

As highlighted in section 3.3.2, the Consumption Footprint Top-down, which was relatively stable within 2005 to 2014, highlights a decoupling of GDP and FCE from environmental impacts, which raised respectively by 8% and 7%. The Consumption Footprint Bottom-up, instead, decreased by 23% and showed an absolute decoupling, aligned with the decrease of the Domestic Material Consumption (DMC), measuring the total amount of materials directly used by an economy. Such divergences rely on the different methodological approaches, which add uncertainty in measuring the decoupling. While the top-down approach is based on economic data from Multi-Regional Input-Output Tables, the bottom-up approach uses process-based LCA for assessing individual products and up-scale the impact according to mass volumes.

The gap between the Consumption Footprints Top-down and Bottom-up is justified by the higher differences in absolute values between Trade Footprints Bottom-up and Top-down, (Figure 32). In other words, this means that import plays a considerable influence in the Consumption Footprint Top-down (the ratio between Import and Consumption Footprints is between 84% and 108% depending on the years), which is not the case of the Consumption Footprint Bottom-up, having a ratio between Import and Consumption Footprint comprised between 32% and 38%. Beneficial to the negative trend of Consumption Footprint Bottom-up are the concomitant reduction of the Domestic Footprint (-19%), the reduction of the Import Footprint Bottom-up (-5%), and the considerable increase of the Export Footprint Bottom-up (+27%) (“export effect”).

Figure 31. Temporal trends (2005-2014) of Trade and Consumption Footprint Top-down and Bottom-up, and economic figures (GDP, FCE, RME).



Note. Ec. value=Economic value; GDP=Gross Domestic Product; FCE=Final Consumption Expenditure; RME= Raw Material Equivalents; DMC=Domestic Material Consumption. (Sources: Eurostat, JRC analysis). Bottom-up footprints are calculated for 2005, 2010, and 2014, whereas the other years are interpolated.

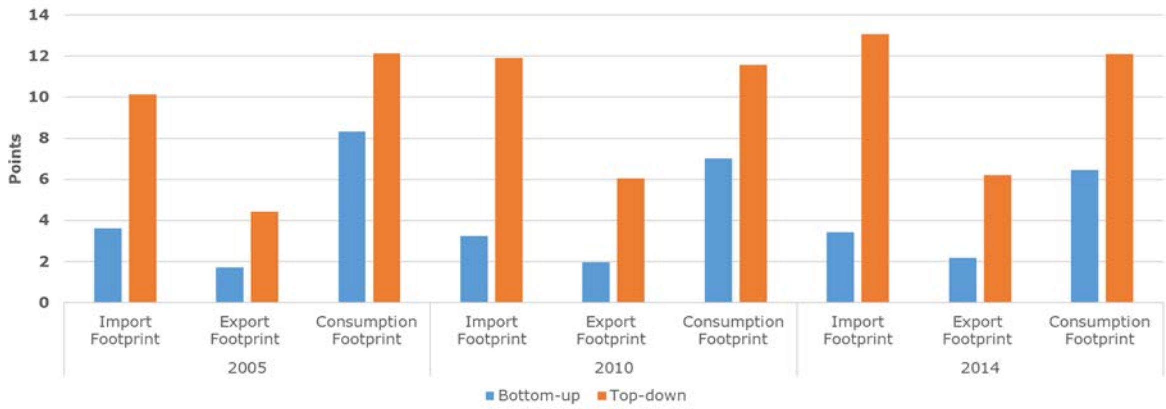
The Import Footprint Top-down follows the trend of the economic value of imported products, although a relative deviation happens, since the economic value increases more (+43%) than the Export Footprint Top-down (+29%). The Import Footprint Bottom-up, instead, has a decreasing trend (-5%) very similar to the mass of imported products (-6%), opposite to the increasing trend of the economic value. The Raw Material Equivalents (RME), which describes the amount of raw materials embodied in imports over the whole production chain, increased by 8% despite an overall reduction of the mass of imports.

The Export Footprints, the indicators related to mass and resources embedded in exported products (RME), and the economic figures related to export highlight a considerable increasing trend from 2005 to 2014. A partial deviation from the trend of the economic value of exported products, which increase by 62%, is found both with the top-down and the bottom-up approaches, although the extent of the deviation is different: the Export Footprint Top-down increases by 40%, whereas the Export Footprint Bottom-up increases by 27%. Overall, the top-down approach brings to a higher estimation of the impacts, compared to the bottom-up. Possible reasons for this difference may be the broader objective of the top-down approach, which includes services and governments, intrinsic differences in the way the inventories are calculated with the two approaches, and potential overestimation of the impact on mineral resource use, which has a considerable influence on the Consumption Footprint Top-down (see section 3.3.1 for details).

The bottom-up approach is in general closer to the trend expressed in mass of products, e.g. Consumption Footprint Bottom-up and DMC, and Trade Footprints Bottom-up and mass of imported/exported products. In contrast, the top-down approach is more similar to the trends of economic indicators, e.g. Consumption Footprint Top-down and GDP or Final Consumption Expenditure (FCE), Trade Footprints Top-down and economic value of imported/exported products. This divergence may rely on the different scope of the two approaches, namely the fact that the top-down approach accounts for elements, e.g. services, which do not have any mass but have an economic value, which are instead omitted in the bottom-up approach. The increase in the indicator related to resource use, the RME, is in case of both imports and exports, between the increase of the mass of products and the economic value.

Further refinements of the modelling in both bottom-up and top-down approaches would be beneficial for a more in-depth analysis of the extent of decoupling at EU level. From a bottom-up perspective, an option to improve the account would be to include selection criteria for products based on environmental relevance as reported by Lavers et al. (2017), to increase the number of representative products and to refine life cycle inventories for representative products (Box 6). For the top-down approach, a broader coverage of elementary flows and, at the same time, a higher disaggregation of flows, would guarantee a more adequate assessment of impacts.

Figure 32. Import, Export and Consumption Footprints.



3.6.2 The decoupling in the different European Member States

Following the top-down approach, the Consumption Footprint can be assessed at the EU Member State level, thereby enabling the identification of different decoupling patterns along the EU. A decoupling index (DI) that quantifies the ratio between the environmental impact variation (i.e. Consumption Footprint or Domestic Footprint) and the economic growth (GDP) is presented in Table 17. The decoupling assessment allowed the identification of four groups of countries showing a different level of decoupling (Table 16).

Table 16. Decoupling groups, decoupling index (DI) and Member States in that group for the Domestic and the Consumption Footprint (both EU normalised, 2004-11, 14 indicators).

Decoupling group	**DI**	**Member States[10] (Domestic Footprint)**	**Member States[10] (Consumption Footprint)**
Absolute decouplers	< 0	13: BE, HR, CY, DK, FR, IE, LT, LU, LV, MT, ES, SE, GB	14: BG, CY, DK EE, FR, IE, LT, LV, MT, SL, SK, PT ES, GB
Relative decouplers	(0, 1)	9: AT, BG, CZ, DE, NL, PL, RO, SK, SL	6: AT, BE, CZ, PL, RO, SE
Stagnant (GDP variation <0.5%)	< 0	3: PT, GR, IT	2: GR, IT
Non-decouplers	> 1	3: FI, HU, EE	6: HR, DE, FI, HU, LU, NL

In the decoupling groups of the Consumption Footprint, some outliers arise showing large environmental impact or economic growth variations. An assessment of the drivers to these

[10] See the list of abbreviations for Member States at the end of the report.

variations highlights which element of the consumption (i.e. domestic, import, export), impact categories, elementary flows and economic sectors have a key role in each case (Annex 8).

Regarding the **absolute decouplers**, the decrease of electricity production by means of nuclear power plants, fossil fuels consumption, trade of manufactured products, imported bio-based products (including meat) and the domestic emissions of $PM_{2.5}$ are recurrent for Slovakia, Lithuania and Estonia. Poland, example of the **relative decouplers**, decreases the export of food while some impact categories vary due to data gaps in the initial period of assessment (e.g. photochemical ozone formation and CO and CH_4 emissions).

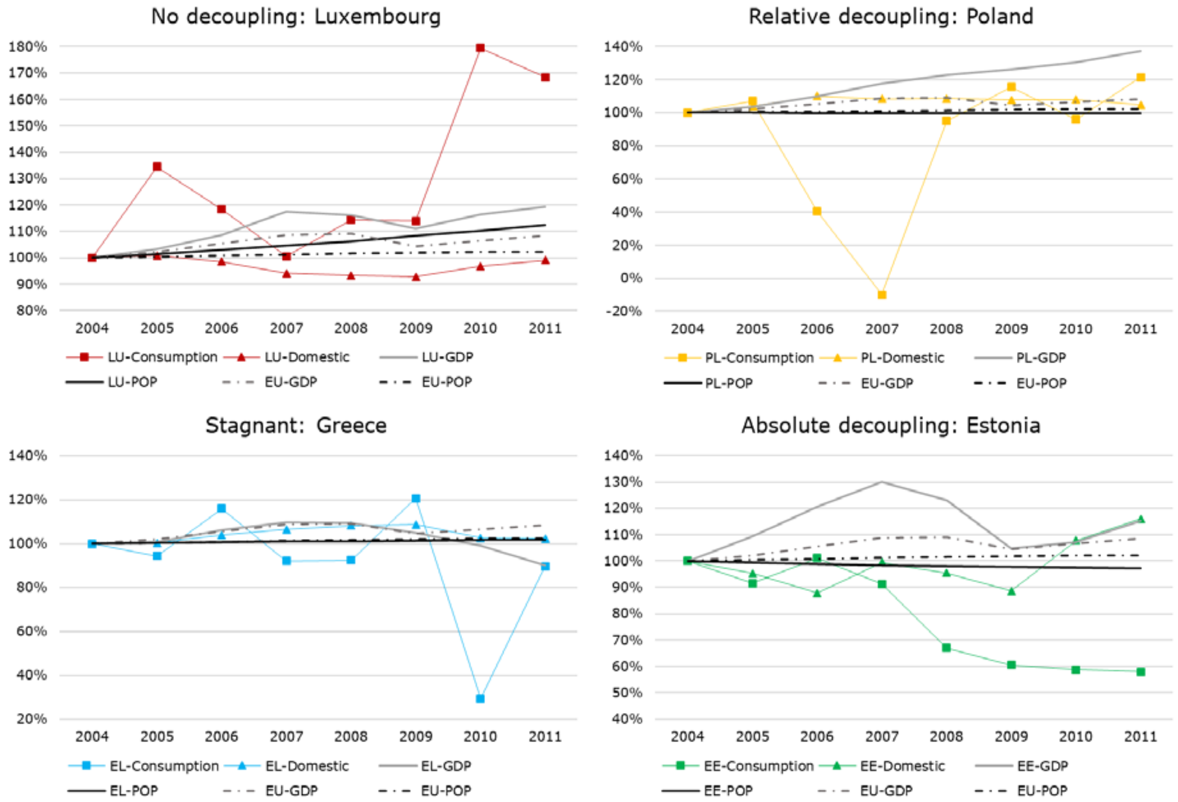
With reference to the **stagnant countries**, each of them shows a contrast pattern. Italy reductions are mainly related to a variation in the role of fossil fuels in the energy mix of the country, where renewable energy is growing, and to a variation in the water impacts related to food imports. In the case of Greece, the decrease of the Consumption Footprint is associated to reduced domestic emissions of sulphur and nitrogen oxides (e.g. solvents, road transport, international shipping) and environmental impacts embodied in the exports related to the sea and coastal water transport sector.

Concerning the **countries that show no decoupling**, some common trends arise. Meat trade is crucial for the environmental impact variations of Luxembourg and The Netherlands. For Luxembourg, the embodied burdens of the 'hotel and restaurant' trade and the trade of manufactured products have also an important role. Finally, the increase of the Consumption Footprint of Germany is related to an increase of imports of gold and other industrial minerals, as well as to a low decrease of grassland land use in contrast to the rest of EU countries.

The assessment of the decoupling of the Domestic Footprint from the economic growth during the period 2004-2011 (Table 17) also outlines the existence of four groups of countries (from absolute decouplers to stagnant countries). In this case, the share of non-decouplers is lower than for the Consumption Footprint, although the share of absolute decouplers is similar. Such results indicate that the degree of decoupling is higher from a territorial perspective than from a consumption-based approach and emphasise the importance of trade, as already detailed in previous sections. The reasoning for outliers in each group is also detailed in Annex 8.

The pattern of a representative country of each of the decoupling groups regarding the Consumption Footprint is displayed in Figure 33. The trends of the Consumption Footprint, Domestic Footprint, GDP and population of the country show how the different countries behave in the period 2004-2011. In the four patterns, the comparison of the two footprints stresses the high variability of the Consumption Footprint between years and the relevance of environmental burdens embodied in trade for assessing the apparent consumption. Furthermore, the effect of the economic crisis of 2008 can be seen in the pattern of the four countries, which varies before and after this year.

Figure 33. Decoupling for the Consumption Footprint Top-down: country patterns.



Note: Selected examples of each decoupling group: Consumption Footprint (square line) and Domestic Footprint (triangle line) in relation to country's GDP (grey) and population (black) trends. EU GDP (dash grey) and population (dash black) is displayed as reference.

According to the Beyond GDP initiative and some authors (van den Bergh & Botzen, 2018), overall sustainability, including several dimensions, should be considered instead of economic growth when assessing environmental policy. In this context, the Human Development Index (HDI) might be used as reference, instead of the Gross Domestic Product (GDP). The decoupling of the Domestic Footprint and Consumption Footprint from the HDI is show in Table 17. In general, the group of stagnant countries (Italy and Greece) disappear, as HDI is increasing for all the countries under assessment. While they become absolute decouplers regarding the Consumption Footprint, the decoupling is relative concerning the Domestic Footprint.

Regarding the Consumption Footprint (Table 17), the HDI decoupling is more dichotomic than the economic decoupling. The Member States with an absent decoupling from GDP growth keep the same trend for HDI decoupling, with an impact increase between 15% and 68%. As well as those with an absolute GDP decoupling continue the same trend for the HDI decoupling, since the Consumption Footprint has a decreasing trend in both cases (between -7% and -40%). Half of the Member States that show a relative GDP decoupling result in an absent HDI decoupling as the Consumption Footprint increase (6-21%) is larger than the HDI variation (3-5%), which is between 2.9 and 8 times lower than the GDP increase (12-37%). Belgium, Hungary and Romania show a relative decoupling from both GDP and HDI growth, as the variation of the Consumption Footprint is lower (2-4%) than the variation of both indexes (5-22% and 3-7% for GDP and HDI) (Annex 8).

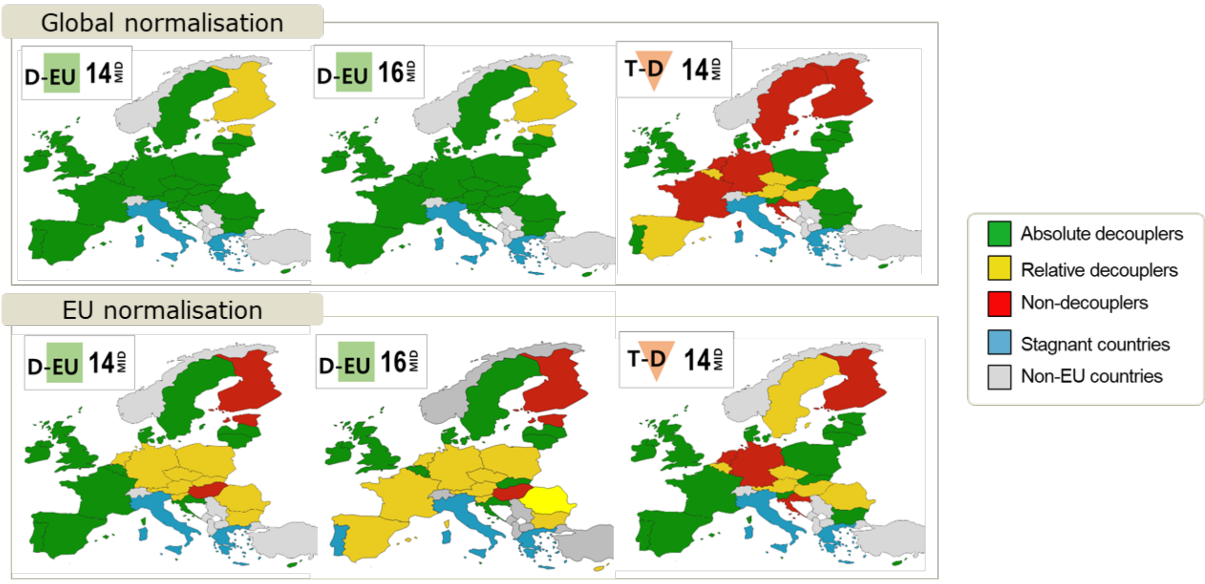
In the case of the Domestic Footprint (Table 17), the division of the Member States among absolute decouplers, relative decouplers and non-decouplers is more equilibrated. The Member States performing as absolute decouplers for GDP keep their behaviour for the HDI decoupling, with an impact decreasing between -0.1 and -13%. On the opposite, the non-decouplers show an increase of the Domestic Footprint between 8 and 23%. Most of the relative decouplers keep their category, with the addition of Italy, with environmental impact growth rates (1.8-2.2%) higher than the HDI ones (2.2-3%) (Annex 8).

Table 17. Decoupling Index (DI) calculated as the change in Domestic Footprint (DF) (14 and 16 indicators) and Consumption Footprint (CF) and the variation of GDP and HDI by Member State. Key: absolute decouplers (green), relative decouplers (yellow), stagnant (blue) and non-decouplers (red).

Member State	DF16/GDP 2000-14	DF16/GDP 2004-11	DF14/GDP 2000-14	DF14/GDP 2004-11	CF/GDP 2004-11	DF16/HDI 2000-14	DF16/HDI 2004-11	DF14/HDI 2000-14	DF14/HDI 2004-11	CF/HDI 2004-11
Austria	0.82	0.26	0.74	0.20	0.50	2.70	0.74	2.45	0.59	1.45
Belgium	-0.35	-0.04	-0.745	-0.43	0.17	-3.03	-0.18	-6.40	-1.72	0.68
Bulgaria	0.22	0.30	0.24	0.33	-0.23	1.26	1.91	1.34	2.20	-1.51
Croatia	-0.33	-0.39	-0.35	-0.40	5.16	-0.78	-1.24	-0.84	-0.54	6.95
Cyprus	-0.07	0.04	-0.18	-0.01	-0.88	-0.22	0.04	-0.59	-0.06	-5.38
Czech Republic	0.19	0.25	0.16	0.23	0.33	1.15	2.29	1.01	1.81	2.61
Denmark	-0.72	-1.50	-0.72	-1.50	-1.60	-1.26	-2.12	-1.27	-2.58	-2.75
Estonia	0.15	1.06	0.25	1.36	-2.63	0.88	4.30	1.50	4.45	-8.61
Finland	1.38	2.22	1.59	2.34	1.68	5.74	4.63	6.62	9.92	7.10
France	0.28	0.07	-0.27	-0.18	-1.97	0.89	0.11	-0.87	-0.47	-5.27
Germany	0.54	0.65	0.51	0.65	3.00	1.21	1.45	1.14	1.96	9.12
Greece	-1.55	-0.22	-1.54	-0.22	1.03	0.44	0.94	0.44	0.96	-4.61
Hungary	0.24	3.29	0.21	1.67	0.46	0.84	5.93	0.75	2.36	0.65
Ireland	-0.10	-0.86	-0.11	-0.82	-1.10	-0.75	-3.75	-0.78	-15.86	-21.22
Italy	-3.04	-41.84	-0.63	-35.04	65.96	0.39	3.08	0.08	0.59	-1.11
Latvia	0.65	-0.17	0.56	-0.35	-2.60	3.17	-1.13	2.74	-1.98	-14.64
Lithuania	0.24	-0.13	0.25	-0.06	-1.75	1.62	-0.70	1.72	-0.29	-9.21
Luxembourg	0.45	-0.01	0.45	-0.01	3.53	4.20	-0.42	4.18	-0.04	33.25
Malta	-0.38	-0.68	-0.40	-0.72	-1.09	-1.87	-5.79	-1.99	-5.86	-8.93
Netherlands	1.05	0.99	0.65	0.63	5.11	3.26	2.49	2.03	1.81	14.63
Poland	0.26	0.13	0.26	0.12	0.57	1.92	1.17	1.91	0.99	4.54
Portugal	9.9	-0.37	-7.38	-5.01	-19.71	1.54	-0.43	-1.15	-2.32	-9.16
Romania	0.19	0.17	0.16	0.09	0.20	0.99	2.88	0.85	0.29	0.62
Slovakia	0.005	-0.25	0.13	0.08	-0.21	0.04	-2.35	0.95	0.47	-1.22
Slovenia	0.08	0.03	-0.08	0.20	-1.66	0.29	1.20	-0.31	1.01	-8.28
Spain	-0.44	0.28	-0.50	-0.71	-0.88	-1.23	-0.73	-1.39	-1.45	-1.78
Sweden	0.07	-0.60	0.03	-0.15	1.07	0.55	-0.34	0.25	-1.46	10.43
United Kingdom	-1.07	-2.05	-0.86	-2.07	-1.35	-5.75	-4.66	-4.65	-9.73	-6.33

The assessment of the decoupling can vary depending on the parameters employed in the environmental calculations (Sanyé-Mengual et al., 2019). In particular, the impact assessment results can be normalised at different geographical levels. This report presents the results with an EU normalisation, where the environmental impacts of the entire EU in the domestic boundaries are used as reference. However, results can also be normalised at the global level, thereby employing the environmental impacts of the entire world as reference. Figure 34 shows the difference in the results at the country level with global and EU normalisation. In general, more countries show absolute decoupling in the Domestic Footprint when considering a global normalisation due to the low contribution of EU to the overall environmental impacts, compared to other world regions. When considering an EU normalisation, the decoupling levels include the behaviour of the Member States in relation to the EU average.

Figure 34. Decoupling of the Consumer Footprint Top-down and Domestic Footprint at the country level by normalisation type and number of indicators (2005-2014).



*D-EU – EU Domestic Footprint; T-D – Consumption Footprint top-down; MID – midpoint categories.

3.7 The Consumption Footprint platform

The goal of the Consumption Footprint is to quantify the environmental impact by means of all the indicators included in EF 2017 (EC, 2017). Each of these indicators accounts then for a number of elementary flows, and most of the time they differ from one impact indicator to another. Given all these aspects, the final database is significantly large and needs a specific web-based tool aimed at:

— making calculations by running the whole available datasets (domestic and trade) and to optimize results visualization;

— improving data management and data checking;

— simplifying documentation availability;

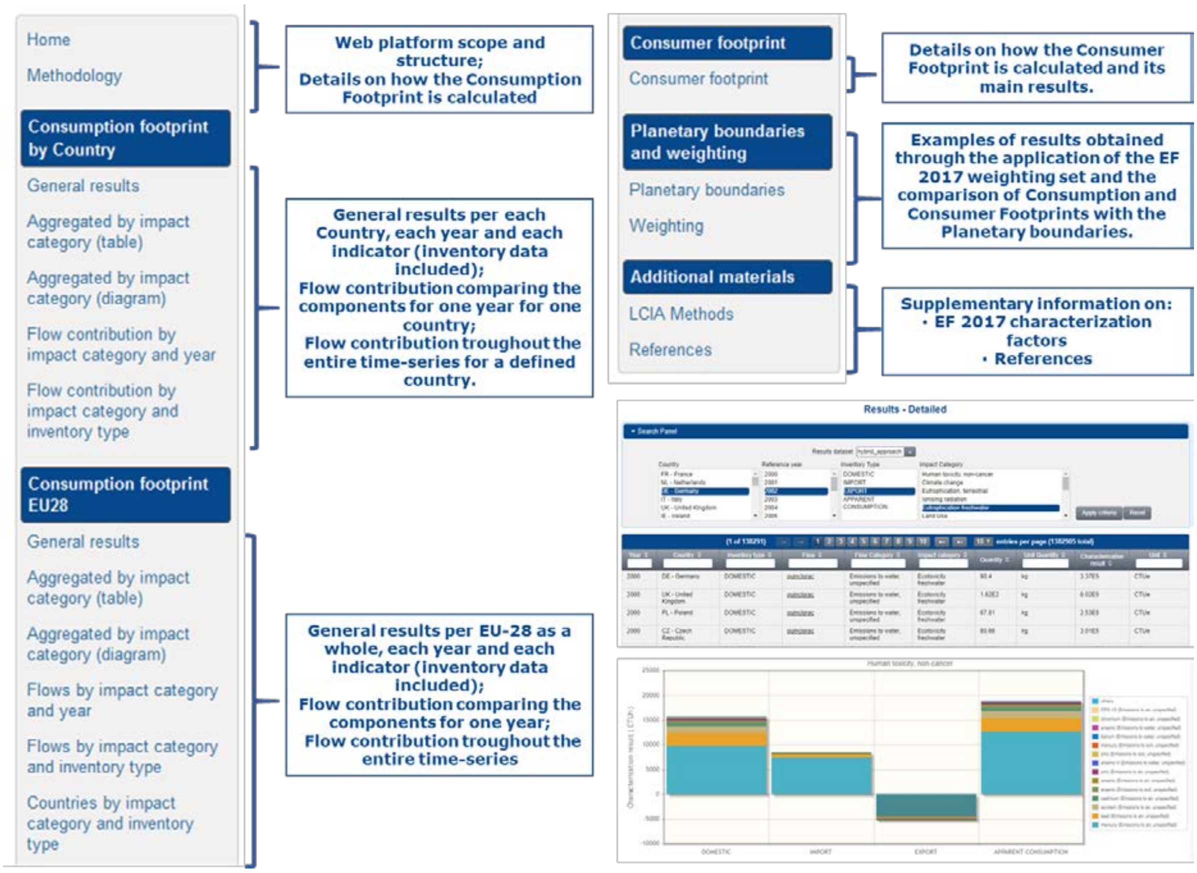
— fulfilling communication purposes.

A complex and complete visualization tool based on a navigable website[11] has been developed for visualizing several typologies of charts according to users' needs. Options for the visualization and communication of the results are presented as multiple alternatives are possible. These include: (i) comparison of country performance by multiple

[11] The link to the web-based platform is the following: http://eplca.jrc.ec.europa.eu/ConsumptionFootprint/. Access to the platform is available upon request to the email JRC-ConsumptionFootprint@ec.europa.eu.

or single indicator(s); and (ii) ranking amongst countries by single indicator(s). Details are reported in Figure 35, showing all the sections in the menu bar.

Figure 35. Consumption Footprint web platform sections and types of calculation.



Note: The visualisation presented in the example above refer to the section “Consumption Footprint Countries – Flows by impact category and year”. Results refer to France impact on Particulate matter for 2010 by analysing the hybrid approach (i.e. the Consumption Footprint Top-down). All the inventory types (i.e. domestic, import, export and apparent consumption) are included at the same time.

The web-based platform showcases the Consumption Footprint results by displaying it in two sections: the first one showing results related to each Member State (**Consumption Footprint by Country**) and the second reporting results associated to EU28 as a whole (**Consumption Footprint EU28**). The related subsections have the same structure in order to have a user-friendly design. The sections are listed as follows:

— in **General results**, an overview of the results is given, detailed by Country, year, dataset (i.e. domestic, import, export or apparent consumption), impact category and approach[12]; at this level, for each elementary flow the generated table always report both inventory amount and impact score;

— the aggregation of the results at higher levels is presented in the section **Aggregated by impact category**, where only the impact score is given, as total for each impact category, for each year. At this level, it is possible to generate results both as tables and as charts (showing the entire trend);

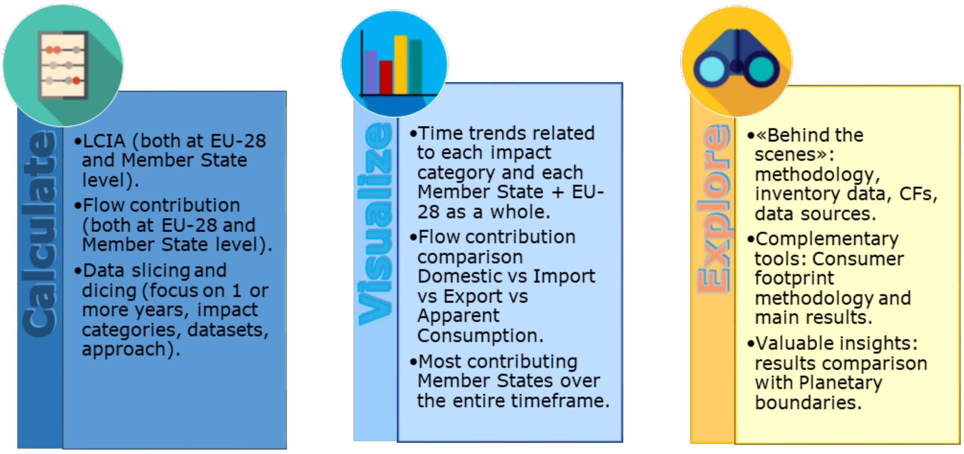
— in **Flow contribution by impact category and year** and **Flow contribution by impact category and inventory type**, the contribution of each elementary flow is displayed, for each impact category, for each dataset, as single year or trend over time;

[12] The full bottom-up approach is given only for EU as a whole.

— in **Countries by impact category and inventory type**, a Country contribution over the entire time frame is generated (as bar graph) for each impact category, for each type of dataset.

Currently, in the platform it is possible to perform the calculations listed in Figure 36. Further improvements are foreseen, such as: simplifying data import and allowing data export; introducing regionalisation in the impact assessment step; optimising the layout in order to ease the use of the tool.

Figure 36. Consumption Footprint platform: tools and calculations.



As calculations, in the platform the user may consult the full inventory, the characterised results, complemented with the flow contribution. Additionally, through data slicing and dicing, the user is able to focus on one «slice» of data (i.e. one year, one impact category, one dataset, one country) or zoom to a sub-set of data taking into account all the dimensions (i.e. time, impact category, dataset, geography). All the results can be pictured in charts and graphs showing the trends, the flow contribution or even the country contribution. The user can easily keep track of the inventory and have a look at the method used to assess the impacts. Moreover, a specific section is devoted to the Consumer Footprint, i.e. the counterpart of the Consumption Footprint, and its methodology and main findings. Finally, the user is able to explore the "surroundings" of these indicators; for instance, it is possible to investigate how far are the environmental impacts of the EU consumption compared to the Planetary Boundaries. Main results from this comparison are reported in the corresponding section (**Planetary Boundaries**), just above the Weighting section, which allows investigating the relative importance of: (i) each country with regard to EU or a global normalisation reference, and (ii) each impact category compared to the others in a weighted score analysis.

3.8 Allocating Consumption Footprint to final consumers/Final Consumption Input-Output Footprint and Household Input-Output Footprint

An additional alternative to calculate the Consumption Footprint is to fully rely on environmentally-extended Input-Output database (such as EXIOBASE 3) to build the inventory, and to calculate the environmental impacts induced by the final consumption (that is, the sum of expenditures from households, from government and from Non-Profit Institutions Serving Households). Such an approach builds on the same methodological framework as the one described in section 3.3.1. The final consumption of goods and services is considered to induce emissions to the environment and resources extraction along these goods and services' supply-chain. Input-Output Analysis enables to allocate the emissions and resource extraction of the production stages to the goods and services of the final consumption, through the application of the Leontief inverse equation (Leontief and Ford, 1970).

The calculated indicator, named EU Final Consumption_I/O Footprint, is presented in Figure 37 and compared to Household expenditures component (Household_I/O Footprint) in Table 18. The latter stands for the largest share in the total final consumption expenditures and at the same time for the largest share in the total environmental impacts of consumption. Household expenditures have a higher impact intensity compared to other types of expenditures: while representing 69% of the total expenditures, they contribute to between 68 and 76% of the total impacts regarding five impact categories (with respect to human toxicity, ecotoxicity and resource use), and even up to between 81 and 90% of the total impacts regarding the other nine impact categories under study. Conversely, the share of Government expenditures in impacts (between 7 and 22% of the total impacts considering all impact categories) is lower than their share in total expenditures (29%) due to a lower impact intensity compared to household expenditures. The environmental impacts associated with household consumption are further explored in the next chapters.

Figure 37. EU Final Consumption_I/O Footprint by type of final consumption expenditures, calculated using EXIOBASE 3 and considering 14 impact categories and year 2011, in perspective with the share in total expenditures.

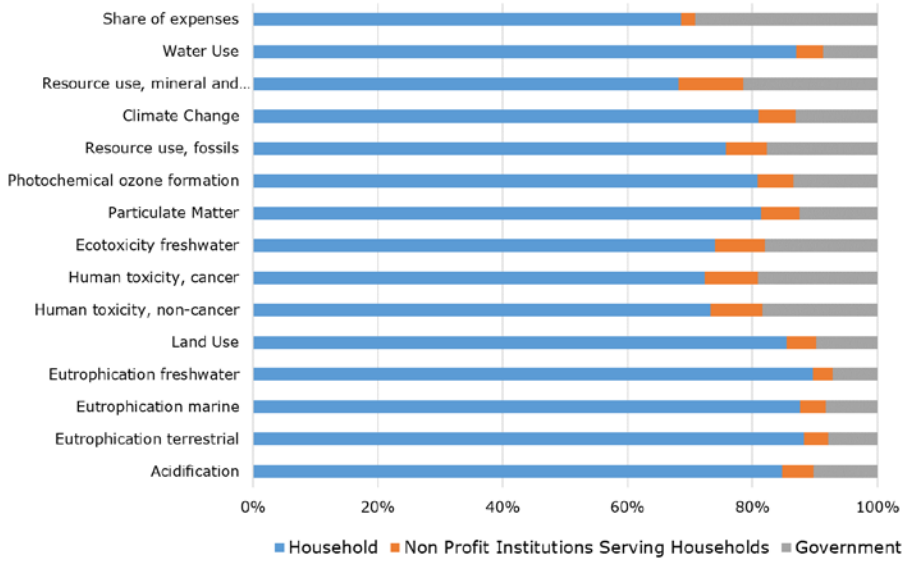


Table 18. EU Final Consumption_I/O Footprint and Household_I/O Footprint for year 2011: total impact considering 14 impact categories.

Impact categories	Unit	EU Final Consumption_I/O Footprint	EU Household_I/O Footprint
Climate Change	kg CO_2 eq	6.76E+12	5.48E+12
Eutrophication freshwater	kg P eq	4.20E+08	3.77E+08
Eutrophication marine	kg N eq	1.66E+10	1.46E+10
Particulate matter	Disease incidence	8.88E+05	7.23E+05
Acidification	molc H^+ eq	6.92E+10	5.87E+10
Eutrophication, terrestrial	molc N eq	2.28E+11	2.01E+11
Water use	m^3 world eq	4.80E+12	4.18E+12
Land use	Pt	1.10E+15	9.40E+14
Resource use, fossils	MJ	8.46E+13	6.41E+13
Photochemical ozone formation	kg NMVOC eq	4.65E+10	3.76E+10
Ecotoxicity freshwater	CTUe	7.25E+11	5.37E+11
Human toxicity, cancer	CTUh	3.00E+04	2.17E+04
Human toxicity, non-cancer	CTUh	6.38E+05	4.68E+05
Resource use, minerals and metals	kg Sb eq	3.62E+08	2.46E+08

Box 8. Top-down approach to calculate the environmental impacts of EU consumption: comparison of results from EXIOBASE 3 and Eurostat environmentally extended Input-Output tool

Eurostat publishes air emissions by final product and by final use categories, for several greenhouse gases and air pollutants, for the aggregated EU, based on an environmentally extended input-output tool (see http://ec.europa.eu/eurostat). These values can be compared with those calculated from EXIOBASE 3, here considering the EU final consumption expenditures in 2011 (with accounting for investments; see table below). Whereas the difference in embodied emissions is relatively limited regarding CO_2 emissions (+16%), a much larger discrepancy is observed considering most other air pollutants (in particular, NH_3, NMVOCs and CO). In both cases of approaches, Input-Output Analysis is implemented, yet with different data sources and modelling assumptions, which ultimately induce the differences in embodied emissions. In particular, we may cite the following: a domestic technology assumption is made in the Eurostat tool, whereas EXIOBASE 3 is a World Multi-Regional Input-Output database; monetary Input-Output tables are used in the Eurostat tool, compared to hybrid Monetary-Physical IO tables in the hybrid version of EXIOBASE 3 used in this study; environmental extensions are drawn from different sources (this not only concerns statistical sources, but also the use of “modules” for modelling emissions from agriculture and energy in EXIOBASE 3); a larger level of disaggregation of products and economic activities is considered in EXIOBASE 3. Yet, at this stage, the way each of these elements may more or less explain the differences in embodied emissions from one approach to the other should be further assessed. Finally, beyond these differences in total embodied emissions, it should be noticed that the two databases still lead to some common conclusions. For example, regarding the contribution of agriculture and food products to the emissions of nitrous oxides and ammonia embodied in the EU final demand, relatively similar results from one database to the other are observed (respectively 56-58% regarding nitrous oxides and 65-68% regarding ammonia).

Emissions to air induced by EU final consumption expenditures in 2011, as calculated from Eurostat environmentally extended IO tool, Consumption Footprint Top-down and EXIOBASE 3.

	Unit	CO_2	CH_4	N_2O	NOx	NH_3	NMVOCs	CO	$PM_{2.5}$
Eurostat IO-based footprints	tonnes	3.98E+09	2.27E+07	8.08E+05	1.08E+07	4.06E+06	7.80E+06	2.25E+07	1.53E+06
EXIOBASE 3	tonnes	4.73E+09	4.12E+07	1.16E+06	1.89E+07	1.10E+07	2.10E+07	1.05E+08	2.07E+06
Difference with Eurostat	%	16%	45%	31%	43%	63%	63%	79%	26%
Consumption Footprint Top-down	tonnes	4.60E+09	3.88E+07	1.07E+06	1.10E+07	5.99E+07	4.97E+06	2.86E+07	2.22E+06
Difference with Eurostat	%	87%	59%	76%	98%	7%	157%	79%	69%

4 Consumer Footprint: main areas of consumption and products driving the impacts

The Consumer Footprint indicator allows for identifying the main categories of consumption and the main products, within those categories, driving the impacts generated by household consumption in the EU. In section 4.1 the analysis is focused on the products included in each area of consumption. Therefore, results are calculated starting from the baseline scenarios modelled for each of the five baskets considered. Section 4.2 illustrates the changes in household consumption between the reference year used for the main calculations (2010) and the year 2015, taken as reference to investigate how much apparent consumption is changing over time. Finally, section 4.3 illustrates the results of the analysis done to identify the main areas of consumption, and the main activities within those areas, that are contributing to the impact generated by household consumption in EU. Results are calculated starting from the sum of the five BoPs selected for the Consumer Footprint indicator.

4.1 Consumer Footprint: products driving the impact

Box 9. Key messages on products driving the impact in the main categories of consumption

— The analysis done on the five BoPs that compose the Consumer Footprint indicator - namely food, housing, mobility, household goods and appliances - allows for identifying which are the products driving the impact in those areas of consumption.

— Dwellings in the moderate climate have the highest contribution to the environmental impacts of housing due to highest number of dwellings in that area. The use phase contributes for more than 50% to the overall impact of the dwellings, for the most of the impact categories.

— Passenger cars are the most contributing mode of transport among the transportation used by European citizens, being air transport the second highest contributor.

— The food product groups that emerge as hotspots in most of the impact categories are meat, dairy products and beverages. Main contributing processes are related to animal feeding.

— The most contributing household appliances are dishwasher, washing machine, refrigerator, lighting and TV screen, with different shares depending on impact category considered.

— The most contributing household goods are paper products, detergents, furniture and clothes, with different shares depending on impact category considered.

— In the case of BoP Food, BoP Appliances and BoP Household goods, the environmental impacts generated in 2015 are higher compared to 2010, due to a general increase in apparent consumption. On the contrary, impacts generated in 2015 by the housing sector are lower than in 2010 due to better energy efficiency. In the case of BoP Mobility, the environmental impact is generally higher due to increase in pkm (passenger-kilometres).

The analysis done on the five BoPs that compose the Consumer Footprint indicator - namely food, housing, mobility, household goods and appliances - allows for identifying which are the products driving the impact in those areas of consumption. Detailed results of the hotspot analysis on the five baskets are provided in Annex 9. The following paragraphs present the representative products included in each basket and which of them is a potential hotspot of impact in the EU. This could be because of their environmental profile or because the products are consumed (or used) in high quantities by EU citizens.

4.1.1 Housing

The BoP Housing is focused on the impact associated to housing in the EU. **The basket is composed by 24 reference dwellings, representative of the EU-27 housing stock in the year 2010, divided by type of building, climate zone and year of construction.** The system boundaries include production, construction, use (energy and water consumption), maintenance, and end-of-life phases of each dwelling. A disaggregated inventory model was developed for each product in the basket, based on a modular approach and using statistics on the EU building stock. The functional unit (FU) is the average use of one dwelling by an EU-27 citizen during one year.

To define the “representative products” (dwellings) of the BoP Housing a quantitative and qualitative analysis of the structure of the EU building stock is carried out, in order to identify building archetypes. Since the ultimate goal of the study was to assess the environmental impacts of the housing of EU-27 citizens, the study focuses on analysing the stock of permanently occupied dwellings, i.e. the main residence of households. In the study, a dwelling is defined as a unit of accommodation, i.e. the entire building in the case of Single-Family Houses (SFH) or an apartment in the case of Multi-Family Houses (MFH).

The features chosen to define the representative dwellings in the BoP Housing are:

— the dwelling type: Multi-family house (MFH) or Single- Family House (SFH);

— the climate of the area in which the building is located: cold, moderate or warm;

— the period of construction: before 1945, between 1946 and 1969, between 1970 and 1989, between 1990 and 2010.

Based on this classification, **24 archetypes (representative dwellings) were selected to represent the entire EU building stock** in the reference year 2010 (Figure 38)[13]. The contribution of the representative dwellings to the overall impact of housing in the EU depends on two factors: the impact of one unit of each type of dwelling and the number of dwellings of that type in the EU area.

Figure 38. Composition of the BoP Housing and relative importance of the representative dwellings (as number of dwellings in the EU building stock in 2010).

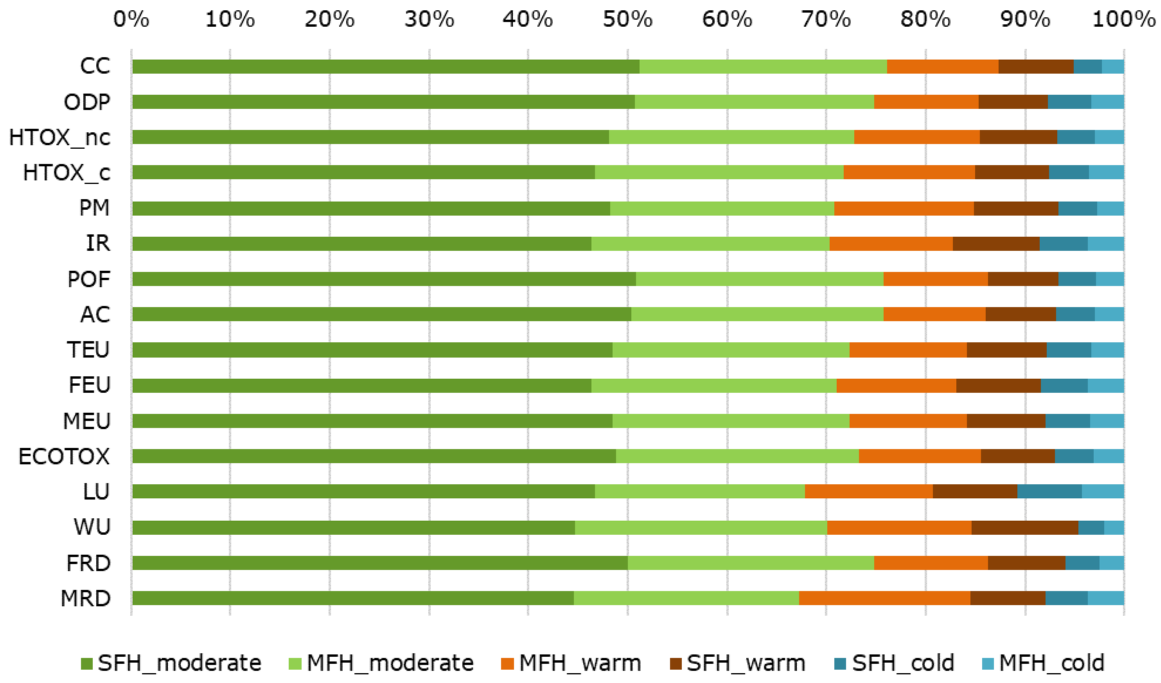
	<1945		1946-1969		1970-1989		1990-2010	
	Single-family	Multi-family	Single-family	Multi-family	Single-family	Multi-family	Single-family	Multi-family
Cold	0.6%	0.6%	0.5%	0.8%	0.6%	0.9%	0.3%	0.4%
Moderate	9.3%	6.3%	10.6%	8.1%	12.2%	9.7%	7.8%	5.9%
Warm	2.0%	2.7%	1.9%	5.4%	2.5%	6.0%	1.5%	3.4%

Dwellings are classified according to the type (single-family or multi-family), the climate area (cold, moderate and warm), and the year of construction (<1945, 1946-1969, 1970-1989, 1990-2010).

[13] The following codes are used in the figures of this chapter to identify the 24 dwelling types. SFH_W1: SFH_Warm_before 1945; SFH_W2: SFH_Warm_1945-1969; SFH_W3: SFH_Warm_1970-1989; SFH_W4: SFH_Warm_1990-2010; SFH_M1: SFH_Moderate_before 1945; SFH_M2: SFH_Moderate_1945-1969; SFH_M3: SFH_Moderate_1970-1989; SFH_M4: SFH_Moderate_1990-2010; SFH_C1: SFH_Cold_before 1945; SFH_C2: SFH_Cold_1945-1969; SFH_C3: SFH_Cold_1970-1989; SFH_C4: SFH_Cold_1990-2010; MFH_W1: MFH_Warm_before 1945; MFH_W2: MFH_Warm_1945-1969; MFH_W3: MFH_Warm_1970-1989; MFH_W4: MFH_Warm_1990-2010; MFH_M1: MFH_Moderate_before 1945; MFH_M2: MFH_Moderate_1945-1969; MFH_M3: MFH_Moderate_1970-1989; MFH_M4: MFH_Moderate_1990-2010; MFH_C1: MFH_Cold_before 1945; MFH_C2: MFH_Cold_1945-1969; MFH_C3: MFH_Cold_1970-1989; MFH_C4: MFH_Cold_1990-2010.

As shown in Figure 39, **the higher contribution comes from the building in moderate climates, both SFHs and MFHs**. These two types of dwelling together represent about 70% of the European building stock (Figure 38) and contribute to about 70-80% of the overall impact (30% MFHs and 40% SFH), depending on the impact category considered.

Figure 39. Contribution of the representative dwellings to the overall impact of housing in the EU (assessed with EF 2017 method).



When analysing the impact per single dwelling, irrespectively of the number of dwellings of that type in the EU building stock, **the SFHs in cold climate are the ones with the highest impact per dwelling per year** for all the impact categories considered, except for climate change and resource depletion. The difference with the ranking obtained for the other impact categories considered (i.e. highest impact of SFHs in cold climate) is partially due to the slightly higher energy consumption for space heating. However, the main reason of the difference is the higher impact of concrete and bricks used in the moderate climate compared to the construction technology used in cold climate (timber frame), which has a lower contribution to climate change compared to concrete.

Details on the impact of each type of dwelling are reported in Annex 10. **The use phase contributes for more than 50% to the overall impact of the dwellings**, for most of the impact categories. Therefore, dwellings in cold climate, which have on average a higher energy consumption for space heating, are the ones impacting the most. SFH contribute more than MFH in the same climate area because SFHs have a larger surface area both in absolute terms and per person compared to MFHs, and this implies a higher energy demand for space heating. Similarly, more ancient dwellings (built before 1945) contribute more than the same building type (SFH or MFH) built in more recent years in the same climate area. The only exception is represented by SFHs in warm climate built between 1990 and 2010, which have on average a larger surface (130 m^2) compared to SFHs built before 1990 (100 m^2). In this case, the energy consumption per square meter is lower (76 kWh/m^2 in SFH of 1970-1989 compared to 62 kWh/m^2 in SFH of 1990-2010) but this improvement in energy efficiency is offset by the increased amount of materials input, due to the larger surface of the dwelling. When considering the contribution to climate change, the dwellings with the highest impact are SFH and MFH in moderate climate built before 1945. The detailed analysis on the BoP Housing is available in a dedicated report (Baldassarri et al., 2017).

4.1.2 Mobility

The BoP Mobility aims at assessing the environmental impact related to mobility of citizens in Europe. The main sub-sectors related to passenger mobility are road, rail and air transport. The BoP Mobility considers two major groups of products: private road transport, which consists of private transportation modes such as passenger cars and two-wheelers, and mass transit, which consists of shared passenger transport services available to the public, including buses, rail and flights. Due to their low environmental impacts, activities such as walking and cycling are excluded from this analysis. A selection of **27 representative means of transport** was made, to represent the fleet composition in the EU in 2010. Two additional types of cars (electric and hybrid car) were modelled to be used in future scenarios. The means of transport (as representative mobility products) included in the BoP Mobility are the following:

— 12 types of Gasoline passenger cars (with three engine capacities: <1.4L, between 1.4-2.0L and >2.0L, and 4 emissions standards: Euro 0-Euro 3, Euro 4, Euro 5 and Euro 6);

— 8 types of Diesel passenger cars (with two engine capacities: between 1.4-2.0L and >2.0L, and 4 emissions standards: Euro 0-Euro 3, Euro 4, Euro 5 and Euro 6);

— LPG passenger car;

— Electric car (used to model future scenarios);

— Hybrid car (used to model future scenarios);

— 3 types of 2-wheelers (mopeds, motorcycles <250cc, motorcycles >250cc);

— 3 types of buses (diesel urban buses, CNG urban buses and coaches);

— 2 types of trains (electric and diesel);

— 3 types of flights (national, intra-EU and extra-EU).

To assess the use of each transport mode, the mobility service provided by each representative product is quantified through an estimation of its level of service. This is translated in kilometres travelled and, more importantly, in number of passengers transported, which is reflected in a passenger-kilometres (pkm) analysis. Different type of usage conditions of each mobility product were considered for each EU country and the total level of service for the EU-27 was obtained from the sum of all countries. The main input for the quantification of the annual impacts of the mobility products are the vehicle-kilometres travelled for the road transport sector for each of the vehicle categories considered or passenger-kilometres travelled for rail and air transport (Figure 40).

The BoP Mobility considers 100% of the kilometres travelled by EU citizens with private means of transport (private cars and 2-wheelers), 100% of the air transport, and 100% of rail transport. Those km are allocated to the representative means of transport chosen for the BoP. Tram and metro, as part of urban public transport, are not modelled in the BoP Mobility. Hence, km travelled with those means of transport are not included in the model. Also marine passenger transport is excluded, because Eurostat database does not provide statistics on the share of those means of transport over the total kms travelled by EU citizens. According to the Statistical Pocketbook on transport (EC, 2016a), tram and metro contributed to about 1.5% of all pkm travelled by European citizens in 2010. Similarly, marine passenger transport accounted for only 0.4% of all passenger transport in the EU in 2010. Therefore, the means of transport included in the BoP Mobility could allow for assessing the impact of about 98% of the pkm travelled in the EU with private and public means of transport.

Among the product groups considered in the BoP Mobility, i.e. the modes of transport used by EU citizens, **passenger cars are by far the most important ones, in terms of impact generated, compared to the other product groups** (Figure 41).

A deeper look at the results of the product group **"passenger car" highlights the relevant contribution of cars in the size range 1.4-2.0L, both diesel and gasoline fuelled**. This is due to a combination of the impact of this type of cars (and especially the fuel consumption in the use phase) and the number of cars in the EU fleet belonging to these categories (36% diesel and 23% gasoline). Diesel cars 1.4-2.0L are particularly relevant for human toxicity non-cancer effects, particulate matter, photochemical ozone formation, terrestrial eutrophication, marine eutrophication and land use. This is mainly due to the emission of nitrogen oxides coming from diesel burning in the internal combustion engine and, in the case of land use, land transformation for the cultivation of biodiesel (which represents 6% of EU diesel mix in the BoP Mobility model).

Figure 40. Composition of the BoP Mobility and relative importance (as number of kilometres travelled per year) of the representative means of transport, aggregated by type.

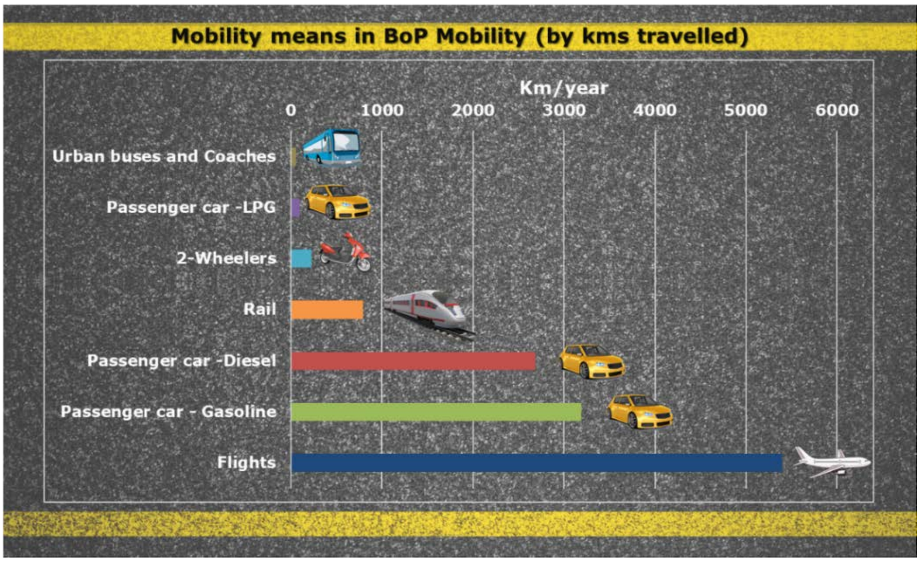
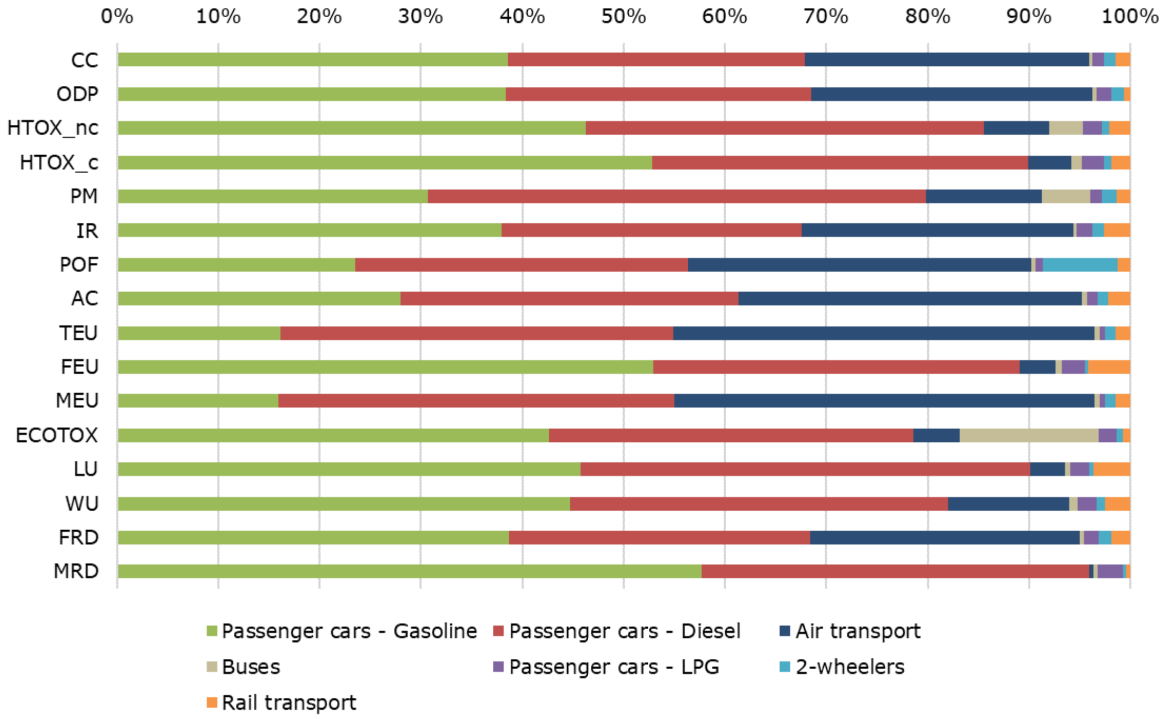


Figure 41. Contribution of the different means of transport to the overall impact of mobility in the EU (assessed with EF 2017 method).



As expected, in general the vehicles that are compliant with lower emission standards (from Euro 0 to Euro 3) are among the highest contributors to almost all the impact categories. **Diesel cars with engine capacity between 1.4L and 2.0L, with Euro 0 to Euro 3 emission profiles, have the highest contribution to all the impact categories.** As explained before, this is due to a combination of higher emissions and a high relevance in terms of number of vehicles in the EU fleet (27% of all passenger cars).

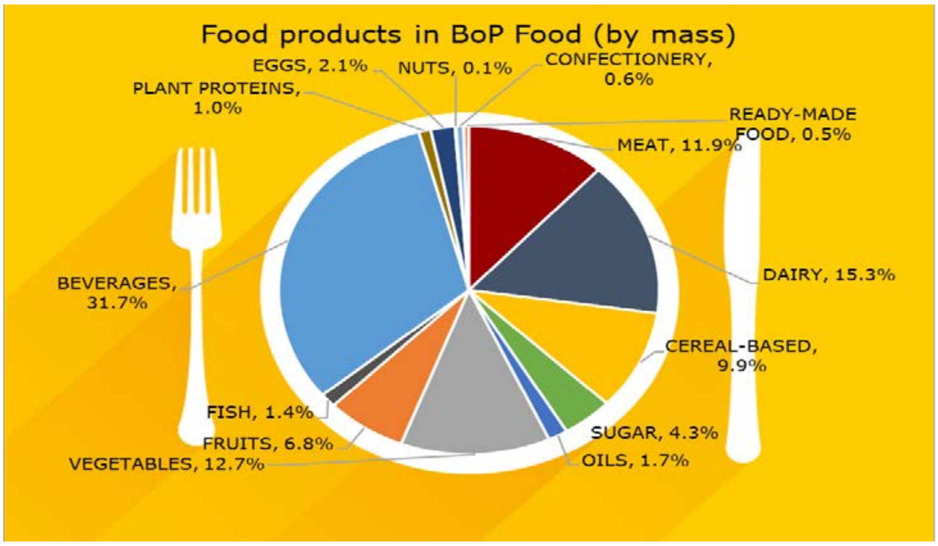
Air transport, and especially extra-EU flights, is the second highest contributor to climate change, ozone depletion, ionizing radiations, photochemical ozone formation, acidification, and terrestrial and marine eutrophication. The main reason for this contribution is the emission of CO_2 and NOx from fuel burning during the flight. Again, the high number of kilometres travelled, even if partially compensated by the occupancy factor, plays a relevant role. On the other hand, the occupancy factor of urban buses and coaches allows these means of transport to have a low contribution compared to the others.

Finally, 2-wheelers contribute less to the overall impact of mobility needs in the EU compared to other means of transport, due to a combination of lower fuel consumption per km travelled (i.e. lower emissions) and a lower number of vehicles in the EU fleet, compared to cars. The detailed analysis on the BoP Mobility is available in a dedicated report (Castellani et al., 2017a).

4.1.3 Food

The BoP Food consists of a process-based LCI model for a basket that represent the most relevant food product groups, selected by importance in mass and economic value, to depict the average consumption for nutrition of EU citizens in 2010 (Figure 42). The BoP Food also includes products that are representative of emerging food consumption trends and types of food and beverages whose consumption has been increasing during the past decade, independent of the magnitude of their environmental impact and the extent of their apparent consumption (e.g. tofu, pre-prepared meals). The product groups (and the representative products) in the basket are: beverages (mineral water, beer, wine, coffee and tea), fruits (oranges, apples and bananas), vegetables (potatoes and tomatoes), cereal-based products (bread, pasta, rice and biscuits), oils (olive oil and sunflower oil), sugar, dairy (milk & cream, cheese and butter), eggs, meat (beef, pork and poultry meat), fish (cod, salmon and shrimp), beans and tofu, and others (ready-made food, chocolate, and almonds). For each product group in the basket, an inventory model based on a representative product has been developed. **The inventory of each representative product is then multiplied by the mass of products in that product group that is consumed in one year by an average EU citizen**.

Figure 42. Composition of the BoP Food and relative importance of the representative products (as kilograms consumed per year).



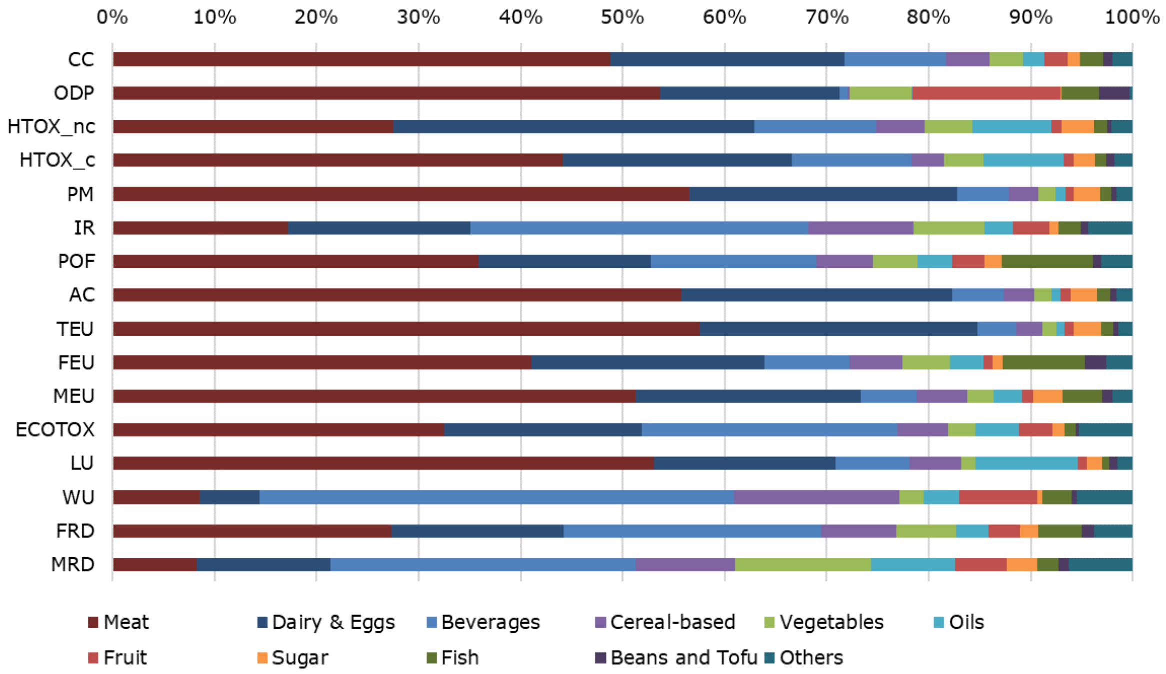
Specific data on apparent consumption (defined as Production - Exports + Imports) were taken from Eurostat and FAO databases, as well as from specific nutrition and food consumption literature concerning current emerging consumption trends (e.g. EFSA, 2018; EEA, 2012; EC, 2014a). The apparent annual consumption represented in the BoP Food amounts to 643 kg per inhabitant per year. The BoP consumption is thus representative of 69% in mass of the total apparent yearly consumption per inhabitant (933 kg/inhabitant) of all food and beverage products reported in the Eurostat-Prodcom database for the year 2010 (Eurostat, 2017h).

As for the economic value, the BoP Food covers 56% of the apparent consumption of food by EU citizens (697€ per inhabitant per year, out of a total of 1246€ per inhabitant per year, calculated as apparent consumption from Prodcom data). The choice of Prodcom database as the basis to calculate the apparent consumption of food is due to the completeness of the database itself and to the need of identifying the share of imported products (either intermediate or finished product) in support to supply chain modelling.

The food product groups that emerge as hotspots in most of the impact categories, even if with different levels of contribution, **are: meat, dairy products and beverages** (Figure 43) (Sinkko et al., 2019). The main impact for the life cycle of pork and beef meat products comes from the **emissions due to production of feed** (mainly compound feed, but also grass silage and grass in pasture). Direct emissions from animal husbandry (methane, dinitrogen oxide, ammonia, etc.) contribute as well.

Dairy products, as co-product of meat, share the same contribution. In both product groups, the processing phase is less relevant than the agricultural one. The majority of the contribution to those impacts is due to three processes related to animal feeding: “grass, at dairy farm”, “grass, at beef farm”, “Maize silage, at dairy farm” (source: Agrifootprint database - Blonk Consultants, 2014). These processes are the major contributors to human toxicity cancer effects and non-cancer effects, terrestrial eutrophication and marine eutrophication.

Figure 43. Contribution of the different product groups to the overall impact of food consumption in the EU (assessed with EF 2017 method).



As for the most relevant emissions, human toxicity impacts (both cancer and non-cancer) are dominated by the emission of heavy metals to water and to soil, especially chromium, zinc, mercury and lead. These substances derive again from the agricultural process related

to animal feeding, and more specifically from manure application to soil. Emissions of heavy metals (especially copper and zinc, both to water and to soil) coming from the same animal feed related activities contribute also to freshwater ecotoxicity impacts, jointly with the use of pesticides. Beverages emerge as hotspot in several impact categories.
The impact of beverages on water resource depletion is due to the water content in the products. Impacts on ionizing radiation and resource depletion, coming mainly from beer and coffee products, are related to the electricity used for the processing of the product and the production of packaging materials (especially glass), even if partially compensated by the credits of recycling at the end of life of packaging.

Cereal-based products emerge as hotspot in water use impact, after beverages, because of high water use in rice cultivation. In addition, almond cultivation consumes significant amount of water, but almond consumption is low, when also the total impact of “Others” is low. Fish consumption has quite low impact compared to other products groups. Main hotspots in fish consumption are photochemical ozone formation and freshwater eutrophication. These are due to different fish products, i.e. photochemical ozone formation is mainly due to fuel use in cod fishing, and freshwater eutrophication is mainly due to salmon farming. The detailed analysis on the BoP Food is available in a dedicated report (Castellani et al., 2017b) and in Sinkko et al. (2019) where details on additional food products are provided.

4.1.4 Appliances

The BoP on household appliances (BoP Appliances) consists of a process-based LCI model for a basket of products that represent the most relevant household appliances in terms of energy consumption and market share in the EU.

The selection of the **16 products included in the BoP household appliances** covers three main types of appliances: i) white goods (e.g. fridge); ii) appliances for basic functions related to the housing (e.g. space cooling); iii) appliances for entertainment and leisure. An additional criterion for the selection of the products has been its inclusion among the products covered by the Ecodesign directive (EC, 2009b), because this is a proof of the product’s relevance in terms of environmental impacts and potential improvements (especially in terms of energy performance and emissions of CO_2).

The amount of representative products included in the BoP Appliances is calculated starting from the analyses of the existing stock done for the Ecodesign preparatory studies. This is different from what has been done for the BoP Food and the BoP Household goods, based on apparent consumption data taken from the Eurostat database (Eurostat, 2017h). The reason of this choice is twofold. Firstly, 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 apparent consumption would not capture the effective environmental impacts due to the annual purchase and use of appliances. Hence, a different approach was followed.

For each product, we considered the whole stock present in EU households, allocated to the reference year (dividing it by the number of service life years of the representative product chosen), and then to the number of users (i.e. European citizens in the reference year). The resulting amount (in pieces/year) attributed to EU-27 citizens in the reference year 2010 is reported in Figure 44. As a complementary information, Figure 45 reports the relative share of each representative product over the total in terms of mass (kg), to highlight the differences between white goods and small appliances.

Figure 44. Composition of the BoP Appliances and relative importance of the representative products (as pieces per year, considering the number of appliances in each household and their service life).

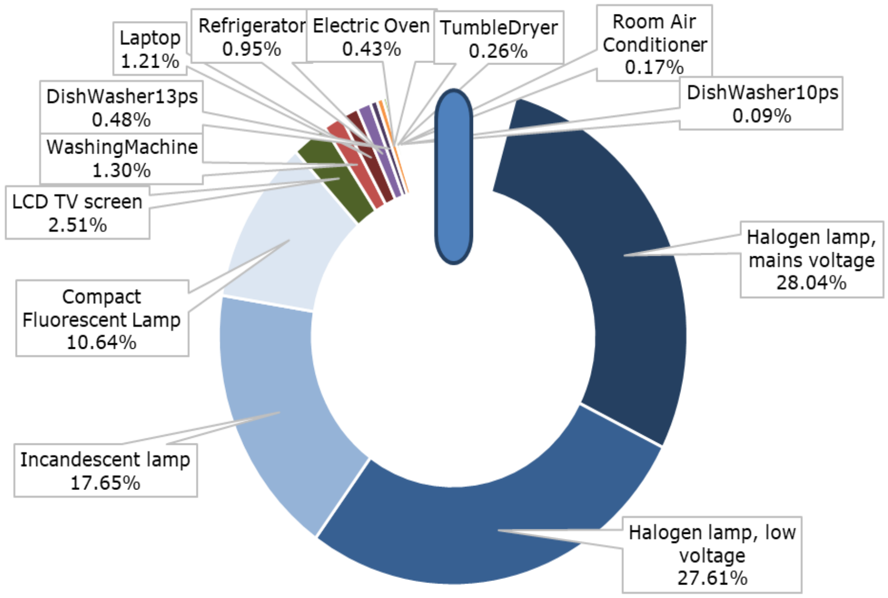
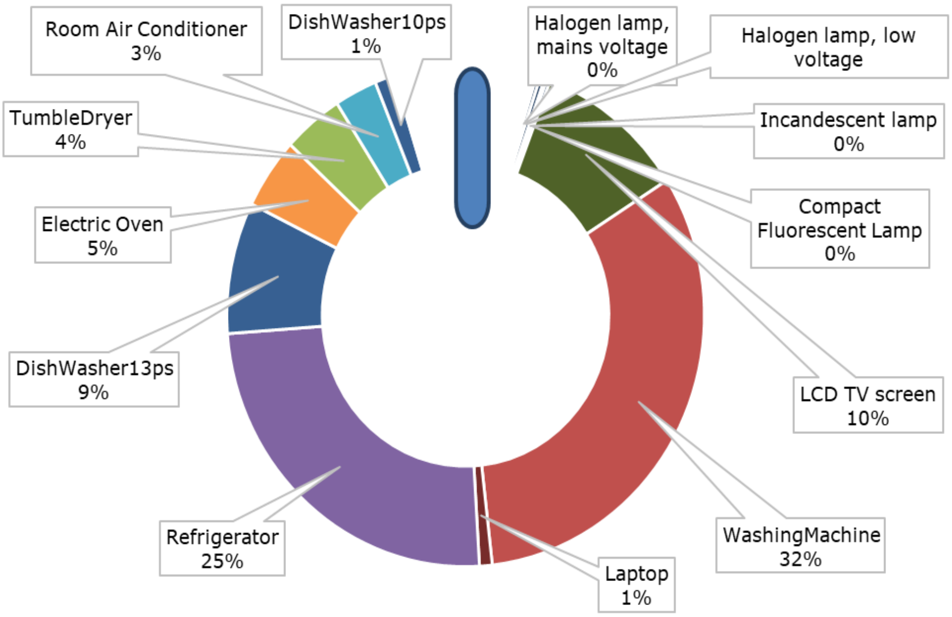
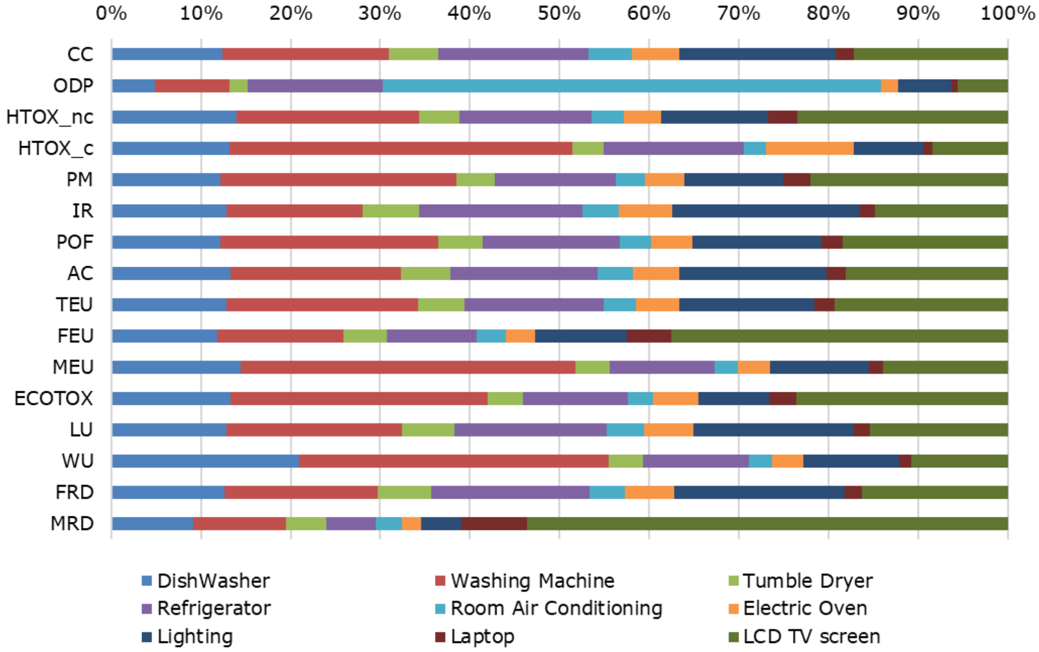


Figure 45. Composition of the BoP Appliances and relative importance of the representative products (as kilograms per year, considering the number of appliances in each household and their service life).



The larger contribution to the overall impacts generated by the purchase and use of appliances in the EU comes from dishwasher, washing machine, refrigerator, lighting and TV screen (Figure 46). 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 (Figure 44 and Figure 45).

Figure 46. Contribution of the different product groups to the overall impact of appliances purchase and use in the EU (assessed with EF 2017 method).



Each product group contributes with a different share depending on the impact category (Figure 46). **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 (wastewater treatment) of the detergent used in the washing cycles. Wastewater treatment, together with the production of chromium, steel and cast aluminium contained in the product, are responsible for the high contribution of washing machine on human toxicity, cancer effects and freshwater ecotoxicity.

The second major contributor is the LCD TV screen, due to the gold production used in the PCBs. Lighting, refrigerator and dishwasher have a relevant contribution to almost all the 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, acidification, marine eutrophication and terrestrial eutrophication depends on the electricity needed to use the product. The contribution of washing machine and of dishwasher to mineral resource depletion is due to the extraction of metals used in the machine components. The contribution of washing machines and dishwashers to marine eutrophication is due to the use of detergents and related wastewater treatment.

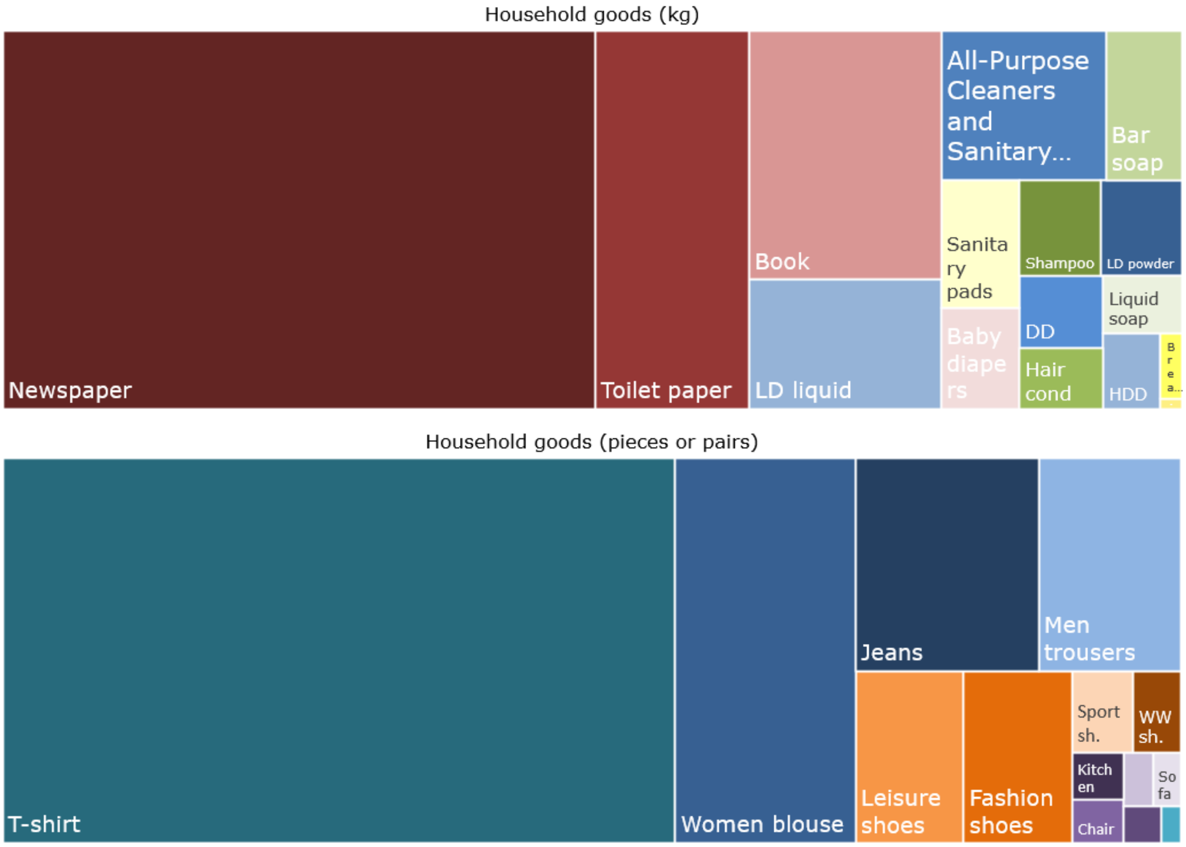
The highest impact on ozone depletion is coming from room air conditioners and refrigerators and this is due to the production of the refrigerant and to the refrigerant leakages in the use phase of the room air conditioner. Refrigerator and lighting are responsible for the major impact in ionizing radiation, being the most electricity-consuming product categories in the BoP (considering the number of pieces in the BoP and the electricity used by single piece). The highest contribution to freshwater eutrophication comes from the LCD TV screen. 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 screen are quite relevant in weight compared to the PCBs used in the other products. This explains also the contribution of the TV screen to mineral resource depletion. The detailed analysis on the BoP Appliances is available in a dedicated report (Reale et al., 2019) and a paper (Hischier et al., 2020).

4.1.5 Household goods

The BoP Household goods consists of a process-based LCI model for a basket of products that represent the most relevant product groups consumed in households (Figure 47). The selection of the product groups to be included in the basket was based mainly on the list of product groups already covered by the Ecolabel and for which Green Public Procurement (GPP) criteria were available, complemented with the product groups for which a Product Environmental Footprint (PEF) (EC, 2013a) pilot was ongoing. The reason of this choice is that the selection of product groups that are covered by Ecolabel or GPP criteria follows a set of criteria (including market significance in terms of stock volume and sales and importance of the environmental impact generated) that is in line with the ones that drove the selection of the representative products for the other BoPs.

The selected product groups (and the **30 representative products**) that form the basket are: detergents (all-purpose cleaners and sanitary cleaners, detergents for dishwashers, detergents for hand dishwashing, liquid laundry detergents, and powder laundry detergents), absorbent hygiene products (baby diapers, sanitary pads, tampons, and breast pads), rinse-off cosmetic products (bar soaps, liquid soaps, shampoos, and hair conditioner), furniture (bedroom wooden furniture, kitchen furniture, upholstered seats, non-upholstered seats, wooden tables), bed mattresses, footwear (work and waterproof (WW), sport, leisure, and fashion footwear), textile products (t-shirt, blouse, trousers, and jeans), and paper products (newspapers, books, and toilet paper).

Figure 47. Composition of the BoP Household goods and relative importance of the representative products (as kilograms or pieces per year, depending on the unit used in statistics on apparent consumption).



DD: dishwasher detergent, LD: laundry detergent, HDD: hand dishwashing detergent, WW: work and waterproof.

A quantitative and qualitative analysis of the structure of EU-27 household consumption was performed for the product groups selected before, including an analysis of international trade. Data on apparent consumption of the representative products were taken from the Eurostat database (Eurostat, 2017h). An additional analysis was performed to check to which extent the apparent consumption of the representative products could represent the overall consumption of the related product groups selected for the basket. According to the results of this analysis, the representativeness (in terms of apparent consumption) of the products included in the basket was relatively low (in some cases, below 50% of the entire product group). Therefore, it was decided to upscale the apparent consumption of each product (i.e. the amount included in the basket) to represent the 100% of the apparent consumption of the product groups selected. The resulting composition of the basket on household goods, either as mass or pieces (coherently with the unit used in statistics) is reported in Figure 47.

This is an approximation, and the result is that for instance the impact of a t-shirt is used to assess the impact of other kind of textiles that are not included in the basket. However, it was deemed more useful to have this approximation instead of underrepresenting the actual consumption of the product groups considered.

Finally, it has to be considered that the product groups selected for the BoP do not represent all the household goods that EU citizens purchase and use in their everyday life. There are some product groups, such as pharmaceuticals, which can generate significant environmental impacts both in the production and in the use stage, but are not taken into account in the present analysis. Therefore, the absence of these missing impacts should be taken into account when analysing the overall sum of the impact of all the BoPs and interpreting the results of the BoP Household goods.

Within the developed BoP Household goods, **the higher contribution to the overall impacts is from the product groups: paper products, detergents, furniture and clothes**, with different shares depending on the impact category considered (Figure 48). This contribution is partly due to the impact of one unit of the products considered and partly to the amount of each product in the BoP (Figure 47). The main hotspots in the life cycle of detergents are the eutrophication potential of some of the ingredients used and the use of electricity to heat the water needed during the use stage. Electricity production generates the impact on ionising radiation and water resource depletion, due to the use of water for cooling in the electricity generation plants.

Furniture products contribute the most to particulate matter, due to the use of coal in the production of the electricity used to produce the flame-retardants of the sofa. Their contribution is quite relevant also for ozone depletion, due to the emissions of Halon 1301 (as fire extinguisher), coming from the production of petroleum, as background process of the production of diesel fuel, used in freight transport.

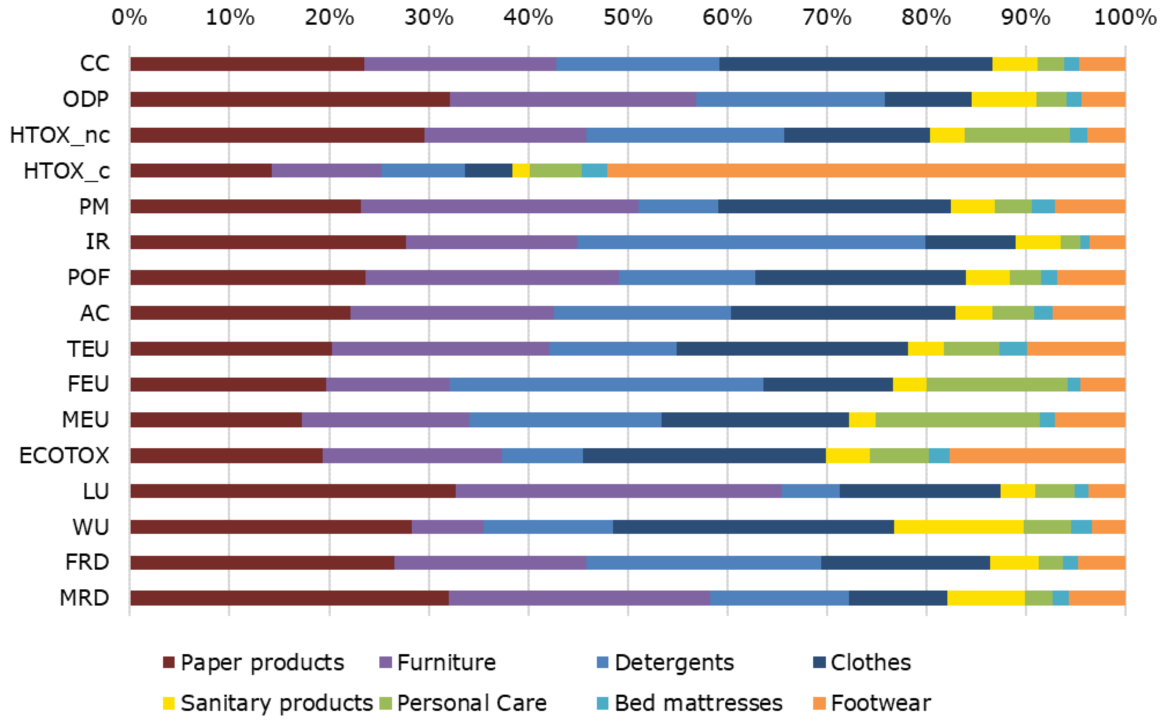
An important hotspot for the textiles (as apparel items) is the use of electricity during the phases that transform the raw fibres into textiles (spinning, yarning, texturizing, etc.), which happen mainly outside the EU. This generates impacts on climate change, particulate matter, acidification and water use. The most contributing product in this group is the T-shirt, mainly because of the high quantity purchased by EU citizens in one year (31 pieces/year per person). The number is quite high, also because of the upscale of apparent consumption for this product group.

Footwear is highly relevant for human toxicity, cancer effects, because of the emissions of chromium that is used in the chrome-tanning process in production of leather used in fashion shoes.

Paper products contribute quite significantly to most of the impact categories, both because of the high amount of paper products consumed in one year (especially newspapers –90 kg/year per person - and toilet paper – 24 kg/year per person) and because of the impacts coming from the pulp production process and the printing of paper.

Cosmetic products do not appear to be significant in most of the impact categories considered. The only exceptions are the contribution to human toxicity non-cancer effects, freshwater eutrophication and marine eutrophication. This contribution comes mainly from the ingredients of the soaps and shampoos and from the wastewater treatment needed after the use of the products.

Figure 48. Contribution of the different product groups to the overall impact of household goods purchase and use in the EU (assessed with EF 2017 method).



Finally, sanitary products do not contribute significantly to any of the impact categories, except for ozone depletion and resource depletion. This is mainly due to the very low amount of products purchased by an average EU citizen in one year (7 kg/year in total), compared to the other product groups. It has to be considered that some sanitary products, such as diapers, are related only to a portion of the population, but their apparent consumption is distributed among the whole EU population in the model of the BoP.

The detailed analysis on the BoP Household goods is available in a dedicated report (Castellani et al., 2019a).

4.1.6 Summary of main results of hotspot analysis on the baseline scenarios of the BoPs

The hotspot analysis performed on the baseline scenario of the five BoPs helped to identify the main activities that contribute to the impact of a specific BoP, but also activities that are significant contributors to impacts across the BoPs. Detailed results are reported in Annex 9; the next paragraph summarizes the most important findings.

As described in the previous sections, some activities are driving the impact of a specific BoP across all or most of the impact categories considered. This is particularly true for **agricultural activities** in the case of BoP Food, with a contribution higher than 80% across all impact categories. For BoP Housing, **heating** (either from coal or from wood) is contributing to climate change, human toxicity- non-cancer, particulate matter, photochemical ozone formation, acidification, terrestrial eutrophication and marine eutrophication. For BoP Mobility, **emissions from air transport and passenger cars** during the use phase (i.e. emissions from fuel burning) contribute to climate change, photochemical ozone formation, acidification, terrestrial eutrophication and marine eutrophication. Finally, **for BoP Household goods the electricity generation outside the EU (i.e. electricity used in the production of goods, when this phase happens**

outside the EU) contributes to several impact categories, namely climate change, particulate matter, photochemical ozone formation, acidification and terrestrial eutrophication.

The contribution of the EU electricity mix, i.e. of the electricity used mainly in the use phase of products and services represented in the BoPs is relevant for climate change, acidification, terrestrial eutrophication and marine eutrophication across the baskets, and especially for Housing, Household Goods and Appliances.

Other activities appear to be particularly relevant for some impact categories, because their contribution is recurrent across the BoPs. This holds true for:

— the contribution of onshore oil and gas production to land use impacts (for Housing, Mobility, Household Goods and Appliances);

— the contribution of the treatment of spent nuclear fuel to ionising radiation (for Housing, Household goods and Appliances);

— the contribution of tap water use to water depletion (for Housing, Food, Household goods and Appliances).

Table 19 reports a summary of the characterized, normalised and weighted results of the baseline scenarios for the five BoPs.

Table 19. Summary of results of the baseline scenarios for the five BoPs. A colour code is used to show weighted results, from red (highest value) to green (lowest value).

Impact category	Unit	BoP Housing		BoP Mobility		BoP Food		BoP Appliances		BoP Household goods	
			NW		NW		NW		NW		NW
CC	kg CO_2 eq	1.29E+12	20%	1.25E+12	24%	1.25E+12	19%	1.75E+11	14%	7.48E+11	20%
ODP	kg CFC-11 eq	1.55E+05	0%	2.91E+05	0%	1.58E+06	1%	4.43E+04	0%	5.97E+04	0%
HTOX_nc	CTUh	5.67E+04	1%	8.82E+04	2%	7.55E+04	2%	2.57E+04	3%	4.27E+04	2%
HTOX_c	CTUh	1.68E+04	5%	1.33E+04	5%	1.40E+04	5%	3.54E+03	6%	2.39E+04	14%
PM	Disease incidence	1.16E+05	10%	4.97E+04	5%	1.30E+05	12%	5.03E+03	2%	3.90E+04	6%
IR	kBq U235 eq	9.71E+10	21%	8.38E+10	22%	2.55E+10	5%	2.11E+10	24%	4.47E+10	17%
POF	kg NMVOC eq	3.12E+09	2%	5.12E+09	4%	2.04E+09	1%	4.50E+08	2%	2.13E+09	3%
AC	molc H^+ eq	6.37E+09	4%	5.09E+09	4%	1.78E+10	12%	1.05E+09	4%	4.10E+09	5%
TEU	molc N eq	8.79E+09	1%	1.51E+10	2%	7.56E+10	9%	1.51E+09	1%	8.17E+09	2%
FEU	kg P eq	6.49E+07	1%	3.65E+07	0%	3.14E+08	3%	3.97E+07	2%	5.55E+07	1%
MEU	kg N eq	8.00E+08	1%	1.38E+09	2%	8.00E+09	7%	1.90E+08	1%	1.14E+09	2%
ECOTOX	CTUe	5.46E+11	1%	9.89E+11	1%	3.36E+12	3%	1.22E+11	1%	8.65E+11	1%
LU	Pt	2.73E+13	1%	9.86E+12	0%	1.21E+14	3%	2.05E+12	0%	2.93E+13	1%
WU	m^3 world eq	2.88E+12	13%	2.19E+11	1%	2.39E+12	11%	7.81E+10	2%	1.06E+12	8%
FRD	MJ	2.29E+13	17%	1.90E+13	18%	7.27E+12	6%	3.52E+12	14%	1.10E+13	15%
MRD	kg Sb eq	2.46E+06	2%	8.56E+06	7%	1.16E+06	1%	6.40E+06	24%	2.91E+06	4%

NW – normalised and weighted results.

4.2 Consumer Footprint in the EU: comparing 2010 and 2015

The BoPs that compose the Consumer Footprint indicator are designed to represent household consumption in the EU in a reference year in five main areas of consumption (housing, mobility, food, appliances and household goods). Each basket includes a selection of representative products and the quantity of each product consumed in one year by an average EU citizen, multiplied by European population in the reference year. The baseline scenarios presented in section 5 refer to the baseline year 2010, and, consequently, to EU-27. This year was chosen because it was the closest year for which a more complete set of data on apparent consumption was in 2014, when the modelling of BoPs started.

However, in the meantime from 2010 to today (2018), there were changes including the increase of the number of Member States of the European Union (from 27 to 28, with the inclusion of Croatia), the number of European citizens, and also their consumption patterns. An updated baseline scenario was therefore also modelled. The analysis was conducted for each of the five BoPs considered, taking 2015 as reference year and enlarging the geography from EU-27 to EU-28. Consequently, the reference population has been updated (from 502 million citizens in 2010 in EU-27 to 508 million citizens in 2015 in EU-28). A new calculation of apparent consumption for representative products was done, taking 2015 as reference year and updating the quantities of representative products purchased, the km travelled by the different means of transport considered and the energy use in the housing sector.

As a general assumption, the technical features and the performance of appliances and household goods and the characteristics of the food production chain for food products have been kept constant from 2010 to 2015, because possible changes in these sectors were considered not significant. On the contrary, in the case of BoP Mobility and BoP Housing, the update included also some modifications in the structure of the baseline model, to account for changes in the composition of the building stock and of the mobility fleet. More in details, dwellings built between 2010 and 2015 were added in the BoP Housing, whereas electric and hybrid cars (which were not significantly used in 2010 but became relevant in 2015) were added to the EU mobility fleet, as well as Euro 6 cars. More details and results are provided in Annex 11.

The analysis of apparent consumption in 2015 revealed a general increase in household consumption per person from 2010 to 2015, with the exception of some food products and some household goods. **The most relevant increase is related to the number of kilometres travelled per person in one year** (10% more in 2015 compared to 2010, affecting the impact of mobility) **and the number of appliances owned** (29% more in 2015 in total, with **room-air conditioner** as the most relevant one in terms of increase, corresponding to 53%).

This increase is reflected in an increased total impact generated by household consumption in the EU, driven also by the increase in population (about 1%). To better highlight the variation due to the changes in apparent consumption and the changes in the relative shares of products, the following figures (from Figure 49 to Figure 53) show the impact of each BoP calculated per person and split into the contribution of the product groups considered. **BoPs' changes between 2010 and 2015 show a general increase in the amount of goods and services consumed per person and, consequently, an increase in the total impact generated in the EU**, due also to the extension of the geography from EU-27 to EU-28 (and the consequent increase in the population, from 502 million people to 508 million people).

BoP Housing is an exception to this trend, because the impact generated in 2015 by the housing sector is lower than in 2010 (Figure 49). The reduction (around 5% for most of the impact categories) is mainly driven by a general reduction of energy use in the buildings (especially for space heating), also due to the support of energy efficiency regulations that came in place since 2010, as confirmed also by other studies (e.g. ODYSSEE-MURE, 2015).

In the case of BoP Mobility, along with the increase of impacts in most of the impact categories (due to the increase in pkm), there are some reductions in 2015 compared to 2010 (Figure 50). This happens for the impact on particulate matter, photochemical oxidation and land use, due to the introduction of new types of vehicles (electric and hybrid cars) and the reduction in the use of more impacting means of transport (e.g. diesel cars).

The impact per person from BoP Food increased from 7% to 17% from 2010 to 2015, depending on the impact category, because of the increase of the amount of food consumed by an average citizen (+6% in total, with significant increase for some products, such as cod - +46%) (Figure 51).

The impact generated by an average citizen with the purchase and use of appliances increased as well from 2010 to 2015. The increase is between 15% and 20% for almost all the impact categories. In the case of ozone depletion the increase is higher (40% more in 2015 than in 2010), due to the significant increase (53%) in the number of air conditioners owned, and related use of refrigerants (Figure 52).

In the case of BoP Household goods, the impact generated by an average EU citizen in 2015 is higher than the one generated in 2010 for all the impact categories considered, due to the general increase in apparent consumption from 2010 to 2015. The increase of the impact per person is around 10% for most of the impact categories (Figure 53).

Figure 49. Comparison of impact of BoP Housing in the reference year 2010 and in 2015 (with total impact of year 2010 set as 100%).

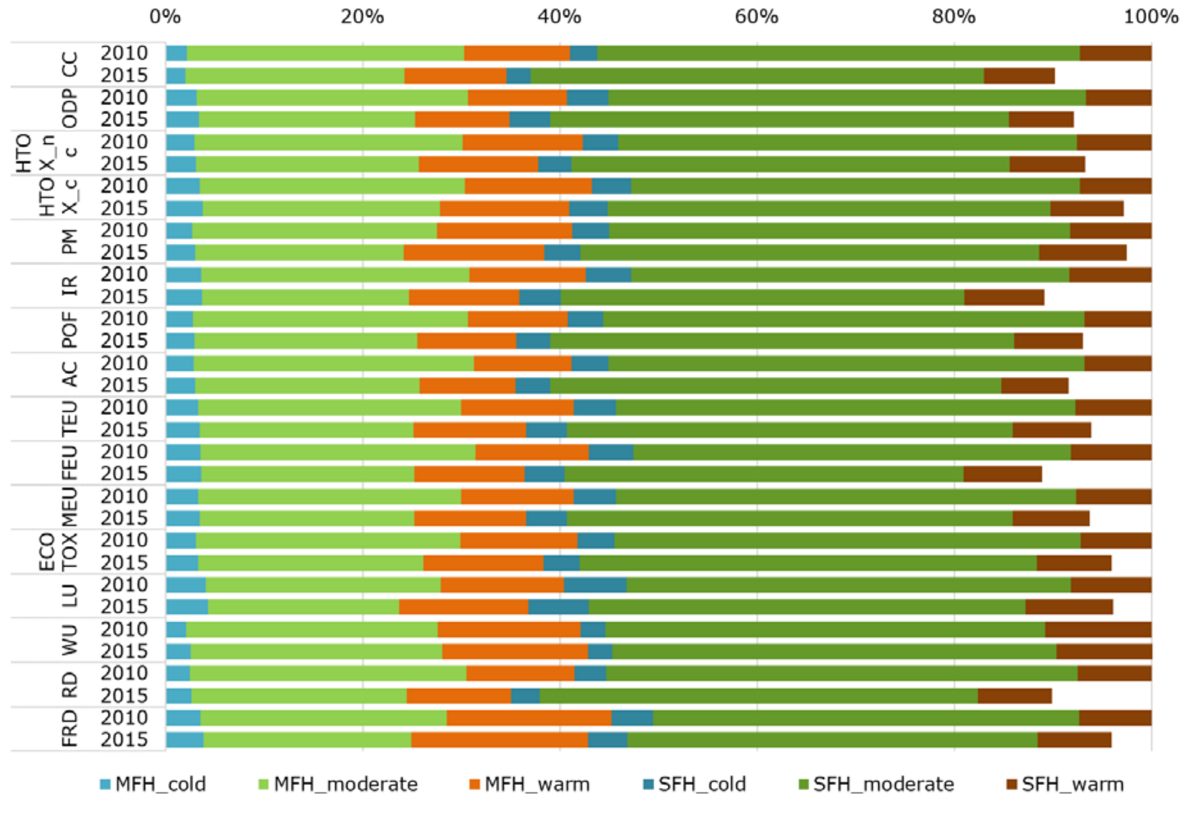


Figure 50. Comparison of impact of BoP Mobility in the reference year 2010 and in 2015 (with total impact of year 2010 set as 100%).

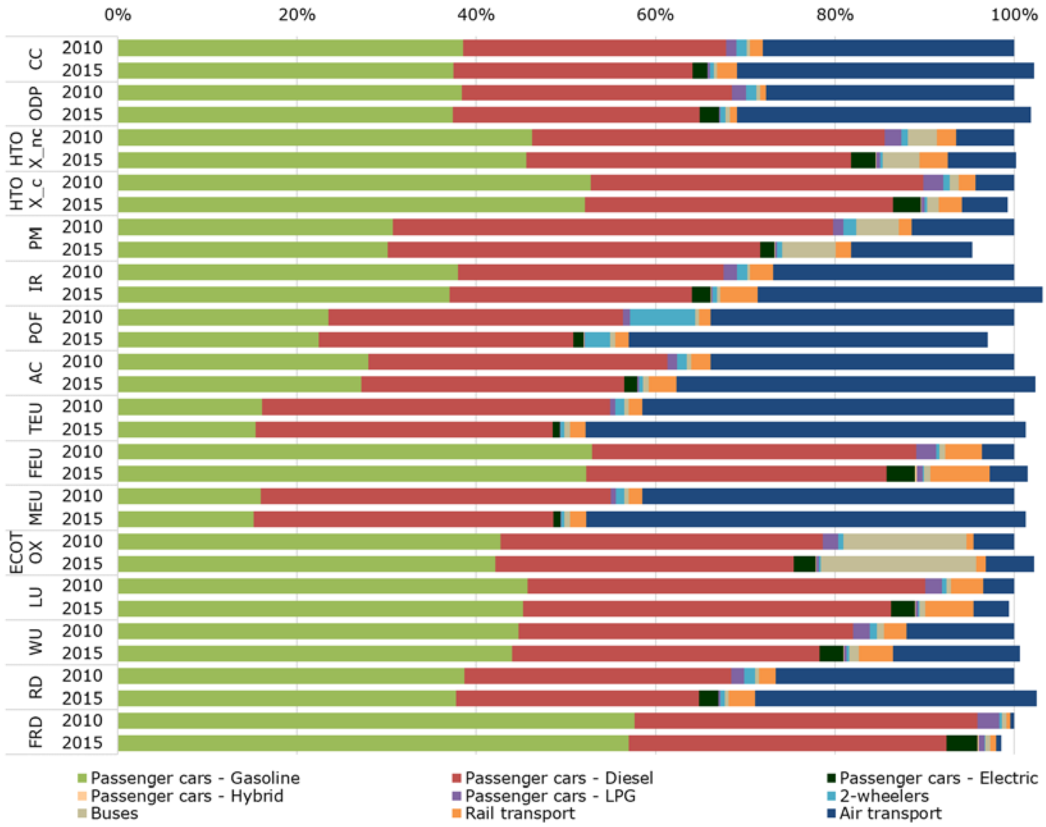


Figure 51. Comparison of impact of BoP Food in the reference year 2010 and in 2015 (with total impact of year 2010 set as 100%).

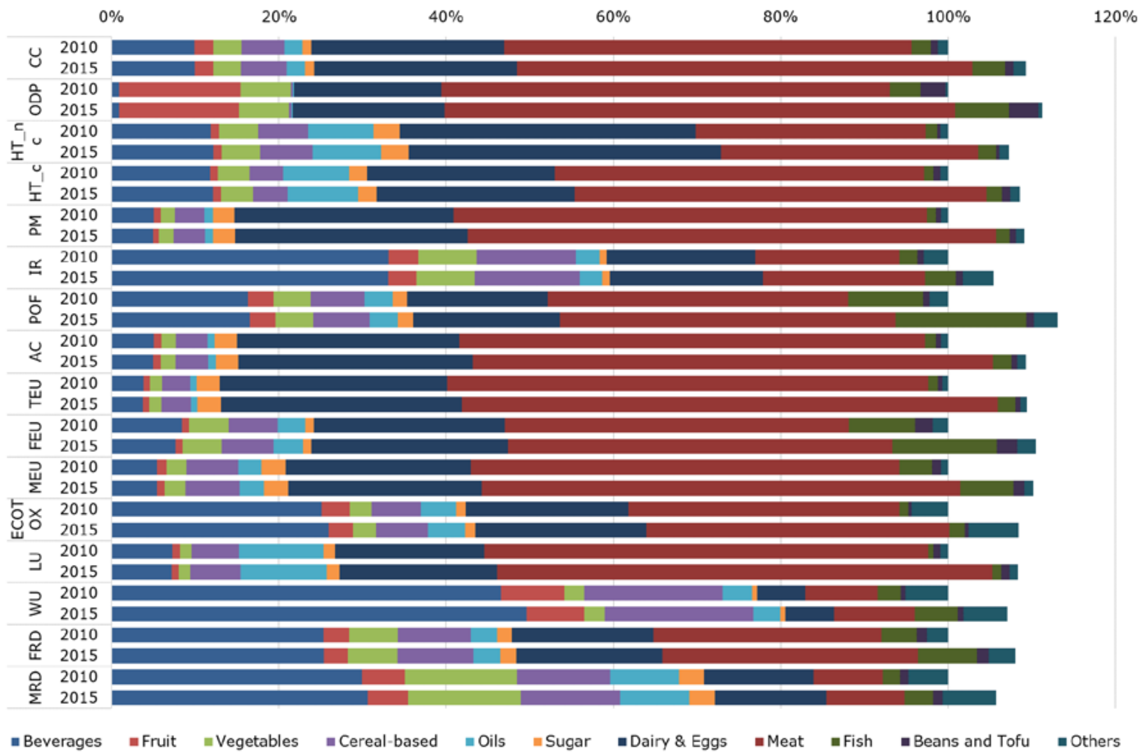


Figure 52. Comparison of impact of BoP Appliances in the reference year 2010 and in 2015 (with total impact of year 2010 set as 100%).

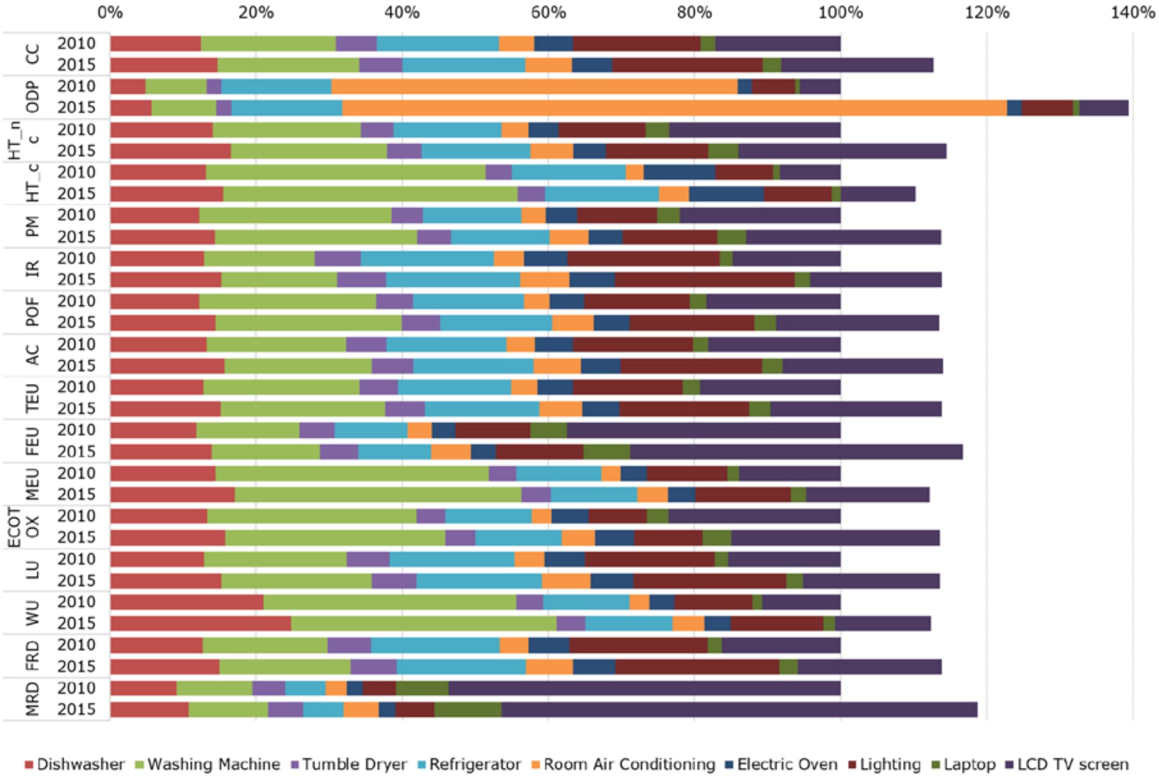
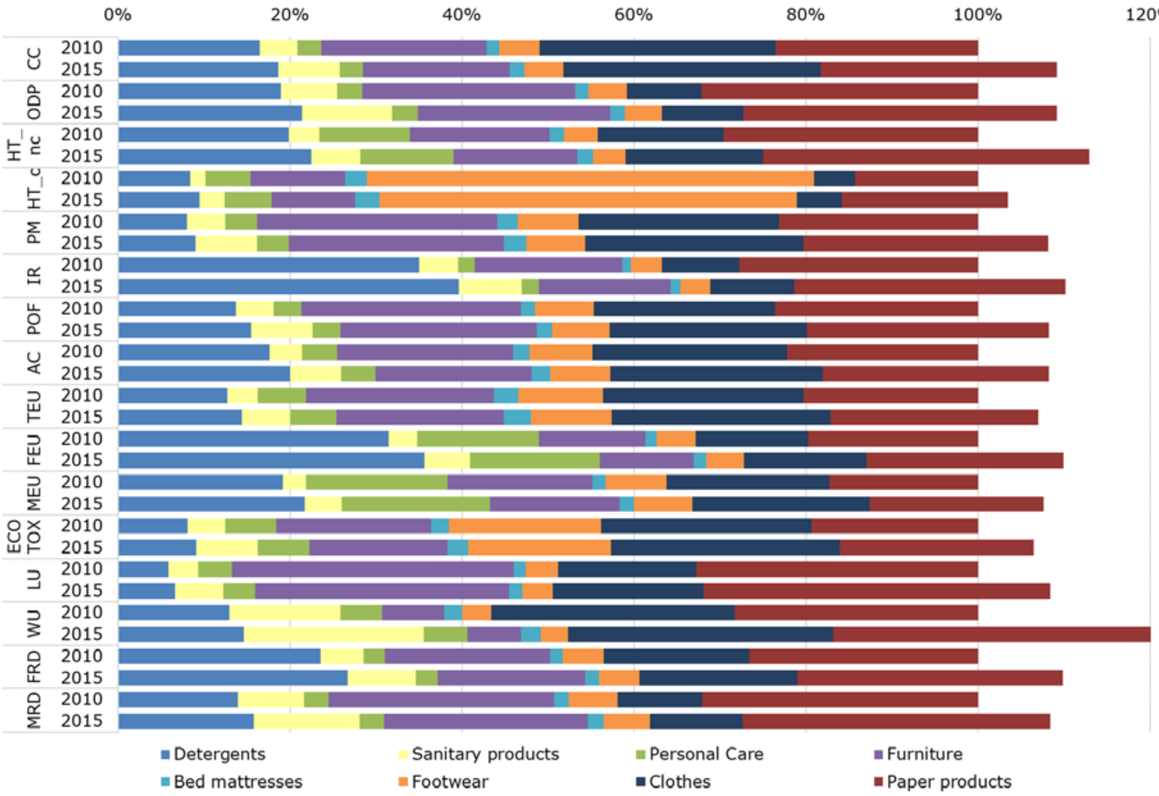
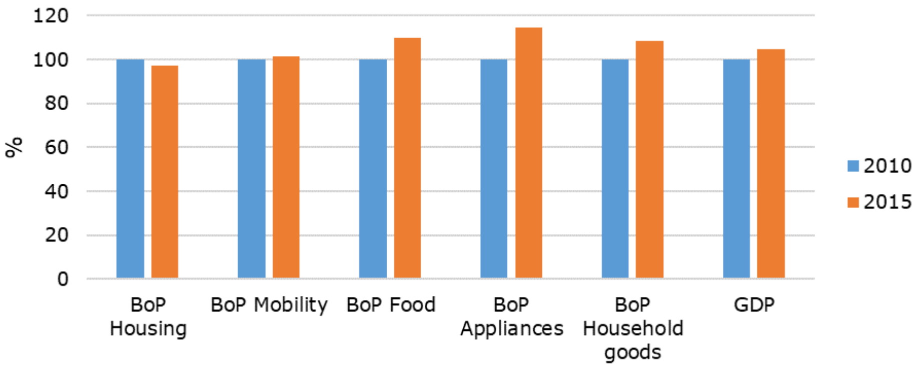


Figure 53. Comparison of impact of BoP Household goods in the reference year 2010 and in 2015 (with total impact of year 2010 set as 100%).



When looking at the weighted impacts of different BoPs per person, it can be noted that **total impact increase in all other consumption areas except in housing** (Figure 54). The highest increase is in household appliances and in food. Also GDP increase from 2010 to 2015.

Figure 54. Variation in the weighted score and GDP per person between 2010 and in 2015 (with total impact of year 2010 set as 100%).



Also **the impact of total consumption (total BoPs) increased from 2010 to 2015 in all impact categories** (Figure 55). The highest increase is in the mineral and metal resource use (9%) due to high increase in household appliances. Table 20 shows the impacts generated by household consumption in EU-28 in 2015.

Figure 55. Comparison of impact of Total BoP in the reference year 2010 and in 2015 (with total impact of year 2010 set as 100%).

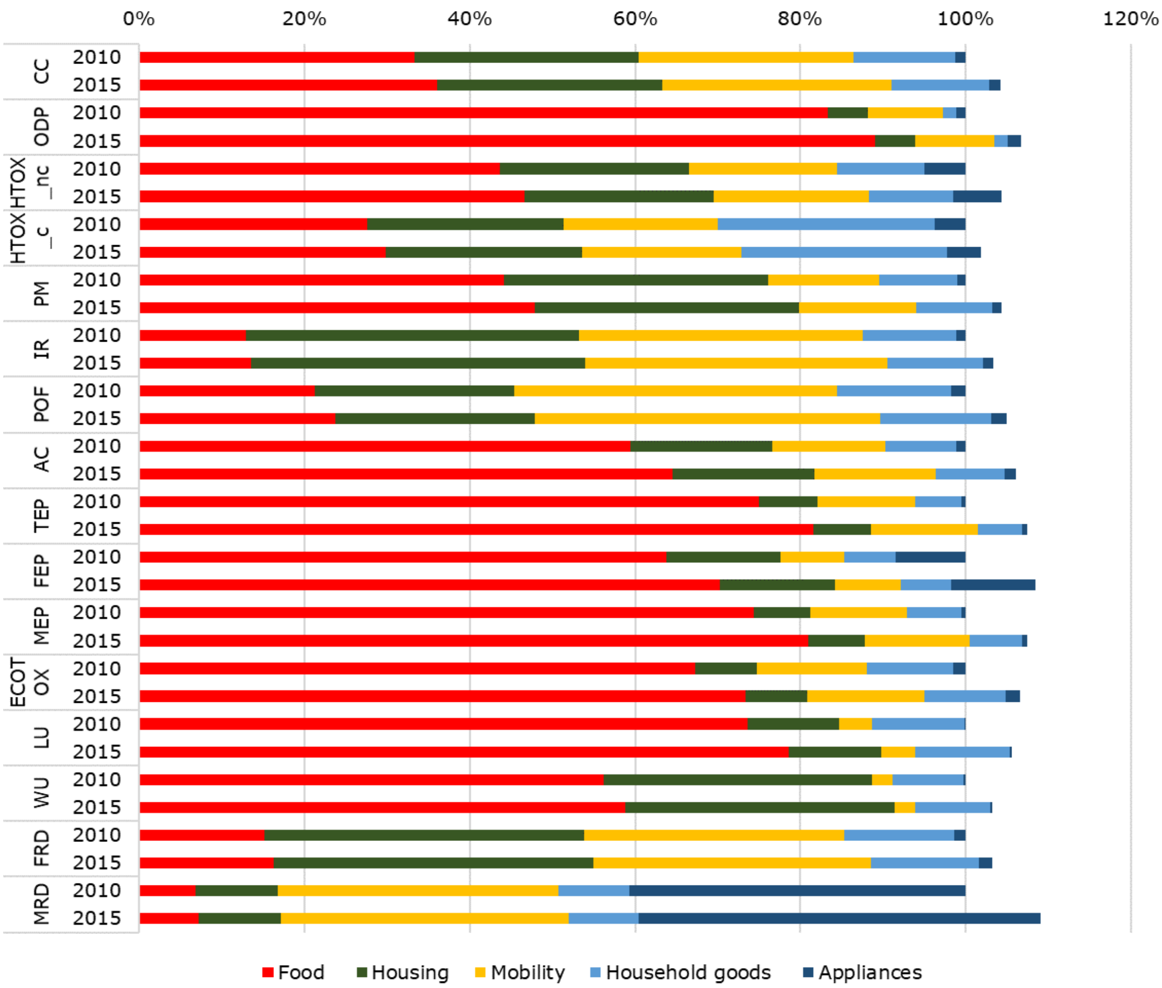


Table 20. Characterized impact of household consumption in the EU calculated as the sum of the five BoPs (year 2015).

Impact category	Unit	Total*	Appliances	Food	Household goods	Housing	Mobility
Climate change	kg CO_2 eq	5.05E+12	6.83E+10	1.74E+12	5.75E+11	1.31E+12	1.35E+12
Ozone depletion	kg CFC-11 eq	3.48E+06	5.30E+04	2.90E+06	5.27E+04	1.59E+05	3.14E+05
Human toxicity, non-cancer	CTUh	2.65E+05	1.48E+04	1.18E+05	2.61E+04	5.78E+04	4.77E+04
Human toxicity, cancer	CTUh	7.35E+04	2.97E+03	2.15E+04	1.79E+04	1.72E+04	1.39E+04
Particulate matter	Disease incidence	3.88E+05	4.13E+03	1.77E+05	3.41E+04	1.19E+05	5.29E+04
Ionising radiation	kBq U^{235} eq	2.53E+11	3.08E+09	3.27E+10	2.84E+10	9.83E+10	9.05E+10
Photochemical ozone formation	kg NMVOC eq	1.38E+10	2.59E+08	3.08E+09	1.77E+09	3.20E+09	5.54E+09
Acidification	molc H^+ eq	3.99E+10	4.89E+08	2.42E+10	3.16E+09	6.52E+09	5.55E+09
Terrestrial eutrophication	molc N eq	1.37E+11	8.25E+08	1.04E+11	6.83E+09	9.03E+09	1.66E+10
Freshwater eutrophication	kg P eq	5.10E+08	4.84E+07	3.29E+08	2.91E+07	6.56E+07	3.83E+07
Marine eutrophication	kg N eq	1.28E+10	7.61E+07	9.64E+09	7.58E+08	8.21E+08	1.52E+09
Ecotoxicity freshwater	CTUe	8.04E+12	1.26E+11	5.55E+12	7.44E+11	5.62E+11	1.07E+12
Land use	Pt	2.65E+14	5.78E+11	1.97E+14	2.87E+13	2.80E+13	1.03E+13
Water scarcity	m^3 water eq	7.29E+12	2.79E+10	3.26E+12	8.19E+11	2.95E+12	2.32E+11
Resource use (fossils)	MJ	6.24E+13	9.97E+11	9.72E+12	7.94E+12	2.33E+13	2.04E+13
Resource use (mineral and metals)	kg Sb eq	2.78E+07	1.24E+07	1.81E+06	2.16E+06	2.51E+06	8.87E+06
Weighted score		**9.35**	**0.35**	**3.36**	**1.03**	**2.49**	**2.11**

*As for the year 2010, the impact of the overall consumption in EU is not equal to the sum of impact from single baskets because: 1) energy consumption in the use phase is totally accounted for in the use phase of housing to avoid double counting); 2) the quantity of food and appliances was up-scaled to cover 100% of consumption by EU citizens.

4.3 Consumer Footprint: main areas of consumption driving the impact and comparison with Household_I/O Footprint

Box 10. Key messages on main categories of consumption driving the environmental impact

— The main driver of impacts generated by household consumption in EU is food, followed by housing and mobility. The only exception is the impact on mineral and metal resources, which is driven by household appliances.

— Results calculated for comparison with an Input-Output top-down approach find a relative lower contribution of the food sector compared to the Consumer Footprint but generally confirm the other findings.

— The impact of services, which are not included in the Consumer Footprint, appears to be quite limited in almost all the impact categories (generally below 10%) when the impact is calculated using a top-down approach.

This section illustrates the results of the Consumer Footprint in EU, i.e. the impacts generated by household consumption in EU-27 in the reference year (2010). This is calculated as the sum of the five BoPs, modified to avoid double counting among the areas of consumption (i.e. removing activities that were overlapping among BoPs, such as the use of electricity for cooking) and up-scaled to cover, to the extent possible, the entire consumption by EU households (as explained in section 2). Along this section, results calculated with the Consumer Footprint indicator were compared to results obtained applying a top-down approach, based on Environmentally Extended Input-Output tables (i.e., EXIOBASE 3), which is called here Household_I/O Footprint (Section 3.8). The comparison could provide additional insights on the findings of the Consumer Footprint, and allows identifying converging (thus more robust) results between the two approaches.

Table 21. Characterized impact of household consumption in the EU calculated as the sum of the five BoPs (year 2010).

Impact category	Unit	Total*	Appliances	Food	Household goods	Housing	Mobility
CC	kg CO_2 eq	4.80E+12	5.78E+10	1.59E+12	5.94E+11	1.31E+12	1.25E+12
ODP	kg CFC-11 eq	3.22E+06	3.68E+04	2.68E+06	5.23E+04	1.58E+05	2.91E+05
HTOX_nc	CTUh	2.51E+05	1.26E+04	1.10E+05	2.65E+04	5.75E+04	4.52E+04
HTOX_c	CTUh	7.14E+04	2.71E+03	1.96E+04	1.87E+04	1.70E+04	1.33E+04
PM	Disease incidence	3.68E+05	3.52E+03	1.61E+05	3.50E+04	1.18E+05	4.97E+04
IR	kBq U^{235} eq	2.43E+11	2.65E+09	3.07E+10	2.78E+10	9.85E+10	8.38E+10
POF	kg NMVOC eq	1.30E+10	2.23E+08	2.72E+09	1.81E+09	3.17E+09	5.12E+09
AC	molc H^+ eq	3.73E+10	4.18E+08	2.20E+10	3.25E+09	6.47E+09	5.09E+09
TEU	molc N eq	1.26E+11	7.05E+08	9.43E+10	7.07E+09	8.93E+09	1.51E+10
FEU	kg P eq	4.66E+08	4.00E+07	2.95E+08	2.92E+07	6.59E+07	3.65E+07
MEU	kg N eq	1.18E+10	6.53E+07	8.75E+09	7.80E+08	8.12E+08	1.38E+09
ECOTOX	CTUe	7.46E+12	1.08E+11	5.03E+12	7.83E+11	5.54E+11	9.89E+11
LU	Pt	2.48E+14	4.99E+11	1.82E+14	2.76E+13	2.77E+13	9.86E+12
WU	m^3 water eq	7.05E+12	2.46E+10	3.11E+12	7.72E+11	2.92E+12	2.19E+11
FRU	MJ	6.00E+13	8.58E+11	8.95E+12	7.94E+12	2.33E+13	1.90E+13
MRU	kg Sb eq	2.52E+07	1.03E+07	1.69E+06	2.17E+06	2.50E+06	8.56E+06
Weighted score		**8.90**	**0.30**	**3.08**	**1.05**	**2.46**	**1.97**

*The impact of the overall consumption in EU is not equal to the sum of impact from single baskets because: 1) energy consumption in the use phase is totally accounted for in the use phase of housing to avoid double counting); 2) the quantity of food and appliances was up-scaled to cover 100% of consumption by European citizens. Acronyms mentioned in Figure 12 are used to identify all the impact categories.

Table 21 shows absolute results of the impact generated by household consumption in EU, whereas Figure 56 highlights the relative contribution of the areas of consumption represented by the five BoPs.

Consumption of food is the main driver of impacts for most of the impact categories, followed by Housing and, to some extent, Mobility (especially for climate change, photochemical ozone formation, fossil resource use and mineral and metal resource use). **Appliances are the main driver for the impact category mineral and metal resource depletion**. This is mainly due to the impacts generated by the extraction of precious metals used in printed circuit boards.

Figure 57 shows the contribution by sector of consumption according to the top-down approach considered for comparison (the Household_I/O Footprint). The nomenclature of sectors in EXIOBASE 3 relies on the NACE nomenclature, with further disaggregation regarding some products. In order to ease the comparison between the Consumer Footprint and the Household_I/O Footprint, the Classification of Individual Consumption by Purpose (COICOP) is adopted for the Household_I/O Footprint. A concordance matrix linking each COICOP product group to one or more EXIOBASE reference products was constructed respectively considering EXIOBASE nomenclature and COICOP nomenclature. One should bear in mind that, due to the nature of the approaches implemented (including in particular different nomenclatures), there is no one-to-one correspondence between the different types of consumption (or sectors) from one approach to the other (see Box 11).

Box 11. Main assumptions used to compare areas of consumption between the Consumer Footprint and the Household_I/O Footprint

The Consumer Footprint and the Household_I/O Footprint are implemented considering a different set of areas of consumption. In order to compare the results obtained from each approach, a correspondence between the BoPs (bottom-up approach) and the COICOP divisions (top-down approach) is required.

Firstly, the top-down and bottom-up approaches enable a relatively good correspondence regarding food products. The representative products of the BoP Food match the COICOP divisions Food and non-alcoholic beverages, and Alcoholic beverages, tobacco and narcotics (yet, tobacco and narcotics are excluded from the BoP Food). The expenditures related to the consumption of food products in Restaurants and hotels are also included in the BoP Food, but the remaining impacts of the activities themselves are considered only in the top-down approach.

Moreover, the sum of the contributions related to the five COICOP divisions “Miscellaneous goods and services”, “Furnishings, household equipment and routine household maintenance”, “Recreation and culture”, “Communications” , and “Clothing and Footwear” in the Household_I/O Footprint could be compared with the sum of the two baskets Appliances and Household goods in the Consumer Footprint approach. For example, most of small appliances included in the BoP Appliances are included in the COICOP division Recreation and culture, whereas big appliances (also known as “white goods”) are included in Furnishings. However, this correspondence is only partial due to the presence of several differences, such as the inclusion of services in the top-down approach (e.g. “Post and telecommunication services” are part of the COICOP division Communications).

In a similar way, the “Transport” COICOP division includes some expenditures on services (e.g. expenditures related to services of travel agencies) whereas these expenditures are not considered in the BoP Mobility. The COICOP division “Housing, water, electricity, gas and other fuels” also includes other expenditures on services (e.g. Real estate services) whereas such expenditures are excluded from the BoP Housing.

Notwithstanding these differences, the two approaches show a quite similar pattern in the contribution of the main sectors for many impact categories (namely climate change, human toxiticy-cancer, photochemical ozone formation, acidification, terrestrial and marine eutrophication, water use and fossil resource use). In particular, the consumption of food is the main driver for impacts on acidification, terrestrial and marine eutrophication, land use and water use in both approaches. Yet, the contribution of the food sector is lower in the Household_I/O Footprint than in the Consumer Footprint, as a recurrent difference.

Figure 56. Contribution of the five BoPs to the total Consumer Footprint in EU, in 2010.

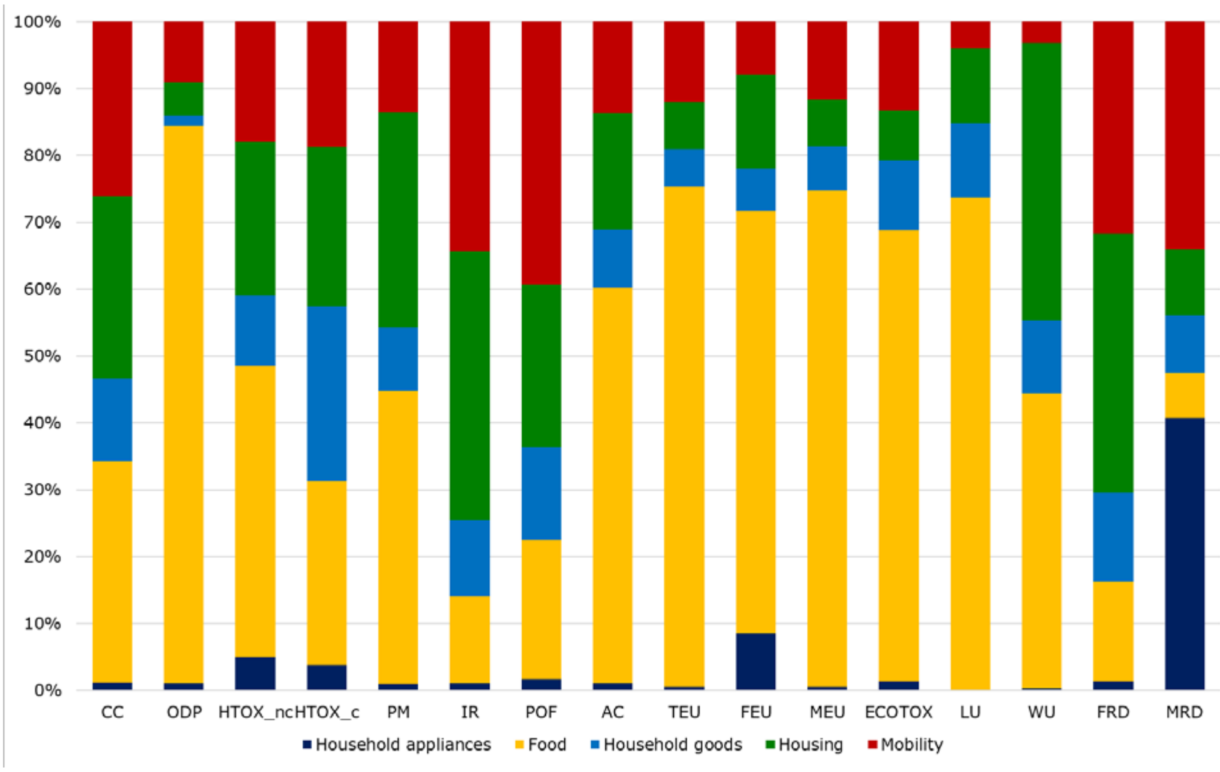
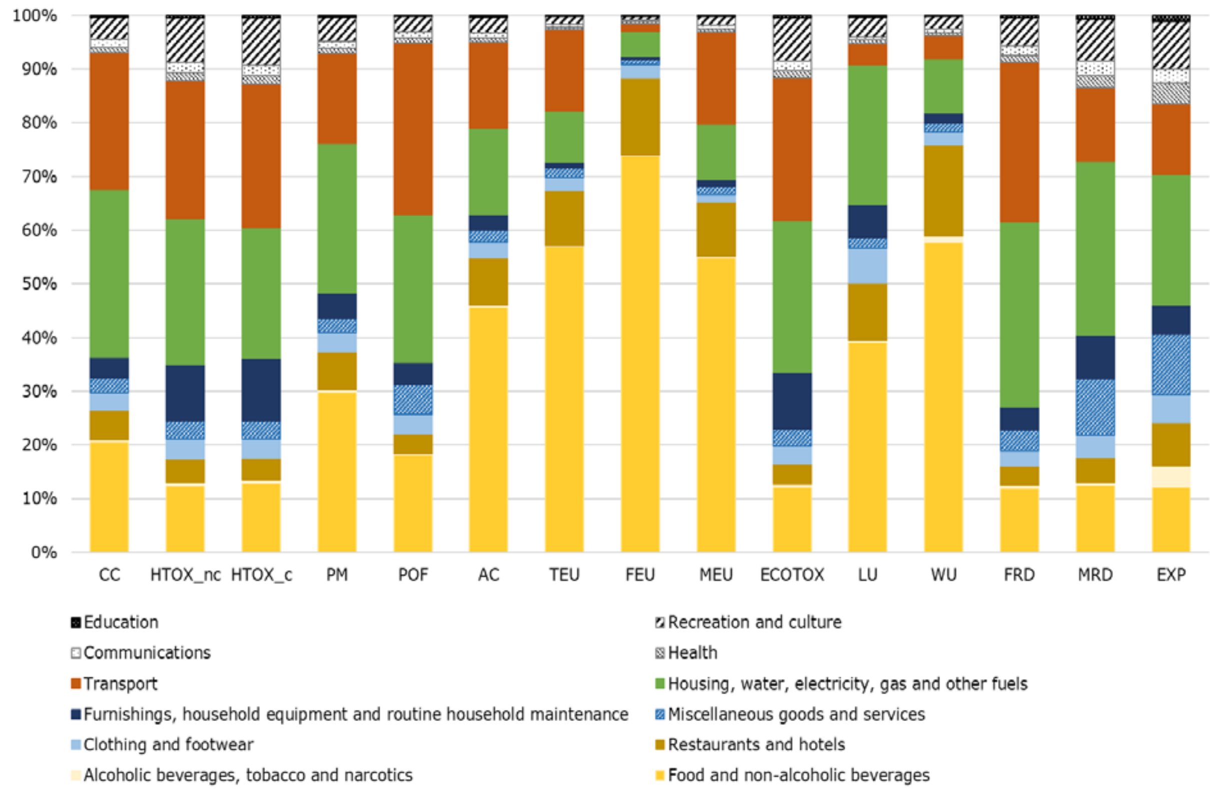


Figure 57. Contribution of COICOP divisions to Household_I/O Footprint in EU, in 2011.



EXP: expenditures.

Regarding freshwater eutrophication, land use and particulate matter, Food is identified as the main contributing sector according to both approaches, yet with differences in the shares of the other sectors. Restaurants and Hotels is observed to generate a significant contribution in the top-down approach, as a complement to the major contribution of food. In both approaches, Housing is the second most important sector for freshwater eutrophication, yet with different contributions (approximately 15% and 10% respectively in the Consumer Footprint and in the Household_I/O Footprint). Similarly, Appliances and Mobility show a higher share in the Consumer Footprint than in the Household_I/O Footprint. On the contrary, the contributions of Housing and Mobility to land use is higher in the Household_I/O Footprint than in the Consumer Footprint (in particular 25% versus 20% regarding housing). In the case of particulate matter, Food represents 45% in the Consumer Footprint and 30% in the Household_I/O Footprint (to which 7% due to Restaurants and Hotels can be considered in addition). Housing has similar shares in both cases (respectively 30% and 28%). Moreover, regarding photochemical ozone formation, Mobility is the main driver (40% in the Consumer Footprint versus 32% in the Household_I/O Footprint).

On the contrary, the most contributing sectors as identified according to the two modelling approaches diverge quite significantly regarding human toxicity, non-cancer effects, freshwater ecotoxicity and mineral and metal resource use. Food dominates the impact on freshwater ecotoxicity and human toxicity, non-cancer according to the Consumer Footprint, whereas a more diverse set of COICOP divisions is identified through the Household_I/O Footprint. In particular, Housing, water, electricity, gas and other fuels has the largest contribution to the total impact on mineral and metal resource use (due to expenditures on Real estate activities and Construction), whereas the Consumer Footprint instead identifies Appliances and Mobility as the most contributing sectors (due to the use of precious metals).

4.3.1 Relevance of use phase and direct emissions

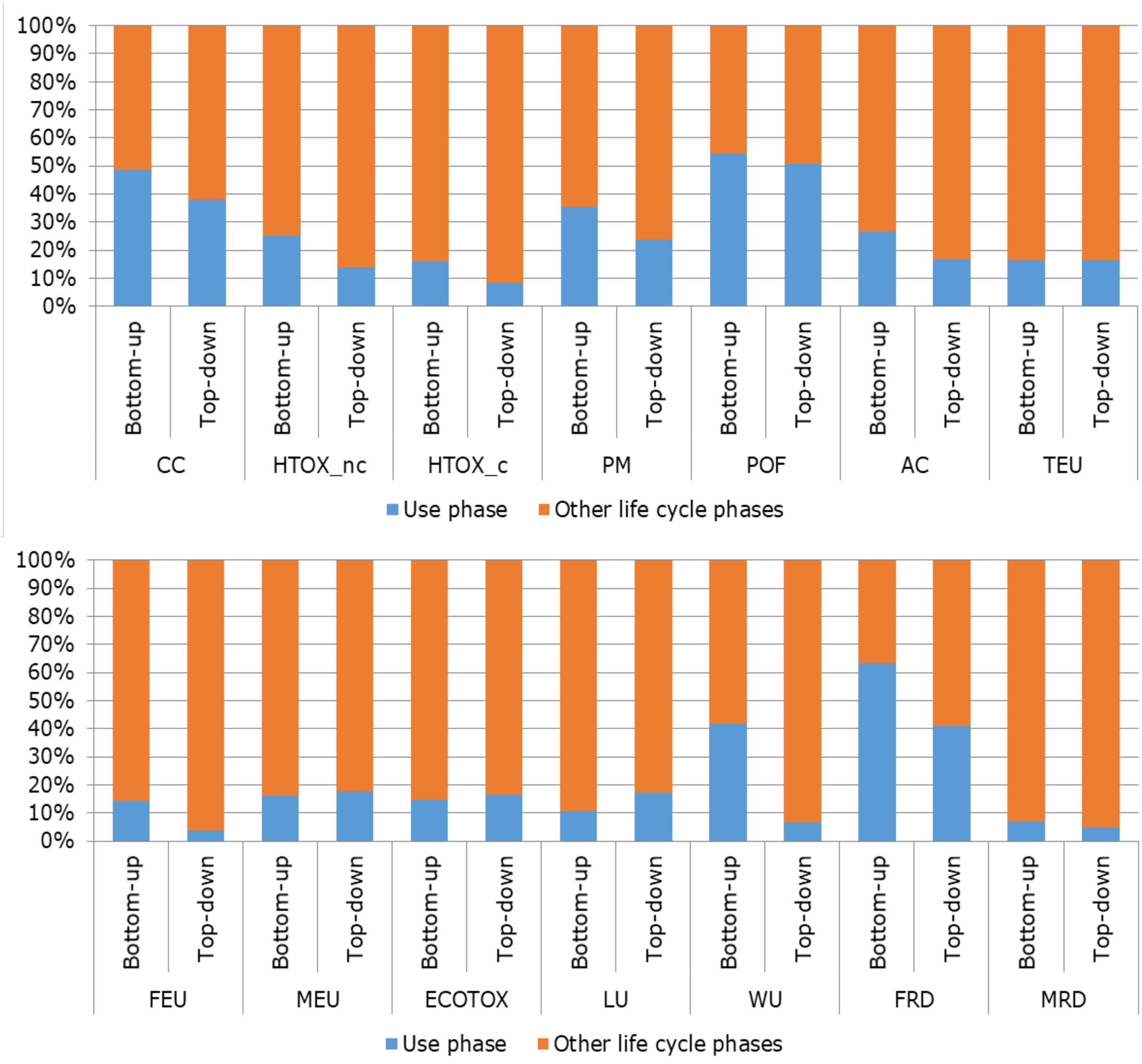
An additional analysis was run to identify the contribution of the use phase over the total impact generated by household consumption. Also in this case, a comparison was done between the Consumer Footprint (bottom-up approach) and the Household_I/O Footprint (top-down approach). According to the results of the two approaches, **for most impact categories the supply chain of products and services consumed and used by EU household drives the impact** (Figure 58). Both according to the bottom-up and top-down approaches, the life cycle phases other than the use phase contribute to more than 80% of the impact on eutrophication (terrestrial, freshwater and marine), human toxicity cancer, freshwater ecotoxicity, land use and mineral and metal resource use.

However the contribution of the use phase is more significant with respect to other impact categories. Firstly, both approaches highlight that the use phase (or direct emissions) contribute significantly to climate change (about 50% in the Consumer Footprint and 40% in the Household_I/O Footprint), particulate matter (35% and 24%) and photochemical ozone formation (53% and 51%). In both approaches, energy consumption (combustion of fuels either for transport or heating of the houses, and production of electricity used in the houses) is observed to be the main driver to the significant contribution of the use phase.

Moreover, both approaches identify the use phase as a significant contributor to the impact on fossil resource use, yet with a larger share according to the Consumer Footprint (63% versus 40% in the Household_I/O Footprint, mainly due to the use of fossil fuels for mobility and space heating in the buildings). Similarly, regarding acidification, the contribution of the use phase respectively amounts to 17% (Household_I/O Footprint) and 26% (Consumer Footprint, in that case mostly generated by the emissions of nitrogen oxides from transport, in particular from air transport). Moreover, regarding human toxicity non-cancer and water use, the contribution of the use phase is also significant in both approaches, yet with larger values in the Consumer Footprint than in the Household_I/O

Footprint (25% versus 14% regarding human toxicity, non-cancer, and 40% versus 10% regarding water use).

Figure 58. Contribution of the use phase over the total impact calculated with the Consumer Footprint and the Household_I/O Footprint.

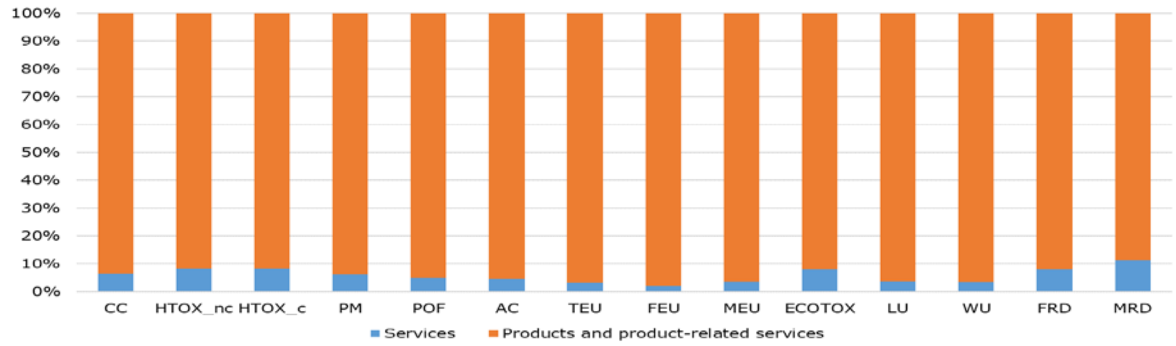


4.3.2 Contribution of services

The use of a bottom-up approach based on representative products, in the Consumer Footprint indicator, entails the cut-off of some activities, and especially of services (which are not represented by physical products) (e.g. tourism, education). In order to check the potential contribution of services to the total impact generated by household consumption in EU, the contribution of services to the Household_I/O Footprint (top-down approach) has been calculated. As shown in Figure 59, considering the Household_I/O Footprint, **the contribution of services to the impact of household consumption is quite limited regarding almost all the impact categories (generally below 10%)**. Yet, the remaining impact is generated not only by products but also by product-related services, and therefore does not fully correspond to the life cycle of products as calculated in the Consumer Footprint.

For instance, “Real estate services” (classified as “Products and product-related services” in Figure 59) relate in the meantime to products (dwellings in the BoP housing) and services (in particular linked to the renting of dwellings). Moreover, in the Household_I/O Footprint, not only the services directly consumed by households are considered, but also the services indirectly required along the supply-chain of products and services consumed by households. The contribution of services consumed by households has to be seen as the lower bound of impacts induced by the consumption of “services” by households, considered in the Household_I/O Footprint but excluded from the Consumer Footprint approach.

Figure 59. Contribution of “services” to the overall Household_I/O Footprint.



5 Environmental impact associated to citizen lifestyle

Box 12. Key messages on environmental impact generated by EU-28 citizens

— The lifestyle of EU citizens is a key driver of the impacts of household consumption in the EU and possible variations of consumer behaviour from the average situation modelled in the calculation of the indicators should be taken into account.

— In the case of BoP Food, BoP Appliances and BoP Household goods, the environmental impacts generated in 2015 are higher compared to 2010, due to general increase in apparent consumption. On the contrary, impacts generated in 2015 by the housing sector are lower than in 2010 due to better energy efficiency. In the case of BoP Mobility, the environmental impact is generally higher due to increase in pkm.

— The increasing levels of environmental impacts induced by EU consumption vary across and within countries by consumption category, whose contextual features and consumption pattern's determinants need to be further investigated.

— In the three consumer profiles considered, food consumption is still the main driver of impact in many impact categories, despite the diet applied in different consumer profiles. In case of family with one children, also mobility has high contribution, due to two cars used in the family. In case of single male and single female, housing is second contributor in addition to food.

— In order to analyse how far the variability of the extent of consumption across different Member States affects the environmental impacts of consumption per person, an alternative calculation approach has been implemented (Household_I/O Footprint as in section 4, calculated using EXIOBASE 3 for year 2011[14]). It can be observed that for some impact categories (acidification, terrestrial eutrophication, marine eutrophication, freshwater eutrophication, climate change and fossil resource use), the larger the households' consumption, the higher the impacts induced. On the contrary, there is minor or no correlation between the volume of consumption per inhabitant and the impacts per inhabitant with respect to human toxicity cancer and non-cancer, freshwater ecotoxicity, photochemical ozone formation, and minerals and metals resource use. Beyond the total volume of household consumption, several parameters may explain the different impacts per inhabitant from one EU country to the other: the consumption profile, emissions intensity of both domestic economic activities and final consumption (e.g. a strong correlation is observed between direct household emissions of NMVOCs and impact on photochemical ozone formation), emissions intensity of imports, etc.

The **lifestyle of EU citizens is a key driver of the Consumer Footprint in the EU**. The baseline scenario of the indicator is calculated taking into consideration a reference year (year 2010) and the average lifestyle of EU citizens. The Consumer Footprint per person is calculated as the apparent consumption in the EU divided by the EU population in the reference year. It is important to highlight that this represents an average of all the possible consumer profiles that can exist in the EU and it is just a snapshot of the specific year to which the assessment is referred. Taking into consideration the variability of the extent of consumption across different years, Member States or consumer profiles, could significantly influence the results.

This section of the report explores some of the variables that can influence the results:

— Section 5.1 discusses the modelling aspects for capturing consumer behaviour in LCA-based models, and in particular in the Consumer Footprint BoPs;

— Section 5.2 presents the results of the Consumer Footprint per person, illustrating some examples of consumer profiles compared to the average one;

[14] Year 2011 is expected to be the most up-to-date and reliable year among the hybrid EXIOBASE data series for any analysis at a disaggregated level.

— Section 5.3 illustrates the features of the Consumer Footprint calculator, a tool to calculate the Consumer Footprint of different consumers profiles, based on the LCI models of the representative products included in the BoPs;

— Finally, section 5.4 discusses the influence of the differences in household consumption profiles, from one EU Member State to another, on the environmental impacts of household consumption per person. This is done using the results of the environmental impacts of household consumption, calculated with a top-down approach with the implementation of EXIOBASE 3 (this approach is called Household_I/O Footprint in this report).

5.1 Modelling consumer behaviour

The Consumer Footprint and the Consumption Footprint indicators adopt a consumption-based approach to assess the impacts of household consumption in the EU. From this perspective, not only the environmentally improved products and production processes but also less environmentally impacting consumption behaviours come into play in reducing the overall environmental impact of goods and services used by European citizens. Therefore, it is important that the methodology used to assess the impact of household consumption is able to model consumer behaviour and the effect of consumer behaviours' drivers.

The research carried out in the field of consumer's choice and behaviour within the framework of this project has shown that there is a huge potential related to the use of life cycle-based indicators for supporting policies in different stages of policy development (Nita et al., 2017). The peculiarity of the set of proposed indicators is the clear focus towards consumption-oriented assessment, highlighting the relative importance and contribution of consumption to the overall assessment of the impacts. Wherever possible, they can be supplemented by incorporating the findings from other fields of consumption and consumption-behaviour research. For instance, household expenditure by consumption category can be used as proxy for existing consumption patterns and lifestyle drivers. Furthermore, understanding consumption entails developing a comprehensive framework covering structural and contextual aspects, individual factors (e.g. values, believes, habits, and moral norms) and "structural constraints" (e.g. Phipps et al., 2013). Consumer behaviour drivers can be found in many studies. According to Scott (2009), there are three main competing, but independent, drivers: **psychological factors** (e.g. values, motivations, habits), **social factors** (e.g. norms and existing social practices), and **external factors** (e.g. economic, infrastructure). Stern (2000) and Sun & Wu (2006) complemented this set of drivers, including also cognitive drivers, such as knowledge and skills.

Bottom-up LCA-based indicators, such as the Consumer Footprint, allow for better incorporating user behaviour aspects, especially in the product use phase, compared to the top-down methods. There are several reasons why identifying consumer behaviour's determinants and capturing their patterns are important for modelling the product use phase in LCA studies and for developing scenarios on consumption-related environmental impact:

— at macro level: the analysis of determinants is useful for understanding how final demand shapes the magnitude and structure of supply;

— at both macro and meso level: determinants play an important role in the actual validation of environmental gains of eco-innovations in the use phase (also considering the rebound effect); additionally, they help to estimate more realistic BoP composition (e.g. based on proxy such as household spending patterns) or consumption dynamics;

— at meso level: emerging consumption behaviour patterns bring about changes in BoP product composition;

— at micro level (use phase in product LCA): Consumer behaviour patterns in the use phase greatly influence the overall life cycle environmental performance of some products (e.g. dwellings, appliances, cars, etc.). Therefore, identifying determinants of behaviour is useful for refining average use-phase assumptions and parameters and for defining use phase scenarios, based on users' actual consumption patterns.

An overview on the potential contribution of behavioural science to LCA is presented in a dedicated report (Nita et al., 2017). A preliminary methodological framework for coupling consumer behaviour and LCA has been depicted by Polizzi di Sorrentino et al. (2016), focusing on how to capture the following elements:

— variability in selecting a product;

— variability in how the product is used, including its fate in the end-of-life stage;

— variability in the ownership of the product (e.g. a shift from purchase to use of products).

Many drivers could influence the range of variability and are presented in literature, e.g.:

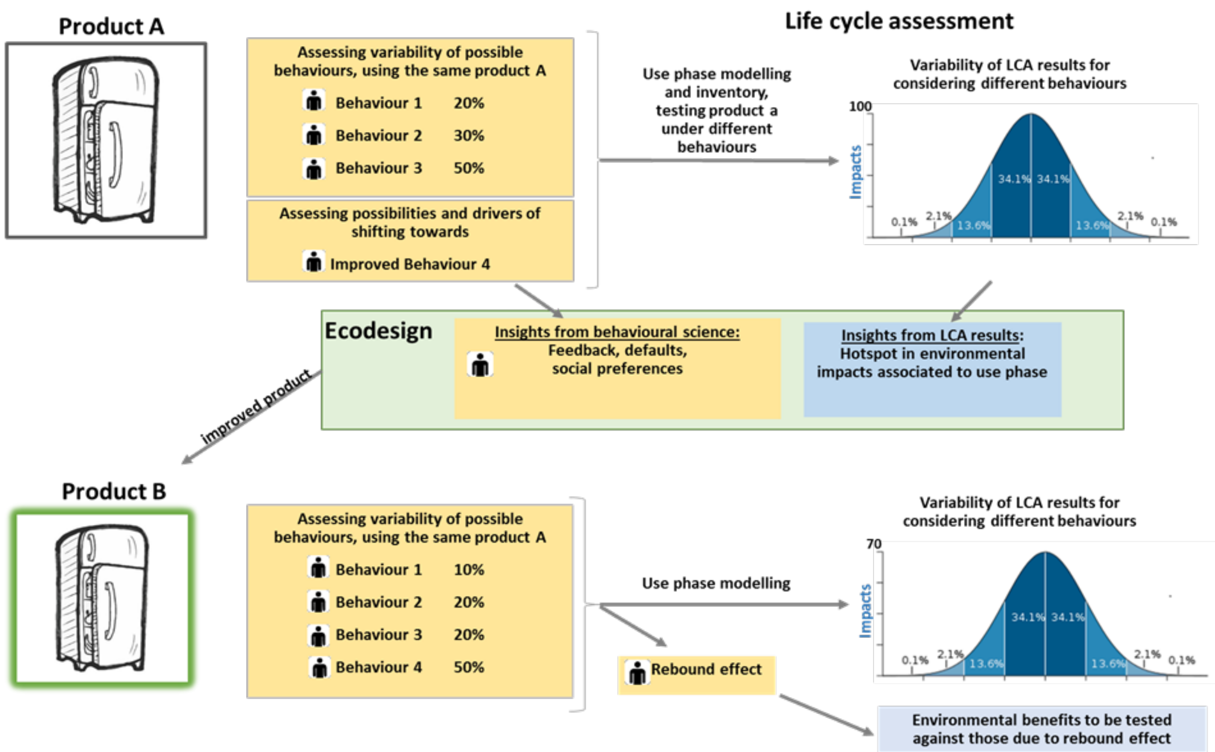
— Different lifestyles can influence variability in consumption (e.g. rural/urban lifestyle, Heinonen and Junnila, 2011) or emission profiles (e.g. CO_2 emissions Bin and Dowlatabadi 2005);

— Income (Girod and De Haan, 2010);

— Specific behaviours, e.g. driving behaviour (Girod et al., 2013), eating "green" (Tobler et al., 2011).

However, the available literature is often relatively limited to a specific context/case study/survey. Currently, there are few studies on larger scale, usually focusing on market penetration (e.g. a worldwide study on car-sharing based on expert surveying, see Shaheen and Cohen, 2008). Moreover, consumer-related and business-related aspects are intertwined, as the evolution of pro-environmental behaviour is also influenced by evolution of business models and vice versa (new business models try to answer new consumer trends).

Figure 60. Conceptual scheme of the mutual interaction between behavioural science, Life Cycle Assessment and eco-design.



Source: Polizzi di Sorrentino et al., 2016.

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Figure 60 illustrates the basic methodological principles of the integration of consumer behaviour within LCA and eco-design. The yellow boxes refer to **the contribution of behavioural science to use phase modelling in LCA and improvement definition in eco-design**. Behavioural science may help identifying more realistic user scenarios and sets of behaviours (behaviour 1, 2, 3) and their possible share among a population, as well as exploring drivers of new or improved behaviours (behaviour 4). Behavioural science may also inform eco-design on specific drivers for behaviour change (e.g. setting the environmentally preferred options as default option in a product). Moreover, behavioural science plays a crucial role in order to properly model direct and indirect rebound effects[15], such as different responses to a marginal increase in income.

In order to overcome the current knowledge gaps and limitations, the various-scale methods for capturing consumption patterns reviewed or developed in the current project can serve as a basis for further research. The increasing levels of environmental pressures induced by European consumption vary significantly across and within countries by consumption category, whose contextual features and consumption pattern's determinants need to be further investigated. For example, since the identification of individual consumer behaviours is context-based and thus does not apply to the "average European citizen" at EU scale, a thorough analysis of consumption patterns at differing scales, including country level, is needed. Section 5.2 illustrates how different consumer profiles can be modelled in the context of the Consumer Footprint, taking into account geographical variability, economic condition, personal attitudes, etc. In addition, section 5.4 presents the results of a preliminary analysis on the differences in footprint per citizen between Member States, using a top-down approach.

5.2 The Consumer Footprint per citizen: exploring different consumers profiles

The lifestyle of EU citizens is a key driver of the Consumer Footprint in the EU. The indicator is calculated for 2010 (baseline scenario, reference year) and for 2015, considering the average lifestyle of European citizens. This, however, represents only an average of all the possible consumer profiles that can exist in the EU and it is also a snapshot of the specific year to which the assessment is referred. Hence, the average EU Consumer Footprint could

[15] According to Font-Vivanco et al. (2014), the rebound effect is "the change in overall consumption and production due to the behavioural or other systemic response to changes in economic variables (income, price and financial gains or costs of product and material substitution) induced by a change in the technical efficiency of providing an energy service" (p.1934).

significantly differ from Consumer Footprint for different years, across Member States, and for different consumption patterns.

Different statistics and data sources can be used to explore household characteristics and possible consumer behaviour. Household characteristics can be obtained from Eurostat database, or other sources, as presented in Table 22 and may be used as basis to build consumer profiles. Food consumption patterns in different countries can be found from FAOSTAT Food Balance Sheets. Food consumption surveys have been done also by EFSA (2018), which shows that 92.8% of EU population consumes meat-based food. In addition, Eurobarometer surveys (2017) give insight of public opinion in the EU in different areas, e.g. attitudes towards environment, food, food waste prevention.

Other relevant insights can be obtained by dedicated studies on specific topics. A recent study commissioned by the EC (2018a) investigated European Consumers' engagement in the circular economy, through literature review, interviews with stakeholders (e.g. business and consumer associations, NGOs, public authorities and academia), and consumer focus groups, coupled with an online consumer survey and a behavioural experiment. Results showed that consumers were generally willing to engage in circular economy practices. Survey respondents reported keeping things they own for a long time (93%), recycling unwanted possessions (78%), and repairing possessions if they break (64%). Most interestingly, the study uncovered a high level of consistency between self-reported pro-circular economy attitudes and actual behaviour in the monetarily incentivised behavioural experiment. Different methods showed that interest in circular economy practices was generally higher for large and expensive products, and lower for fashion items.

Table 22. Statistics on household characteristics and distribution of classes in EU-27 and EU-28.

Statistic	Sub-classes	EU-27 (2010)	EU-28 (2015)	Data available per MS
Age[16]	0-14 years	15.7%	15.6%	x
	15-19 years	5.8%	5.3%	
	20-39 years	27.0%	25.7%	
	40-59 years	28.3%	28.4%	
	60-79 years	18.6%	19.7%	
	80 years and more	4.7%	5.3%	
Gender	Male	48.8%	48.8%	x
	Female	51.2%	51.2%	
Household type	One adult	29.7%	N.A.	x
	One adult with dependent children	4.4%		
	Two adults	28.5%		
	Two adults with dependent children	23.5%		
	Three or more adults	8.7%		
	Three or more adults with dependent children	5.2%		
Socio-economic category[17]	Manual workers in industry and services	20.3%	N.A.	x
	Non-manual workers in industry and services	28.5%		
	Employed persons except employees	9.5%		
	Unemployed persons	5.1%		
	Retired persons	29.0%		
	Other inactive persons	4.1%		
	Unknown	3.1%		
Climatic area	EU population living in cold climate[18]	4.4%	4.2%	Data by country, to be aggregated in climatic areas
	EU population living in moderate climate	71.3%	69.2%	
	EU population living in warm climate	26.2%	26.5%	

[16] Other age groups available
[17] Households by socio-economic category of the reference person
[18] JRC elaboration

Statistic	Sub-classes	EU-27 (2010)	EU-28 (2015)	Data available per MS
Geographical context	Cities	51.3%	N.A.	x
	Towns and suburbs	25.8%		
	Rural areas	23.0%		
Building type	Single-family house		49.8%	x
	Multi-family house		50.2%	
Size of the city	Population living in small size urban area (50,000 - 200,000)	N.A.	15.8% of population	Only 21 countries included (year 2014)
	Population living in medium size urban area (200,000 – 500,000)	N.A.	24.5%	
	Population living in metropolitan area (500,000 – 1,500,000)	N.A.	24.4%	
	Population living in large metropolitan area (> 1.5 million)	N.A.	12.2%	
Diet	Mediterranean diet	N.A.	N.A.	
	Semi-vegetarian	N.A.	N.A.	
	Vegetarian	N.A.	N.A.	
	Vegan	N.A.	N.A.	
Mobility	Private car	Available in Eurostat as total number of kms travelled in Europe, not distinguished by consumers' habits. Should be investigated more specifically.		
	Public transport			
	Car-pooling			
	Car-sharing			
	Different mixes of the previous options, depending on mobility need of the day			
Shopping	Fashion-oriented or not	N.A.	N.A.	
	Online shopping or not	N.A.	N.A.	
Pro-environmental behaviour	Waste separation		65%[19]	
	Buying local products		43%	
	Cutting down water consumption		27%	
	Using more environmentally-friendly ways of travelling		24%	

5.2.1 Comparing the Consumer Footprint of different consumer profiles

The following section illustrates how the parametric structure of the Consumer Footprint allows for comparing different consumer profiles. This is done with an illustrative example consisting of three consumer profiles (a single man, a single woman and a family), compared with the average EU citizen modelled in the baseline scenario of the Consumer Footprint indicator (year 2010). Table 23 presents the summary of different profiles.

Profile 1. Single male - Description of assumptions:

Johan, 25 years, lives in his flat, which is 15 km outside of Gothenburg, Sweden. He drives a gasoline car to his work and does his shopping on the way back home. He considers himself as a semi-vegetarian. Usually he cooks vegetarian dishes at home and chooses non-vegetarian options while eating outside. Occasionally, he just grabs a meat-based pre-prepared dish from the canteen, especially at work. Apples and oranges are among his favourite fruits. He does his dishes manually. The washing and drying machines are in the basement and he shares the machines with six other tenants from the same building. He usually buys his clothes from the local fashion houses. He prioritizes quality over quantity when it comes to shopping. He usually goes to the gym after work, and climbing is one of his favourite sports. Last year he bought a good pair of climbing shoes to combine with his pair of sport and leisure shoes. After the gym, he likes to watch a TV series. He does his laundry once a week. One of his favourite weekend activities is to visit friends in nearby places. Usually he leaves his car at home and takes the train for that. During the vacation,

[19] Share of EU population taking this action (source: Eurobarometer, 2017)

he takes flights to see distant places as well. Sometimes, he is just fine with spending time by himself and reading books.

Profile 2. Single woman - Description of assumptions:

Pati, 23 years, lives at a shared flat in Graz (Austria) with two of her friends. She takes the public bus and occasionally rides her bike to the university since she lives only 2 km away from the university. She went vegetarian last year removing meat from the diet. She takes a train to see her parents and to nearby cities. Occasionally, she also takes flights to visit friends in other European countries. In the shared flat, they have a dishwasher, washing machine and a dryer for themselves. Sometimes they cook together and invite friends over. Her favourite sports are skiing, hiking, and Capoeira.

Profile 3. Family with one kid - Description of assumptions:

Third profile is a whole family consisting of three members; Maria 32 years, Evan 35 years, and their 7-year old children Ana. They have a nice garden in front of their detached house in a small town in Italy. Maria takes Ana to school on her way to work since Evan works in Milan. Maria drives a Diesel car whereas Evan drives a LPG car. They like to share the leisure time with the kid doing different activities. Going to museums is one of their favourites. They maintain the Mediterranean diet as a family heritage. They have their own dishwasher and washing machine. Thanks to the climate in Italy that they do not need a dryer. However, they do need air-conditioning. In fact, they have two single-split air-conditioners for their 2-floor detached house.

Table 23. Description of compared consumer profiles.

Consumption pattern aspects	Family with one children	Single male	Single female
Climate zone	Warm	Cold	Moderate
Housing	Single-family house, <1945	Multi-family house, 1945-69 Living alone	Multi-family house, 1970-89 Shared with 2 of her friends
Appliances	Dishwasher, washing machine and air-conditioning in the house	Washing and drying machines shared with other people in the building	Dishwasher, washing machine and dryer in the flat
Diet	Mediterranean	Semi-vegetarian	Vegetarian
Transport habits	Diesel and LPG cars, occasional flights inside of Europe	Gasoline car for driving work (15 km), also use of train, occasional flights inside and outside of Europe	Public bus or bike to university (2 km), also use of train, occasional flights inside of Europe

The **single female has the lowest environmental impact of the selected profiles in all impact categories** (Table 24). In case of freshwater ecotoxicity, the single male has as low impact as the single female. The family has the highest impact in all impact categories, which was expected, because the family entails impacts of two adults and one children. When the impacts are calculated per person (dividing the total impact of the family by 2.5, to take into account that the children may have lower contribution than an adult), the impact is closer to the one calculated for the average citizen. Impacts of consumption of the single man profile are quite close to those of an average EU citizen, some impacts are slightly higher and some slightly lower.

Food is the most contributing area of consumption in many impact categories, i.e. ozone depletion potential, terrestrial and marine eutrophication, and land use, despite the diet (Figure 61). The average citizen has higher contribution due to food consumption in all impact categories, except mineral and metal resource use, compared to diets applied to the different consumer profiles.

- For climate impact, human toxicity cancer effect, ionizing radiation, photochemical ozone formation and fossil resource use, the most contributing area of consumption is either mobility (family) or housing (single male and female).

- For human toxicity non-cancer effects and acidification, the most contributing basket is different in all profiles, for family it is mobility, for single male housing and single female food.
- For particulate matter formation, the most contributing area of consumption is either housing (family and single male) or food (single female).
- For freshwater eutrophication, the most contributing area of consumption is either food (family and single female) or housing (single male).
- For water use, the most contributing area of consumption is either food (family) or housing (single male and single female).
- For mineral and metal resource use, the most contributing areas of consumption are either mobility (family) or household appliances (single male and single woman).

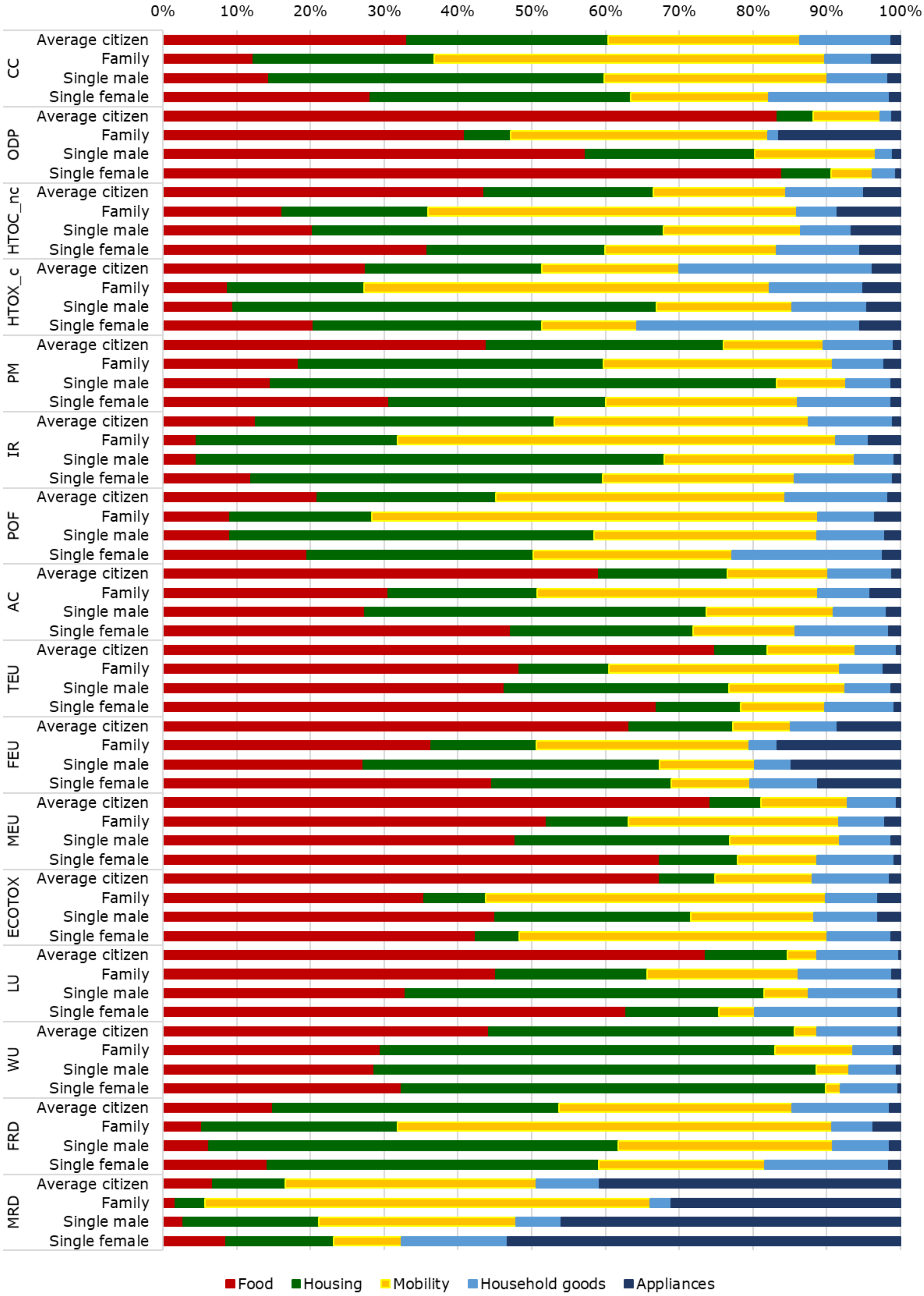
Table 24. Environmental impact of total consumption of an average EU citizen and different consumer profiles. A colour code is applied, from red (highest value) to green (lowest value).

Impact category	Unit	Average citizen	Family	Family (impact per person)*	Single male	Single female
CC	kg CO_2 eq	9.55E+03	2.48E+04	9.91E+03	8.97E+03	4.05E+03
ODP	kg CFC-11 eq	6.41E-03	1.10E-02	4.40E-03	3.51E-03	2.27E-03
HTOX_nc	CTUh	5.00E-04	1.42E-03	5.70E-04	5.35E-04	2.89E-04
HTOX_c	CTUh	1.42E-04	4.28E-04	1.71E-04	1.65E-04	7.11E-05
PM	Disease incidence	7.32E-04	1.61E-03	6.42E-04	8.10E-04	3.38E-04
IR	kBq U^{235} eq	4.85E+02	1.82E+03	7.30E+02	7.90E+02	2.89E+02
POF	kg NMVOC eq	2.60E+01	7.23E+01	2.89E+01	2.76E+01	1.08E+01
AC	molc H^+ eq	7.42E+01	1.37E+02	5.47E+01	6.07E+01	3.10E+01
TEU	molc N eq	2.51E+02	3.65E+02	1.46E+02	1.51E+02	9.11E+01
FEU	kg P eq	9.28E-01	2.28E+00	9.12E-01	8.29E-01	4.13E-01
MEU	kg N eq	2.34E+01	3.62E+01	1.45E+01	1.44E+01	8.82E+00
ECOTOX	CTUe	1.49E+04	3.11E+04	1.24E+04	1.03E+04	1.03E+04
LU	Pt	4.94E+05	7.65E+05	3.06E+05	3.99E+05	1.90E+05
WU	m^3 water eq	1.40E+04	4.29E+04	1.71E+04	1.43E+04	1.20E+04
FRU	MJ	1.19E+05	4.17E+05	1.67E+05	1.49E+05	6.05E+04
MRU	kg Sb eq	5.01E-02	2.73E-01	1.09E-01	6.77E-02	2.12E-02

*To calculate results per person, the impact of the family is divided by 2.5, taking into account that the kid may have a lower contribution to some consumption drivers (e.g. eating less food than an adult). Note: Acronyms mentioned in Figure 12 are used to identify all the impact categories.

In the case of **family, the highest contribution to most of the impact categories is either mobility or food**, except for particulate matter, where the highest contribution is from housing. In case of single female and single male, the highest contribution in most of the impact categories is either food or housing, apart from mineral and metal resource use, where the highest contribution is from appliances (raw materials used in appliances). **Single male has higher share of impact due to housing** in all impact categories compared to other consumer profiles. This is due to the fact that he lives in a cold climate zone needing more heating, and he is not sharing his flat with other persons. For the family profile, the mobility has clearly a higher contribution compared to other profiles. This is because the family has two cars, and the kms driven are much higher compared to the single male, while the single woman is not using a private car at all. The family also uses more air transport as they are three persons compared to the other two profiles, representing single persons (Figure 61).

Figure 61. Shares of individual baskets of products in the total impact generated by the EU average citizen and consumption of different consumption profiles.



5.3 The Consumer Footprint calculator

Each Basket of Products used to model the Consumer Footprint in the EU is built using life cycle inventory models of a number of products, representing most of the products that are purchased and used by an average EU citizen. The amount of products included in the inventory model of the Consumer Footprint (as aggregation of the five BoPs) is based on statistics of apparent consumption in the EU. This means that when the Consumer Footprint is calculated per person, it is assumed that the average person uses all the products across the baskets. Although this does not happen in reality, it is a necessary modelling assumption for calculating the footprint of an average EU consumer. A person cannot live in the 24 different types of dwellings at the same time, or is not using all means of transports.

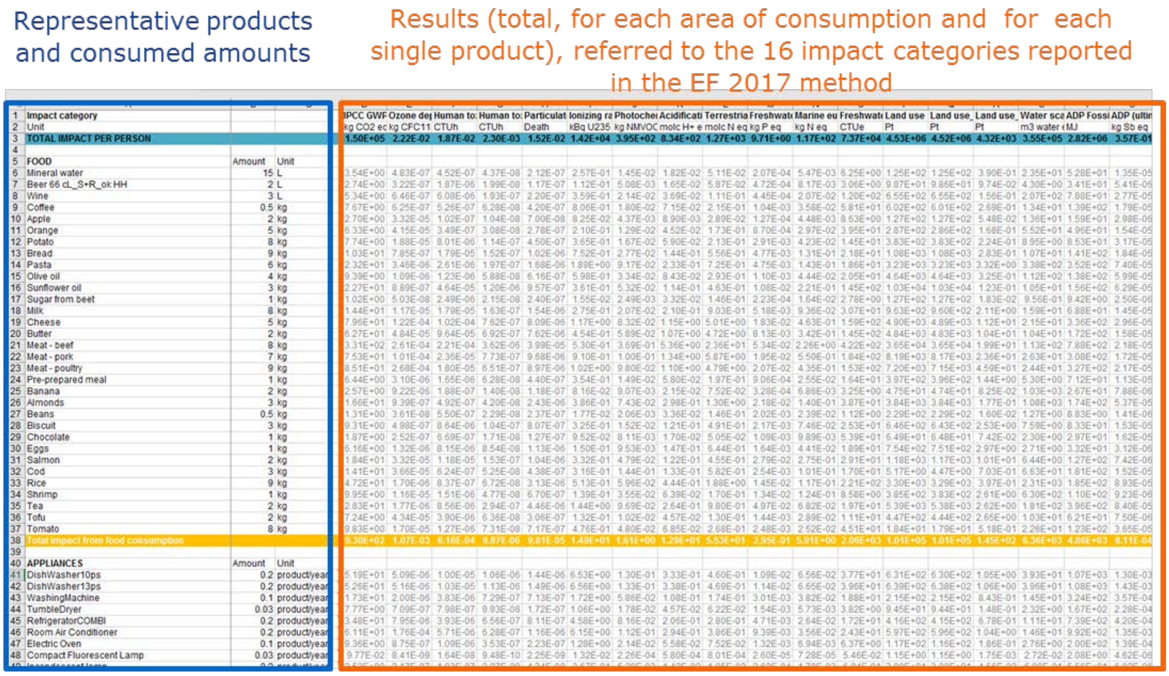
Therefore, when the model is used to calculate the footprint of a given consumer (instead of the Consumer Footprint of an average EU citizen) it needs to be adapted to the consumer profile that shall be assessed. Since a number of data have been collected for the analysis of baseline scenarios presented in section 4, it is now possible **to calculate the footprint for a given consumer using already modelled representative products**. The BoP Housing covers the total building stock. Hence, it is possible to model for housing across the climatic regions in the EU. Similarly, BoP Mobility has 34 types of vehicles across the different transport modes – road, rail, and air. The baskets Food, Household goods and Appliances also cover a good number of products, so that consumer behaviour can be modelled considering persons with different age, diet, work, income, taste, habits, etc. (Figure 62).

Figure 62. Illustration of the products that can be used to model consumer profiles in the Consumer Footprint calculator.

The Consumer Footprint calculator[20] is a tool based on the inventory models developed for the calculation of the Consumer Footprint in the EU, which allows users calculating the Consumer Footprint of different consumer profiles. The user can set a specific diet, define a housing type and location, choose the products that the consumer buys, the way in which she or he moves, etc. (Figure 63).

[20] The calculator will be made available at https://eplca.jrc.ec.europa.eu/sustainableConsumption.html.

Figure 63. The Consumer Footprint calculator: Excel sheet.



5.4 Differences in footprint per citizen between EU Member States, resulting from the application of a Top-down approach

The previous sections of this chapter have discussed the Consumer Footprint per person, considering both the average EU consumer profiles and how far alternative consumer profiles may show different environmental impacts. This section aims at capturing how far the different consumption across different Member States affects its associated environmental impacts. In the following, the Household_I/O Footprint, as calculated based on EXIOBASE 3 as in section 4, is presented and analysed per person for each EU Member State in year 2011 (Figure 64).

Based on this Household_I/O Footprint model, the total volume of expenditures (considering all inhabitants) appears the key explanatory variable to the impacts induced by total household consumption in each country of the EU. The higher the total household consumption is in a country, the higher the environmental impacts this consumption induces. This is particularly true regarding climate change, eutrophication (terrestrial and marine) and acidification, for which the correlation coefficient (R^2) between total volume of expenditures and environmental impact is in the range [0.95-0.96]. However, regarding some other impact categories, there is a slight discrepancy between the level of expenditures and the impact of household consumption (e.g. regarding water use, R^2 = 0.72).

By definition, the number of inhabitants of a country and the volume of household consumption per inhabitant result in the total volume of household expenditures of a country. The environmental impacts of household consumption in EU countries can be analysed not only considering total expenditures but also considering expenditures per inhabitant, which differ from one EU country to the other. In particular, one may notice that in eight countries (Austria, Germany, Denmark, Finland, France, Great Britain, Luxembourg and Sweden), household consumption per inhabitant (in euros/hab./year) is 20% higher than the EU average (Figure 64, considering year 2011). On the contrary, the volume of household consumption per inhabitant is half or less than half of the EU average in eight countries (Bulgaria, Estonia, Croatia, Hungary, Latvia, Poland, Romania and Slovakia).

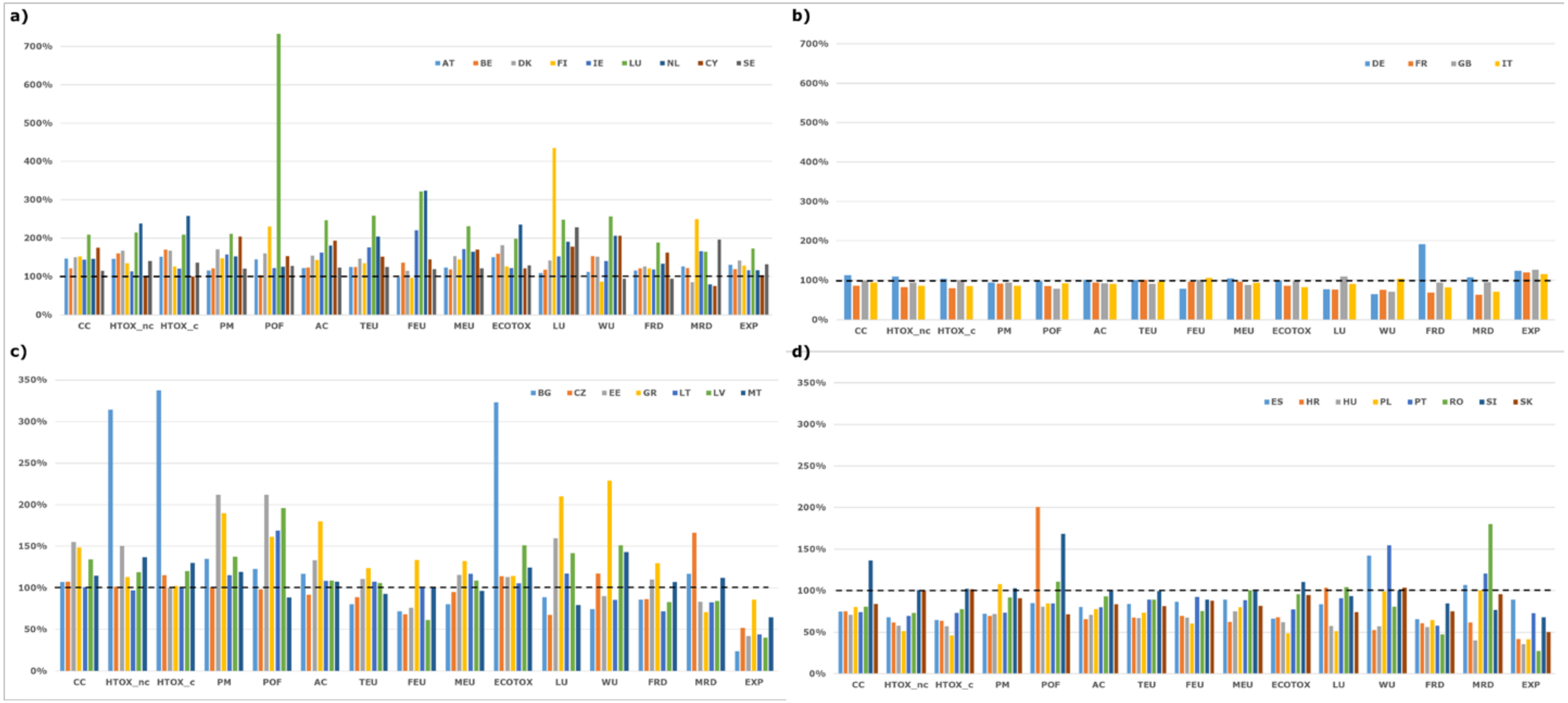
If considering only the countries for which the volume of household consumption per inhabitant is higher than the EU average, it can be observed that for several impact categories (for example climate change, land use, acidification and eutrophication, respectively terrestrial and marine), the impacts per inhabitant are also primarily higher than the EU average (Figure 64). Similarly, considering only countries with household consumption volume lower than the EU average, then in several cases of environmental impact categories (in particular eutrophication terrestrial, eutrophication freshwater and resource use, fossils) it can be observed that, for most countries, environmental impacts per inhabitant are below the EU average. More generally, the volume of consumption per inhabitant is observed to be correlated with the environmental impacts of consumption per inhabitant, with respect to some impact categories. In other words, it can be observed that for some impact categories, the larger people consume, the higher the impacts their consumption induces. However, this correlation is limited compared to the correlation between total volume of household consumption (considering all inhabitants, as presented in the first paragraph of this section) and total impacts. In particular:

- R^2 ranges between 0.28 and 0.46 regarding acidification, eutrophication (terrestrial, marine and freshwater), climate change and resource use, fossils (compared to $R^2 > 0.72$ for all impact categories regarding the correlation between total volume of consumption and total impact);
- there is minor or no correlation regarding human toxicity (cancer and non-cancer), freshwater ecotoxicity, particulate matter and resource use, minerals and metals (R^2 in the range [0.03; 0.09]).

Beyond the total volume of household consumption, several parameters may explain the different impacts per inhabitant from one EU country to the other: the consumption profile, emissions intensity of both domestic economic activities and final consumption, emissions intensity of imports, etc. In particular, the following observations can be made:

- a correlation between consumption of products of meat cattle per inhabitant and impacts on respectively freshwater eutrophication ($R^2 = 0.47$) and to a lower extent terrestrial eutrophication ($R^2 = 0.27$). In the context of the important share of products of meat cattle regarding the impacts on eutrophication (especially regarding freshwater eutrophication) induced by EU household consumption, this correlation is expected to highlight a causality;
- a correlation between household consumption of fossil fuels and impact on resource use, fossils ($R^2 = 0.41$). Once again, in the context of the important share of products of fossil fuels regarding the impact on fossil resource use at the level of EU, this correlation is expected to highlight a causality;
- a strong correlation between direct household emissions of non-methane volatile compounds (NMVOCs) (mainly from the combustion of fuels used for space heating and for transport) and impacts on photochemical ozone formation ($R^2 = 0.91$).

Figure 64. Household_I/O Footprint per inhabitant in the 28 countries of the European Union in 2011, considering impacts of average EU-inhabitant as the reference (100%).



a) EU countries with expenditures per inhabitant > EU average (100%) and impacts > 100% regarding 11 impact categories or more (out of 14); b) EU countries with expenditures per inhabitant > 100% and impacts < 100% regarding 4 impact categories or more; c) EU countries with expenditures per inhabitant < 100% and impacts > 100% regarding 7 impact categories or more; d) EU countries with expenditures per inhabitant < 100% and impacts < 100% regarding 8 impact categories or more. Calculations with EXIOBASE 3, "expenditures" (EXP) drawn from Eurostat (2018e).

6 Comparison between different Consumption Footprints and Consumer Footprint: the key converging messages from the assessment

This section compares the results obtained from the different approaches employed in this project: Consumption and Consumer, and Bottom-Up and Top-down. Section 6.1 compares the results for all the indicators, as well as contrast them with input-output results from EXIOBASE (Household_I/O Footprint, Final Consumption_I/O Footprint). Section 6.2 evaluates the differences at the flow contribution and impact category level, between the Consumer Footprint and the Consumption Footprint Top-down. Finally, Section 6.3 details the convergent messages of the different footprints regarding the environmental impacts of EU consumption.

6.1 Comparison of absolute results by impact categories

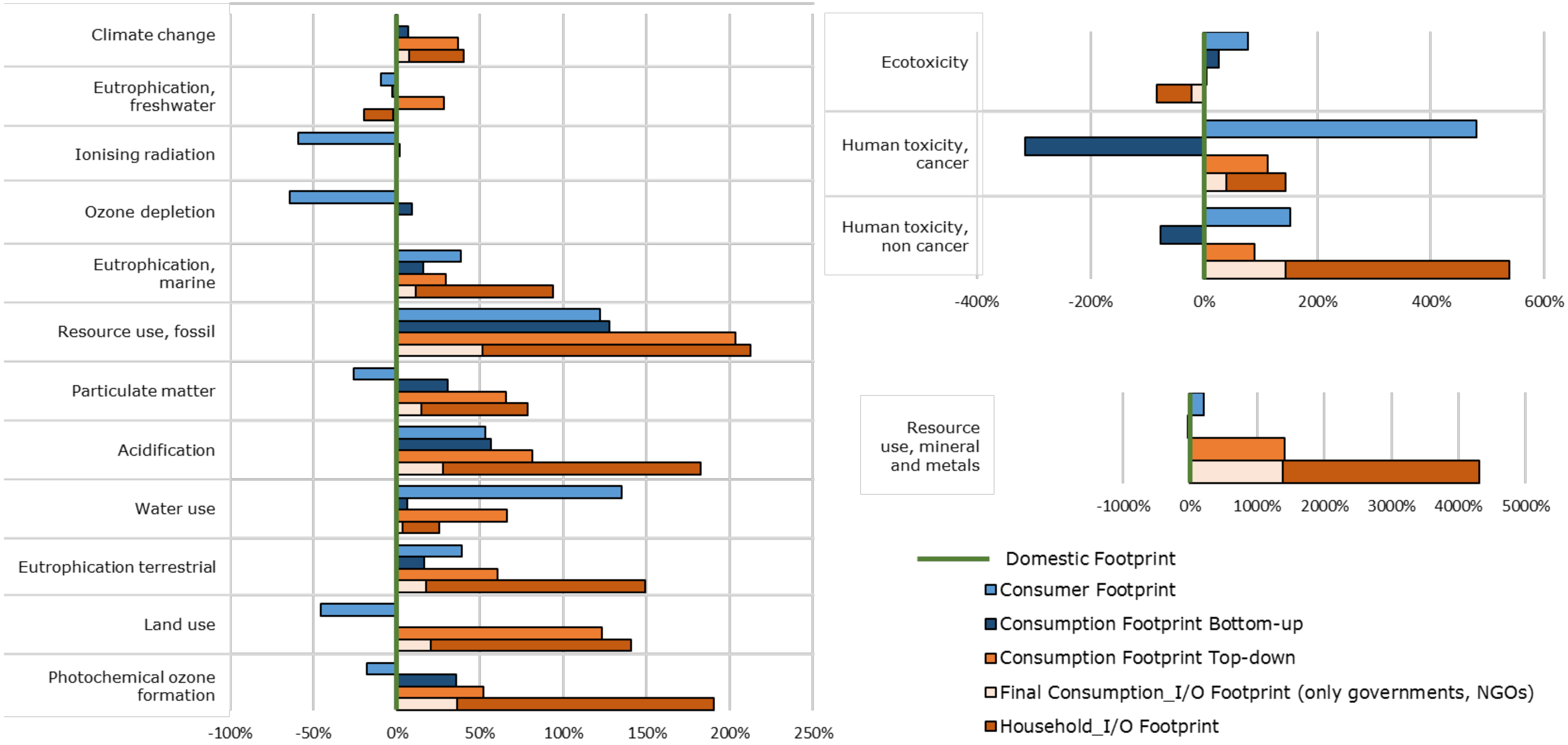
The values of impacts induced by EU, either represented through the Domestic Footprint, the Consumption Footprint (Top-down and Bottom-up), the Consumer Footprint, or the EU Final Consumption_I/O Footprint (with a split between household, and governments and NGOs), differ from one to another, with a range varying depending on the impact category considered (Figure 65). A summary of the overall results is presented in Table 25 (absolute results), Table 26 (per capita results), and Figure 66 (2005-2014 trends).

Differences in the results are due to three main elements, including the scope of the different indicators (i.e. all economic activities, household consumption), the modelling approach (i.e. top-down, bottom-up) and subsequently the elementary flows included in the life cycle inventories. The effects of these differences have been extensively discussed in section 3 regarding the Consumption Footprint Top-down, the Consumption Footprint Bottom-up, and the Final Consumption_I/O Footprint, and in section 4, as far as the Consumer Footprint and the Household_I/O Footprint are concerned. This section aims at depicting an overview of all results obtained in the study, highlighting converging messages and discrepancies, as well as making some considerations on their robustness. Besides the abovementioned indicators, impacts induced by the Final Consumption Expenditure, calculated on the basis of EXIOBASE 3 (therefore with a top-down approach), are included in the comparison.

On the one hand, considering climate change, freshwater, marine and terrestrial eutrophication, particulate matter, acidification, and water use, impacts range between +50 and -50% of the “average” impacts of EU consumption (represented as the average of Consumption Footprints Bottom-Up and Top-down, Final Consumption_I/O Footprint and Consumer Footprint). The values of impacts of the analysed indicators vary whether calculated from a bottom-up approach or a top-down approach, but to a rather limited extent compared to the other impact categories.

Regarding these seven impact categories, the Consumption Footprints Bottom-up and Top-down are larger than the Domestic Footprint in almost all cases, highlighting a converging message of import of impacts by EU. Moreover, impacts embodied in the Final Consumption_I/O Footprint, as calculated from a top-down approach, are larger than those calculated from the bottom-up approach (the Consumer Footprint), in line with the larger scope of final consumption (including household, government, and non-for profit institutions) compared to the Consumer Footprint (focused on household consumption only). Yet, this is not the case regarding water use and freshwater eutrophication, highlighting a lower robustness of results for these two impact categories (in particular water use). Overall, it is noteworthy that a relatively limited variability of results (that is, a limited range of impacts) is observed regarding these seven impact categories, in a context where a limited set of emissions and products are observed as key contributors in the previous chapters of this report. Said in other words, for some other impact categories a more complex picture is observed regarding the most contributing substances and products, while at the same time a larger variability of total impacts is observed.

Figure 65. Results for the Consumer Footprint, Consumption Footprint Bottom-up, Consumption Footprint Top-down, Final Consumption_I/O Footprint (only governments and NGOs), and Household_I/O Footprint presented for the 16 EF 2017 impacts categories, for the year 2010.



Note: Domestic is reported as 0 (green line) and all the other results are rescaled accordingly. For the indicators based on EXIOBASE (i.e. Consumption Footprint Top-down, Final Consumption_I/O Footprint, and Household_I/O Footprint), ionising radiation and ozone depletion are not reported due to the absence of elementary flows in EXIOBASE.

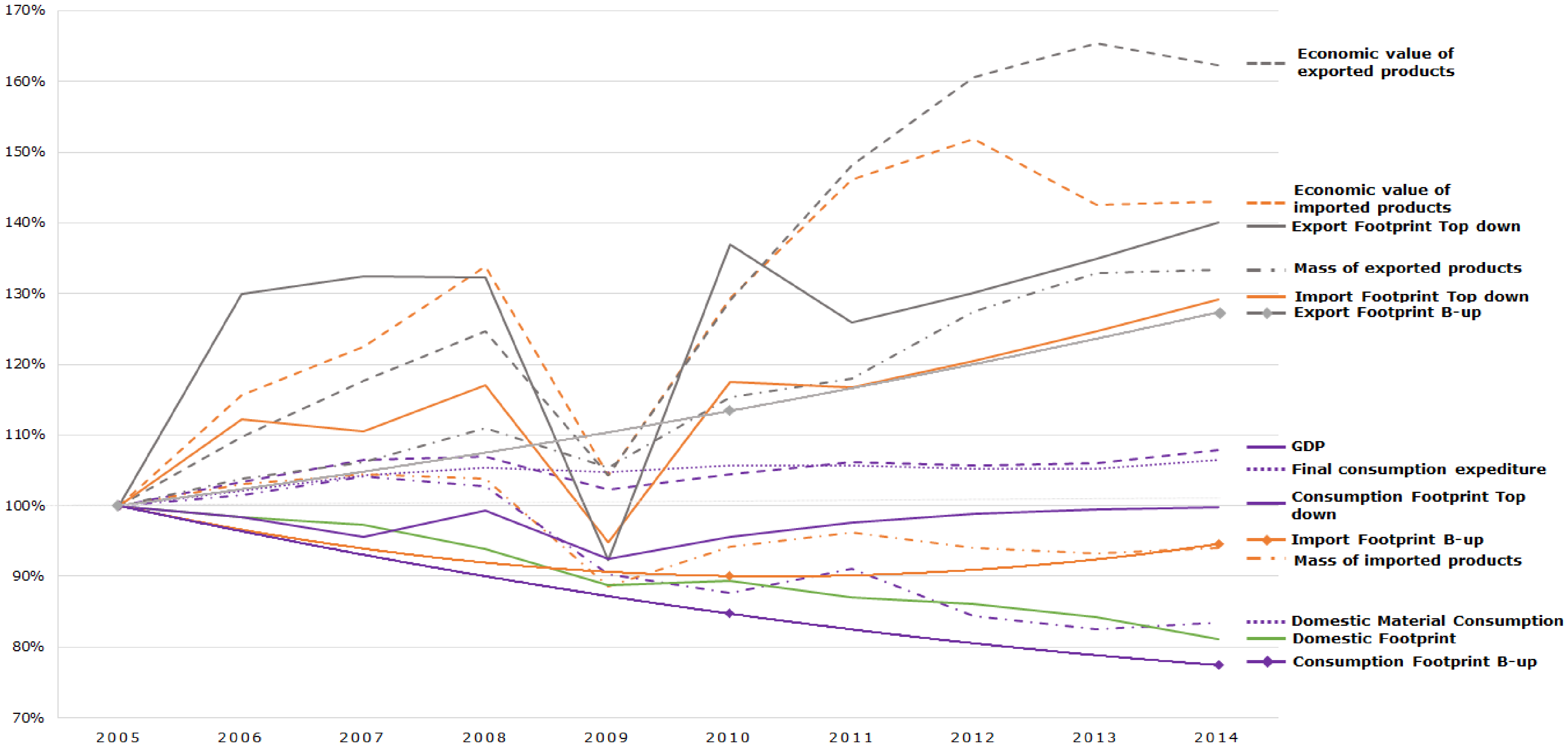
Table 25. Consumption and Consumer Footprint compared to other footprints - summary of the absolute results for 2010.

	Domestic Footprint	Import Top-down	Import Bottom-up	Export Top-down	Export Bottom-up	Consumption Footprint Top-down	Consumption Footprint Bottom-up	Consumer Footprint	Final Consumption _ I/O Footprint	Household _I/O Footprint
Human toxicity, cancer (CTUh)	1.2E+04	4.0E+04	3.0E+04	2.6E+04	6.8E+04	2.6E+04	-2.6E+04	7.1E+04	3.0E+04	2.2E+04
Human toxicity, non-cancer (CTUh)	1.0E+05	1.3E+06	2.1E+05	1.2E+06	2.9E+05	1.9E+05	2.4E+04	2.5E+05	6.4E+05	4.7E+05
Particulate matter (Disease incidence)	5.0E+05	6.2E+05	2.4E+05	3.0E+05	9.1E+04	8.2E+05	6.5E+05	3.7E+05	8.9E+05	7.2E+05
Photochemical ozone formation (kg NMVOC eq)	1.6E+10	2.0E+10	7.9E+09	1.1E+10	2.3E+09	2.4E+10	2.2E+10	1.3E+10	4.6E+10	3.8E+10
Ionizing radiation (kBq U^{235} eq)	6.0E+11	n.a.	4.8E+10	n.a.	3.7E+10	n.a.	6.1E+11	2.4E+11	n.a.	n.a.
Water use (m^3 world eq)	3.8E+12	3.4E+12	9.0E+11	9.2E+11	7.0E+11	6.4E+12	4.0E+12	7.1E+12	4.8E+12	4.2E+12
Ecotoxicity (CTUe)	4.2E+12	1.2E+12	3.1E+12	1.0E+12	2.0E+12	4.4E+12	5.3E+12	7.4E+12	7.3E+11	5.4E+11
Climate change (kg CO_2eq)	4.8E+12	3.7E+12	1.0E+12	1.9E+12	7.0E+11	6.6E+12	5.1E+12	4.8E+12	6.8E+12	5.5E+12
Resource use, fossil (MJ)	2.7E+13	8.5E+13	6.3E+13	3.0E+13	1.9E+13	8.2E+13	7.1E+13	6.0E+13	8.5E+13	6.4E+13
Ozone depletion potential (kg CFC-11 eq)	9.1E+06	n.a.	8.2E+05	n.a.	3.1E+04	n.a.	9.9E+06	3.2E+06	n.a.	n.a.
Eutrophication, marine (kg N eq)	8.6E+09	6.8E+09	2.4E+09	4.3E+09	1.0E+09	1.1E+10	1.0E+10	1.2E+10	1.7E+10	1.5E+10
Eutrophication, freshwater (kg P eq)	5.2E+08	2.1E+08	8.0E+07	6.1E+07	9.3E+07	6.7E+08	5.1E+08	4.7E+08	4.2E+08	3.8E+08
Land use (Pt)	4.6E+14	7.6E+14	3.2E+13	2.0E+14	3.3E+13	1.0E+15	4.6E+14	2.5E+14	1.1E+15	9.4E+14
Eutrophication, terrestrial (molc N eq)	9.2E+10	1.1E+11	2.2E+10	5.3E+10	7.1E+09	1.5E+11	1.1E+11	1.3E+11	2.3E+11	2.0E+11
Acidification (molc H^+ eq)	2.5E+10	3.9E+10	1.8E+10	1.9E+10	4.0E+09	4.4E+10	3.8E+10	3.7E+10	6.9E+10	5.9E+10
Resource use, mineral and metals (kg Sb eq)	8.2E+06	2.5E+08	3.8E+06	1.3E+08	6.5E+06	1.2E+08	5.5E+06	2.5E+07	3.6E+08	2.5E+08
Weighted score	**5.7**	**11.9**	**3.3**	**6.1**	**1.9**	**11.6**	**7.0**	**8.9**	**17.1**	**13.1**

Table 26. Consumption and Consumer Footprint compared to other footprints - summary of the results per capita for 2010.

	Domestic	**Import Top-down**	**Import Bottom-up**	**Export Top-down**	**Export Bottom-up**	**Consumption Footprint Top-down**	**Consumption Footprint Bottom-up**	**Consumer Footprint**	**Final Consumption I/O Footprint**	**Household I/O Footprint**
Human toxicity, cancer (CTUh)	2.4E-05	7.9E-05	5.9E-05	5.1E-05	1.4E-04	5.2E-05	-5.2E-05	1.4E-04	6.0E-05	4.3E-05
Human toxicity, non-cancer (CTUh)	2.0E-04	2.5E-03	4.2E-04	2.3E-03	5.7E-04	3.8E-04	4.8E-05	5.0E-04	1.3E-03	9.3E-04
Particulate matter (Disease incidence)	9.9E-04	1.2E-03	4.8E-04	5.9E-04	1.8E-04	1.6E-03	1.3E-03	7.3E-04	1.8E-03	1.4E-03
Photochemical ozone formation (kg NMVOC eq)	3.2E+01	3.9E+01	1.6E+01	2.2E+01	5.0E+00	4.8E+01	4.3E+01	2.6E+01	9.3E+01	7.5E+01
Ionizing radiation (kBq U^{235} eq)	12E+03	n.a.	9.5E+01	n.a.	7.4E+01	n.a.	1.2E+03	4.9E+02`	n.a.	n.a.
Water use (m^3 world eq)	7.6E+03	6.9E+03	1.8E+03	1.8E+03	1.4E+03	1.3E+04	8.0E+03	1.4E+04	9.6E+03	8.3E+03
Ecotoxicity (CTUe)	8.3E+03	2.4E+03	6.2E+03	2.0E+03	4.0E+03	8.7E+03	1.1E+04	1.5E+04	1.4E+03	1.1E+03
Climate change (kg CO_2eq)	9.6E+03	7.3E+03	2.0E+03	3.8E+03	1.4E+03	1.3E+04	1.0E+04	9.6E+03	1.3E+04	1.1E+04
Resource use, fossil (MJ)	5.4E+04	1.7E+05	1.3E+05	5.9E+04	3.8E+04	1.6E+05	1.4E+05	1.2E+05	1.7E+05	1.3E+05
Ozone depletion potential (kg CFC-11 eq)	1.8E-02	n.a.	1.6E-03	n.a.	6.1E-05	n.a.	2.0E-02	6.4E-03	n.a.	n.a.
Eutrophication, marine (kg N eq)	1.7E+01	1.4E+01	5.0E+00	9.0E+00	2.0E+00	2.2E+01	2.0E+01	2.4E+01	3.3E+01	2.9E+01
Eutrophication, freshwater (kg P eq)	1.0E+00	4.2E-01	1.6E-01	1.2E-01	1.8E-01	1.3E+00	1.0E+00	9.4E-01	8.4E-01	7.5E-01
Land use (Pt)	9.1E+05	1.5E+06	6.4E+04	4.0E+05	6.7E+04	2.0E+06	9.1E+05	4.9E+05	2.2E+06	1.9E+06
Eutrophication, terrestrial (molc N eq)	1.8E+02	2.2E+02	4.3E+01	1.1E+02	1.4E+01	2.9E+02	2.1E+02	2.5E+02	4.5E+02	4.0E+02
Acidification (molc H^+ eq)	4.9E+01	7.8E+01	3.5E+01	3.8E+01	8.0E+00	8.8E+01	7.6E+01	7.5E+01	1.4E+02	1.2E+02
Resource use, mineral and metals (kg Sb eq)	1.6E-02	4.9E-01	7.5E-03	2.6E-01	1.3E-02	2.5E-01	1.1E-02	5.0E-02	7.2E-01	4.9E-01
Weighted score (part per thousand millions)	**11.4**	**23.7**	**6.5**	**12.1**	**3.9**	**23.0**	**14.0**	**17.7**	**34.0**	**26.0**

Figure 66. Trend of Domestic, Consumption and Trade Footprints and economic and mass indicators (2005-2014).



Note: Results for 2005 are reported as 100%, and results for the other years are rescaled accordingly. Sources: Eurostat, JRC analysis. B-up = bottom-up.

On the other hand, the remaining set of impact categories shows a larger variability which can be partly explained by the different scopes of the indicators. In the case of fossil resource use, the relatively large interval of values is essentially driven by the relatively low value for the Domestic Footprint (corresponding to limited resource extraction in Europe). In the case of this indicator, the values respectively referring to the entire economy (Consumption Footprints Bottom-up and Top-down), and to household consumption (Consumer Footprint Bottom-up and Household_I/O Footprint), are relatively similar, underlining a good consistency of results.

Regarding other impact categories, the larger variability underlines a lower robustness of results. Firstly, ozone depletion and ionising radiation could not be quantified with the top-down based approach. Regarding these two impact categories, the results of this study can only be supported by indicators based on a bottom-up approach, and this consequently implies a larger uncertainty over the robustness of results. Moreover, regarding land use, a large discrepancy of values is observed between bottom-up-based results and top-down-based results. This discrepancy is in particular induced by the way land occupation is accounted for in LCI databases compared to Input-Output databases (different levels of details in the representation of land occupation, different occupation intensities). Finally, the interval of values is particularly large regarding photochemical ozone formation, ecotoxicity, mineral resource, use and human toxicity cancer and non-cancer (e.g. [-50%; 76%] in the case of photochemical ozone formation and [-96%; 180%] in the case of mineral resource use).

It can be observed that large values of impact on photochemical ozone formation are observed to be induced by household and final consumption (top-down approach), compared to those found with bottom-up approaches (in particular Consumer Footprint and Domestic Footprint):his is the result of relatively large NMVOC emission factors from households as compiled in EXIOBASE 3.

Moreover, the relatively large intervals of values observed for these five impact categories are accompanied by erroneous rankings in the calculated footprints, essentially due to differences in the coverage of elementary flows in LCI databases compared to Input-Output databases. In particular, impacts of Final Consumption_I/O Footprint should be superior to those of the Consumer Footprint, if the same set of elementary flows was considered in each approach, because the Consumer Footprint only encompasses household consumption expenditures, which is a share of the Final Consumption expenditures. Yet, this is not the case regarding human toxicity cancer and ecotoxicity, for which the Consumer Footprint (sum of BoPs) is larger than the Final Consumption (top-down based). This is the result of a much larger coverage of elementary flows in LCI databases compared to Input-Output databases, especially including metal emissions to water and soil, as well as pesticides, which are primarily disregarded in EXIOBASE 3. Similarly, in the case of human toxicity non-cancer (and to a lower extent regarding mineral resource use), the position of Consumption Footprint compared to the Domestic Footprint depends on the approach undertaken to calculate it (bottom-up or top-down-based, which encompasses different scopes and different underlying modelling assumptions). This highlights the uncertainty of the conclusions drawn from the impacts embodied in trade regarding these impact categories. Once again, the different coverage of elementary flows from LCI databases compared to Input-Output databases is a driver for these discrepancies.

A comparison between the process-based LCA Consumer Footprint and the input-output-based LCA Consumption Footprint top-down is provided in Castellani et al. (2019b).

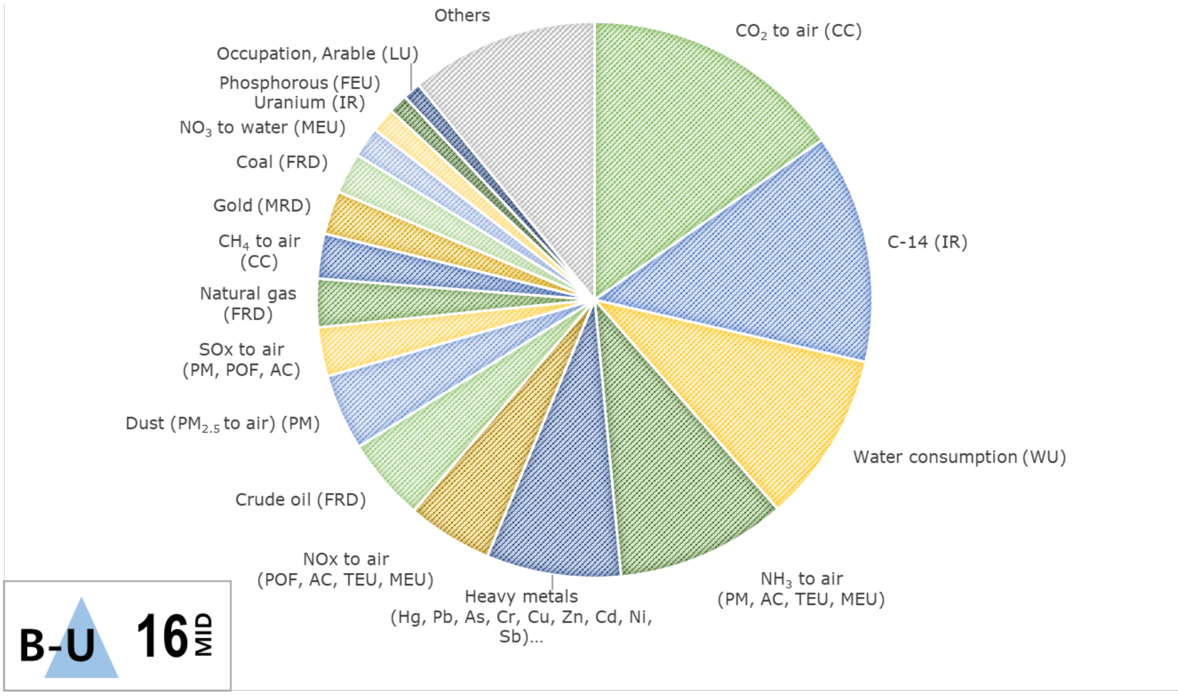
6.2 Comparison of emissions and impact categories driving the environmental impacts

In the previous sections, the contribution of the elementary flows to the Consumer Footprint and the Consumption Footprint for each impact category were evaluated. This section evaluates and compares the flow contribution to the weighted score for both the

Consumer Footprint and the Consumption Footprint Top-down for 2010, considering the set of weighting values of the Environmental Footprint (EF WF).

Figure 67 shows the contribution share to the Consumer Footprint weighted score of each elementary flow and the impact category to which it contributes. Five elementary flows are the main contributors to the weighted score, representing 56% of the impact (Figure 67). These are the emissions of CO_2 (with impact on climate change, and contributing to 15.2% of the total weighted footprint), C-14 (ionising radiation; 13.4%), ammonia (particulate matter, acidification, terrestrial and marine eutrophication; 9.9%) and heavy metals (Hg, Pb, As, Cr, Cu, Zn, Cd, Ni, Sb; human toxicity, ecotoxicity; 7.8%), and the depletion of water (water use; 10.0%). Contributing between 1 and 6%, various elementary flows have a relevant role in the different impact categories: the emissions of NO_x (photochemical ozone formation, acidification, terrestrial and marine eutrophication), $PM_{2.5}$ to air (particulate matter), SO_x (particulate matter, photochemical ozone formation, acidification), CH_4 (climate change), NO_3 (marine eutrophication) and P (freshwater eutrophication), the depletion of gold (mineral resource use), and the depletion of crude oil (fossil resource use), natural gas (fossil resource use), coal (fossil resource use), and uranium (ionising radiation), and the occupation of arable land (land use).

Figure 67. Consumer Footprint weighted score: contribution by elementary flows.

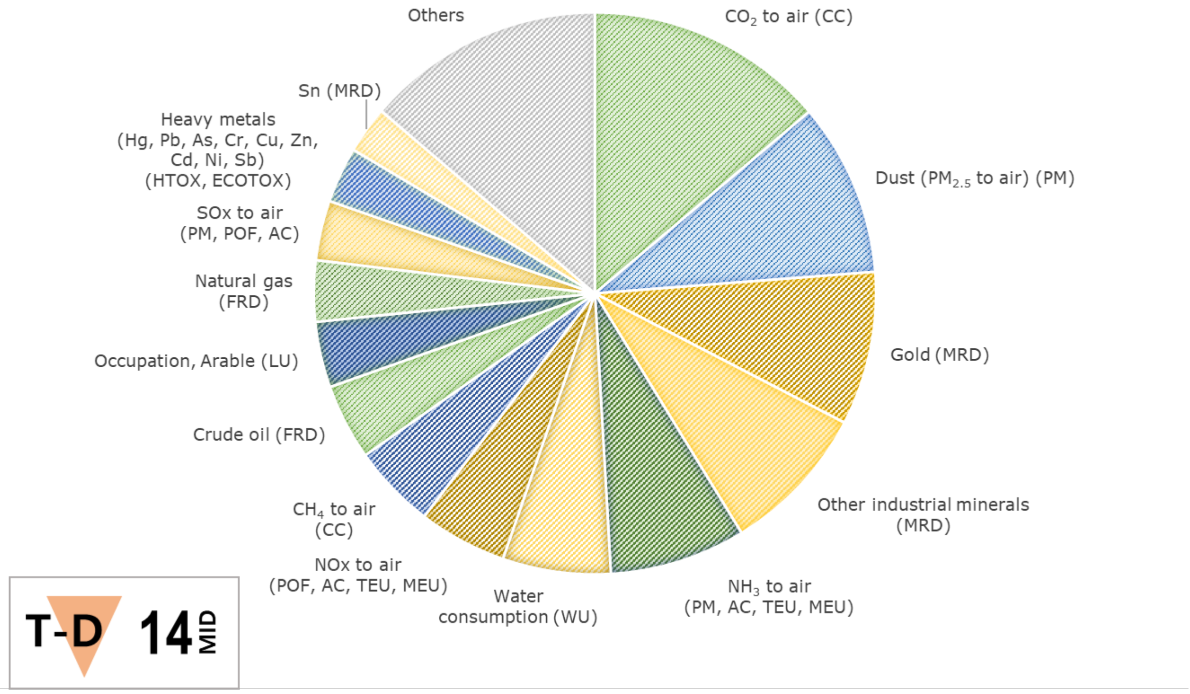


Note: The impact categories to which the elementary flow contributes is indicated in brackets. Year 2010, 16 impact categories

In the case of the Consumption Footprint Top-down (Figure 68), also five substances arise as the leading contributors overcoming 50% of the total impact, namely the emissions to air of CO_2-fossil (climate change; 13.8%), $PM_{2.5}$ (particulate matter; 10.0%), ammonia (particulate matter, acidification, terrestrial and marine eutrophication; 7.8%), and the depletion of gold (mineral resource use; 8.9%) and of other industrial minerals (mineral resource use; 7.5%). With a secondary contribution between 2.8% and 6.2% each are the emission of NO_x (particulate matter, photochemical ozone formation, acidification, terrestrial and marine eutrophication), methane (climate change), SO_x (particulate matter, photochemical ozone formation, acidification) and heavy metals (Hg, Pb, As, Cr, Cu, Zn, Cd, Ni, Sb; human toxicity and ecotoxicity), the resource consumption of freshwater (water use), crude oil (fossil resource use), natural gas (fossil resource use) and tin (mineral resource use), and the occupation of land (land use).

When comparing the absolute contribution of single flows for both footprints (Table 27), the difference between both approaches can be observed. For heavy metals, the Consumer Footprint has a higher impact contribution than the Consumption Footprint (ratios between 0.3 and 0.8). Both footprints has similar values for freshwater (ratio of 1). In some cases, the flow contribution was similar in both approaches (ratios between 1.1 and 1.3), such as for ammonia, NO_x, CO_2 and SO_x. However, for some flows the contribution to the Consumption Footprint Top-down was between 1.8 and 4.1 times higher than for the Consumer Footprint, being the largest differences for $PM_{2.5}$ to particulate matter, gold to mineral resources use and land use. More detailed results are reported in Annex 12.

Figure 68. Consumption Footprint Top-down weighted score: contribution by elementary flows.



Note: The impact categories to which the elementary flow contributes is indicated in brackets. Year 2010, 14 impact categories.

6.3 A convergent narrative of the environmental impacts of the European consumption

The Consumption and Consumer approaches unveil a convergent narrative regarding the environmental impacts of the European consumption, including different levels of detail of the bottom-up and top-down assessments, from more narrowed to broader, respectively. The environmental impacts of EU consumption as a whole have decreased during the last period showing a decoupling from the economic growth. However, such decoupling is absolute for some impact categories and for some countries, while remain relative for other categories and countries. This trend is based on (i) the decrease of the domestic impact (i.e. activities taking place in the European territory), and (ii) the “export effect”, where exports are growing and thus reducing the impacts of the apparent consumption, which also buffers the net importation of environmental impacts from the increasing imports. Both approaches agree in the main contributors to these environmental impacts. Regarding the Consumption Footprint, domestic impacts are driven by the energy sector (electricity, heating and mobility), the use of manure, fertilizers and pesticides in both agriculture and industry and the nuclear energy production. The import of environmental impacts is related to fuels and mineral oils, machinery production, food residues and pulp of wood, depending on the category, from a bottom-up perspective. Beyond these ones, the top-down approach points out as well the imported impacts related to food products (particularly, meat products), the services of hotels and restaurants, the agricultural sector regarding water use, and the sectors of basic and manufactured products for some categories (e.g. toxicity-related ones). Finally, exports are mainly related to manufactured products in general according to both assessments (bottom-up and top-down).

In addition, the aforementioned aspects are concordant with the outputs from the Consumer Footprint, where food has the larger contribution, particularly due to meat, dairy and beverages. The role of housing and energy is also relevant and shows a close relation to the environmental impacts of the energy sector and the way energy is produced (e.g. fossil fuels, nuclear power). Finally, the different manufactured products evaluated in the BoP have a different relevance, depending on the impact category under assessment. Regarding household appliances, the impacts are mostly driven by the use of dishwasher, washing machine, refrigerator, lighting and the TV screen. In the case of household goods, the relevance focuses on paper products, detergents, furniture and clothes. At the substance level, both approaches highlight the role of emissions of CO_2, $PM_{2.5}$, NH_3, NO_x and heavy metals, as well as on the consumption of water (Table 27). In the same line, both approaches converge in highlighting the relevance of climate change, freshwater depletion, acidification, particulate matter, eutrophication, ecotoxicity and human toxicity in the total Footprint. However, the Consumer Footprint approach also includes the evaluation of ionising radiation, where C-14 emissions to air have a relevant role, outlining the role of this substance and impact category in this approach.

Table 27. Comparison of the absolute flow contribution to the EU Consumer Footprint and Consumption Footprint (2010, midpoint). The impact categories to which the elementary flow contributes are indicated. Bold values represent the top 10 contribution to weighted score.

	Category	Unit	Consumer Footprint	Consumption Footprint Top-down	Ratio
CO_2 fossil	Climate change	kg CO_2 eq	**3.41E+12**	**4.35E+12**	1.3
C-14	Ionising radiation	kBq U_{235} eq	**2.30E+11**	**n.a**	-
Freshwater	Water use	m^3 eq	**6.63E+12**	**6.36E+12**	1.0
NH_3	Particulate matter	Disease incidence	**1.36E+05**	**1.51E+05**	1.1
NH_3	Acidification	mol H^+ eq	**1.98E+10**	**2.18E+10**	1.1
NH_3	Eutrophication, terrestrial	mol N eq	**8.82E+10**	**9.72E+10**	1.1
NH_3	Eutrophication, marine	kg N eq	**5.90E+08**	**6.43E+08**	1.1
Heavy metals (Hg, Pb, As, Cr, Cu, Zn, Cd, Ni, Sb)	Human toxicity, cancer	CTUh_c	**6.35E+04**	1.96E+04	0.3
Heavy metals (Hg, Pb, As, Cr, Cu, Zn, Cd, Ni, Sb)	Human toxicity, non-cancer	CTUh_nc	**2.21E+05**	1.73E+05	0.8
Heavy metals (Hg, Pb, As, Cr, Cu, Zn, Cd, Ni, Sb)	Ecotoxicity, freshwater	CTUe	**3.33E+12**	1.85E+12	0.6
NO_x	Particulate matter	Disease incidence	**n.a**	**1.86E+04**	-
NO_x	Photochemical ozone formation	kg NMVOC eq	**8.84E+09**	**1.17E+10**	1.3
NO_x	Acidification	mol H^+ eq	**6.71E+09**	**8.62E+09**	1.3
NO_x	Eutrophication, terrestrial	mol N eq	**3.78E+10**	**4.96E+10**	1.3
NO_x	Eutrophication, marine	kg N eq	**3.42E+09**	**4.53E+09**	1.3
Crude oil	Resource use, fossils	MJ	**2.38E+13**	**3.13E+13**	1.3
$PM_{2.5}$	Particulate matter	Disease incidence	**1.84E+05**	**5.68E+05**	3.1
SO_x to air	Particulate matter	Disease incidence	**3.31E+04**	8.56E+04	2.6
SO_x to air	Photochemical ozone formation	kg NMVOC eq	**6.50E+08**	8.69E+08	1.3
SO_x to air	Acidification	mol H+ eq	**1.08E+10**	1.40E+10	1.3
Natural gas	Resource use, fossils	MJ	**1.37E+13**	2.47E+13	1.8
Au	Resource use, mineral and metals	kg Sb eq	1.34E+07	**4.72E+07**	3.5
Other industrial minerals	Resource use, mineral and metals	kg Sb eq	n.a	**3.97E+07**	-
CH_4	Climate change	kg CO_2 eq	6.24E+11	**1.52E+12**	2.4
Land use	Land use	Pt	2.48E+14	**1.02E+15**	4.1

7 Assessing the environmental sustainability of consumption in the EU

In order to better communicate LCIA results to the public and to help understand how much the EU consumption is environmentally sustainable, this chapter presents three set of results based on the application of the Planetary Boundaries, a reversibility weighting set and the endpoint modelling looking at human health and biodiversity impacts.

7.1 Planetary Boundaries

Box 13. Relative versus absolute environmental impact assessment

- The Planetary Boundaries help quantifying how much the EU consumption is environmental sustainable when compared to the Earth carrying capacity.
- On average, the impacts generated by the EU consumption approaches are not overcoming the boundaries. However, for particulate matter the boundary is surpassed; while for some impact categories (e.g. climate change, resource use) the impact of EU consumption is using from 70% to 97% of the safe operating space available for the whole world, thus leaving less than 30% margin to the rest of the world.
- The impacts generated globally overcome the Planetary Boundaries for six (climate change, particulate matter, both resource use, freshwater eutrophication and land use) out of 16 impact categories.
- When comparing the impacts per capita, both EU and global, the Planetary Boundaries are significantly overcome in many more impact categories.

The relative and absolute sustainability of EU consumption in 2010 is herein defined through the comparison of the results of the different modelling approaches (both bottom-up and top-down) presented in the previous chapters with, respectively, the global impact reference and the Planetary Boundaries. The average impact of EU consumption, calculated as average of the results from all the consumption-modelling approaches, is reported as well.

The contribution of the EU to the global environmental impacts varies greatly depending on the indicators. For instance, when comparing the impacts generated by the EU consumption with the overall impact at global level, on average, the EU contribution spans from 2% of impact on ozone depletion to 45% of ionising radiation for the Consumption Footprint Bottom-up and the Consumer Footprint, respectively. This reflects the differences in production and consumption patterns. Concerning ozone depletion, the result is driven by the bottom-up modelling approaches, since the top-down models do not include this indicator. For what concerns ionising radiation, carbon-14 represents the most important flow in terms of impact both at EU and global scales for this category (Crenna et al., 2019a). The emissions of this radioactive isotope registered at global level mainly come from nuclear power plants installed only in the EU and operating for electricity production. These, together with the other active reactors contribute to around 60% of carbon-14 world emissions, thus explaining why the EU contribution is so high in comparison to the rest of the world.

Comparing the total impacts of the EU with the LCIA-compliant Planetary Boundaries (Figure 69), **all the consumption-modelling approaches are generally below the planetary limits, except for particulate matter**. Furthermore, for the specific case of the Final Consumption_I/O Footprint[21], the impacts due to the use of minerals and metals and land use overcome the respective planetary boundaries. Although the impacts of EU consumption alone are generally within the carrying capacity of the Earth system, according to the different approaches, for some impact categories (e.g. climate change,

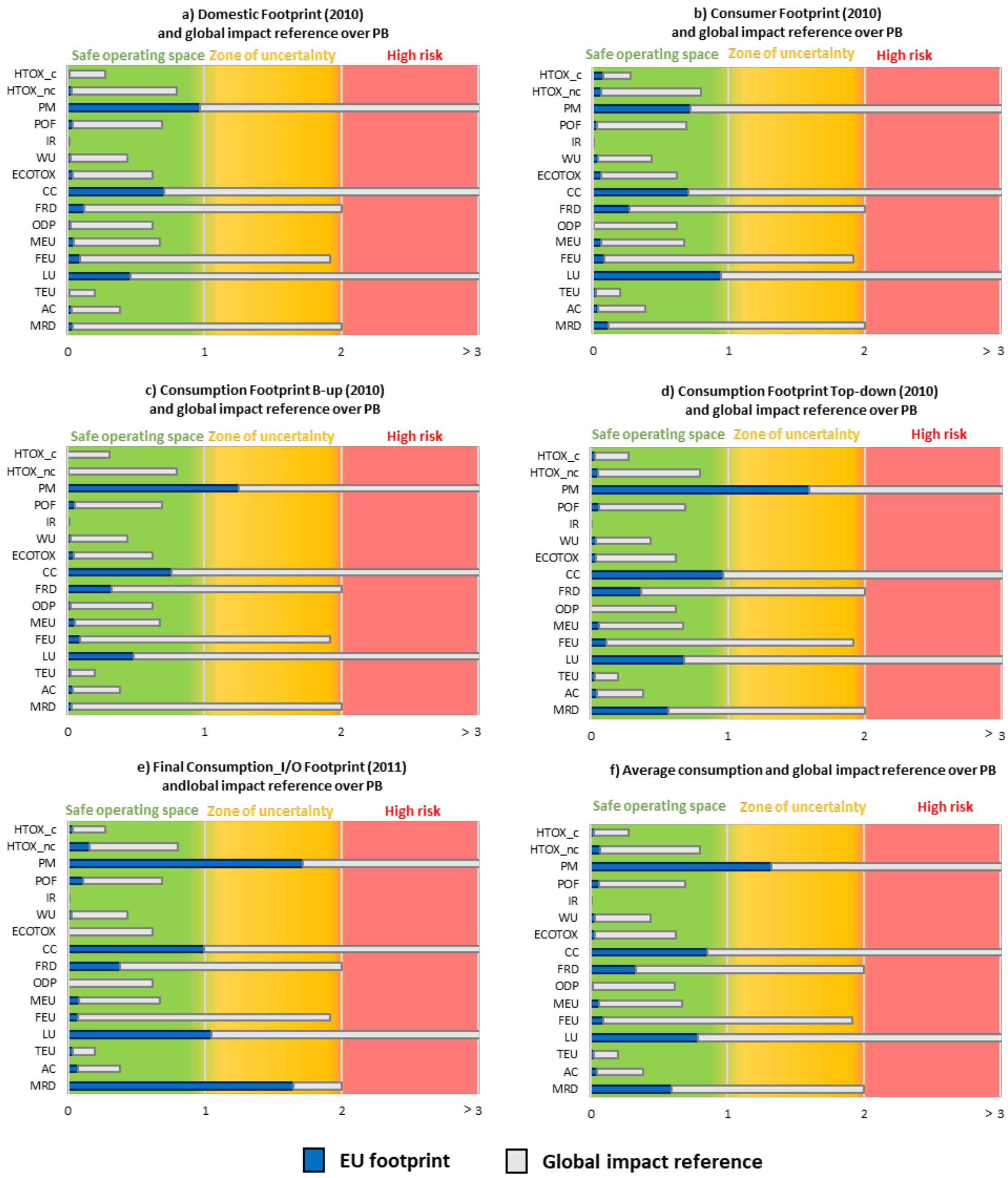
[21] It represents the expenditure by households, government and non-profit institutions serving households on goods or services that are used for the direct satisfaction of individual needs or collective needs of members of the community

resource use) the impact of EU consumption is using from 70 to 97% of the safe operating space available for the whole world, thus leaving less than 30% margin for the rest of the world.

The global impact is for a few categories surpassing the planetary limits, either being in the high-risk zone (i.e. climate change, land use and particulate matter in Figure 69), or in the critical zone (i.e. resource use – fossil, and mineral and metals –, and freshwater eutrophication). For land use and freshwater eutrophication, the global impacts are relatively in line with the current situation highlighted by Steffen et al. (2015). Whereas, the global impact reference for marine eutrophication is not properly in line with the current value presented by Steffen and colleagues (2015), likely due to either a poor availability of data underpinning the calculation of the global reference or the difficulty in precisely measuring the ecological threshold (Sala et al., 2019c).

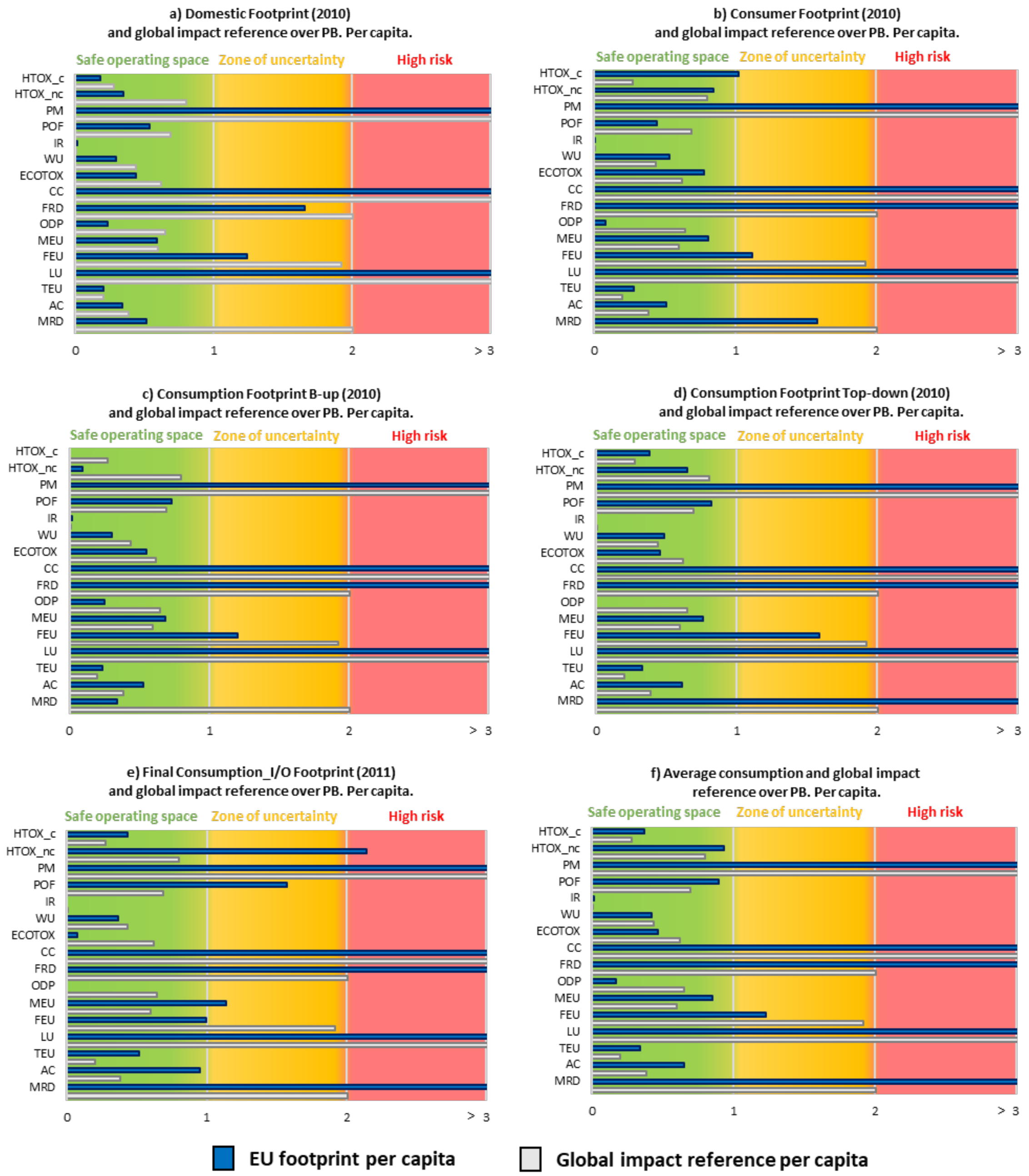
When comparing the impacts per capita (Figure 70), a significant overcoming of the Planetary Boundaries with all the consumption-modelling approaches is observed. In fact, the Planetary Boundaries are surpassed in many more impact categories. **For all the consumption modelling approaches, the impact per capita transgressed the climate change, particulate matter, fossil resources use and land use planetary boundaries**. In most of the modelling options, the safe operating space for freshwater eutrophication was also surpassed. This may be linked to the fact that the consumption-oriented behaviour of an average EU citizen compared to the average citizens of the rest of the world has substantial differences in culture, industrial development, preferences, value system, etc. In fact, the EU per capita results for many impact categories are higher than the impacts of an average world citizen, since the latter account also for the developing countries. The choice of the “reference system” (i.e., considering the impacts generated by the whole population or per capita) is therefore a crucial aspect to be taken into account in the policy making process.

Figure 69. Total impact: different footprints compared to global impacts and Planetary Boundaries.



Note: The colour code of the background indicates the status of the planetary boundary for each impact category: green=below the PB, within the safe operating space; orange=within the zone of uncertainty of the PB; red=beyond the zone of uncertainty of the PB, in a high risk area. Acronyms refer to the ones presented in Figure 12. B-up=Bottom-up. IR and ODP only consider domestic impacts in Figure 69d.

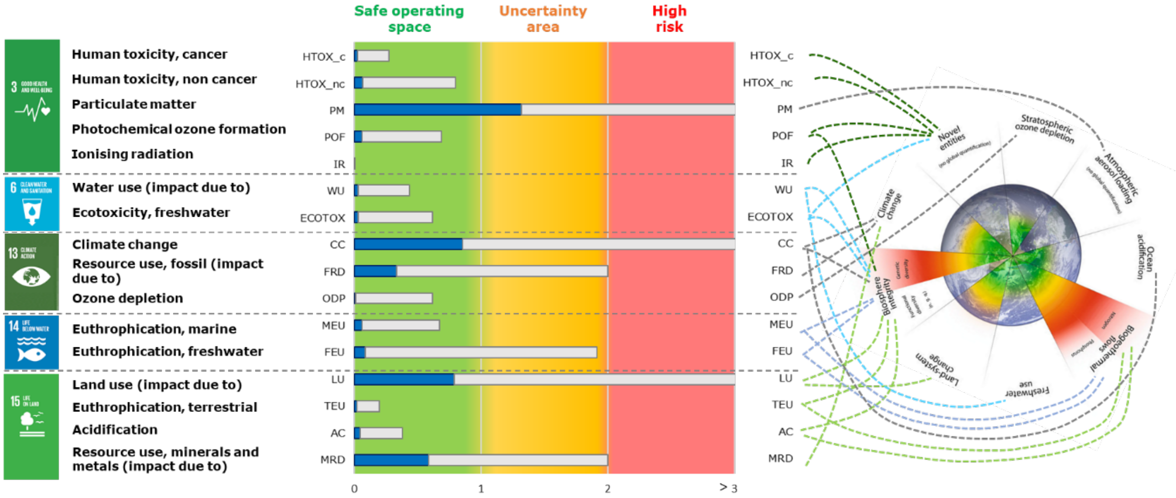
Figure 70. Impact per capita: different footprints compared to global impacts and Planetary Boundaries.



Note: Colour code is explained in Figure 69. Acronyms for the indicators refer to the ones presented in Figure 12. B-up=Bottom-up. IR and ODP only consider domestic impacts in Figure 70d.

The impact categories of the accounted environmental impacts are related to different SDGs (3, 5, 13, 14 and 15) and can be contrasted to the Planetary Boundaries. Figure 71 displays the link between the three sets of elements. The average environmental impacts of EU consumption encompass the impacts of the Consumption Footprint Top-down, the Consumption Footprint Bottom-up, the Consumer Footprint and the Household_I/O Footprint (Figure 71). The environmental impact of the **consumption of an average EU citizen is outside the safe operating space for humanity** for several impact categories, namely climate change, particulate matter, resource use (fossils fuels, minerals and metals), freshwater eutrophication, photochemical ozone formation, and land use. Despite the differences in the robustness of the impact categories, results conclude that for most categories the impacts are close to the threshold, when not over it.

Figure 71. Average impact: Assessing the average impact of EU consumption (Consumption Footprint Top-down, Consumption Footprint Bottom-up, Consumer Footprint and Household_I/O Footprint) with LCA, comparing EU impact against global impact and Planetary Boundaries, and SDG's.



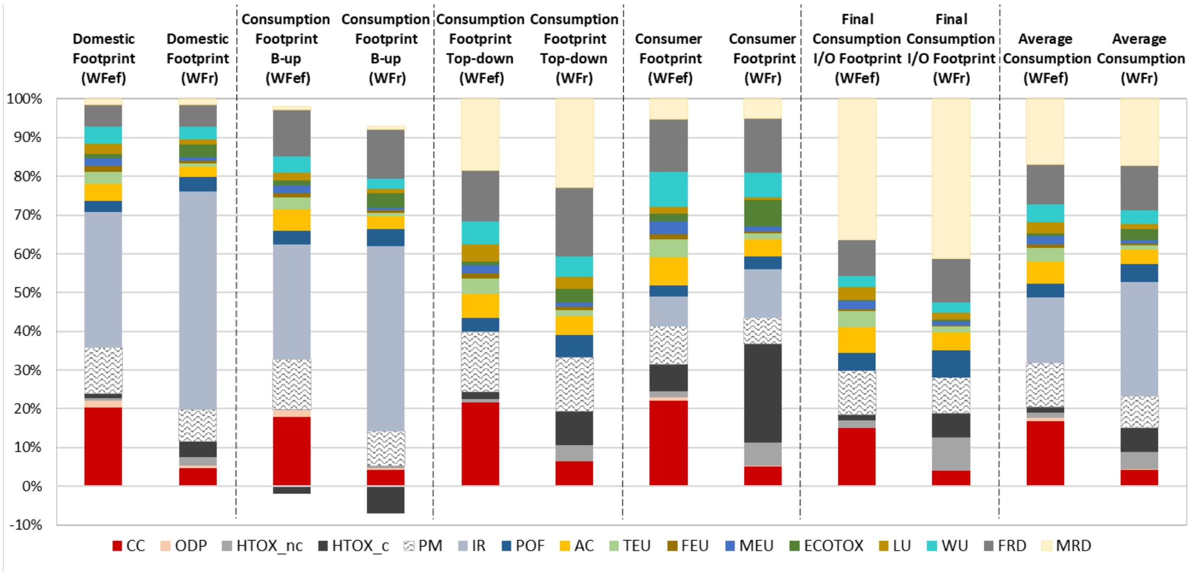
7.2 Weighting considering reversibility of impacts

Box 14. Weighting for communicating LCA results

- By calculating a weighted score to the overall environmental impact, the weighting step allows combining different environmental indicators and expressing their relative importance.
- The results of any LCA study are influenced by the choice of the weighting factors, particularly by the relative importance assigned to the environmental impacts according to the cultural, political, etc. perspective adopted.
- For instance, by comparing the EF weighting factors and the reversibility weighting factors, both developed by the same research team and approach, an evident change is observed in the ranking of the impact categories.
- The reversibility weighting factors give more importance to fossil resource use, whereas climate change dominates in the EF weighting set.
- Therefore, while helping in defining the environmental sustainability of products and scenarios, the choice of the weighting set leads to depict the related results towards decision.

Reversibility defines to which extent the EF 2017 midpoint indicators could be considered to have reversible impacts on the environment. Therefore, applying the reversibility weighting factors (Table 4) allows to identify the main hotspots on which it is critical to intervene to make the EU consumption more sustainable. See Figure 72 for the comparison between the EF weighting factors and the reversibility weighting factors, and Annex 13 for extended reversibility weighted results.

Figure 72. Contribution of the EF 2017 midpoint impact categories to the weighted scores, obtained by using the EF weighting factors (WFef) and a different set of weighting, namely the reversibility weighting factors (WFr).



Acronyms for the indicators refer to the ones presented in Figure 12.

Ionising radiation has the highest contribution to the overall environmental impact for both the Domestic and Consumption Footprint Bottom-up. This impact category is followed by climate change when using the EF weighting set, or by fossil resource use when applying the reversibility weighting set.

For the Consumer Footprint, human toxicity cancer is the main contributor to the overall environmental impact when adopting the reversibility weighting set. On the other hand, climate change pops up on top of the contributors' list when applying the EF weighting set.

Generally, when weighting the results by using the reversibility weighting set, climate change and particulate matter show a visible reduction in their relative importance in all the approaches, namely 71% and 15% respectively. This is due to the lower score of their reversibility weighting factors compared to the EF weighting set. On the other hand, fossil resource use, ionising radiation and human toxicity cancer gain more importance due to the low reversibility of their environmental impacts.

This comparison highlights that the results of LCA studies are influenced by the choice of the weighting factors, which leads to depict the results for decision making and communication purposes.

7.3 Biodiversity and human health impacts

Box 15. Endpoint impact assessment applied to the Domestic and Consumer Footprints

— For both the approaches, the most relevant impact category is climate change, which affects human health and biodiversity, thus highlighting the necessity of carrying on committing to climate-related policies to meet the SDG 13.

— Land use impact category drives the potential loss of species, being the major contributor to the damages to ecosystem quality, as confirmed in the literature.

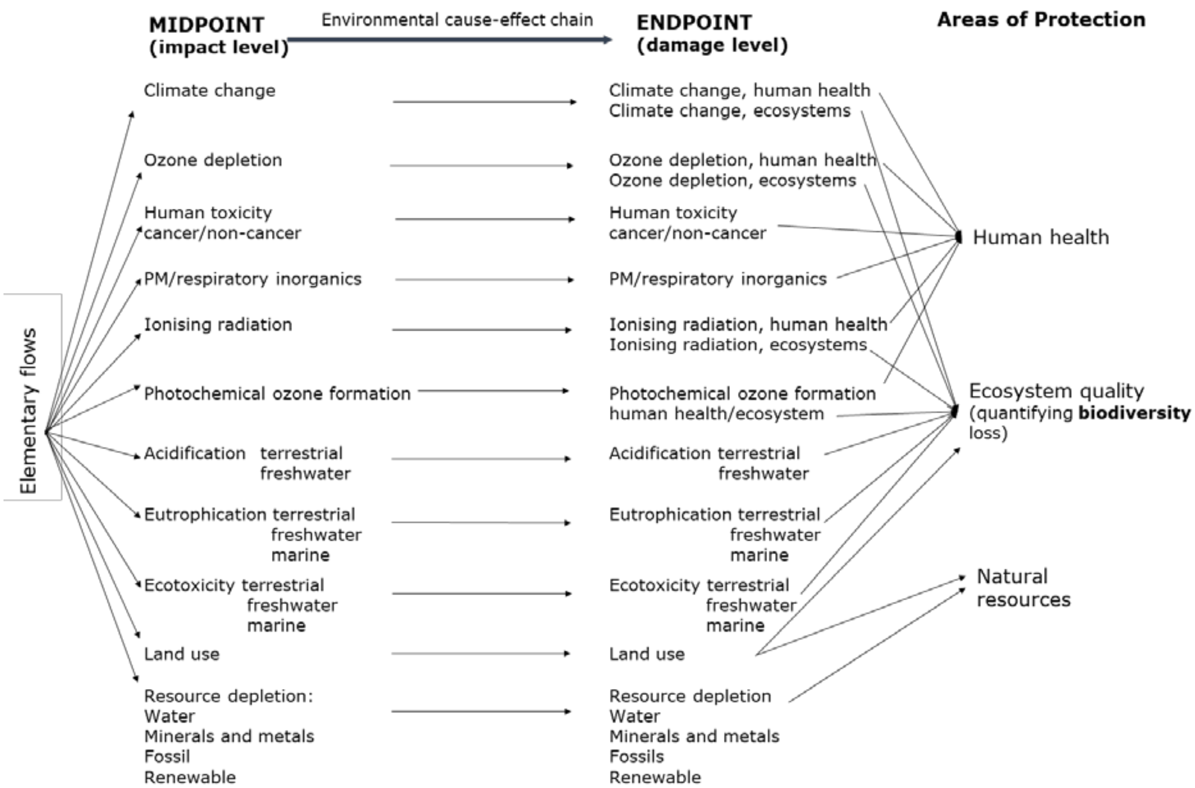
— Particulate matter represents the second most important category affecting human health, mainly due to electricity production and consumption, thus raising the need of intervening for ensuring better health conditions according to the SGD 3.

As alternative to the midpoint modelling of impacts, several impact assessment methods are modelling impact indicators as endpoint.

The endpoint is a damage-oriented approach. It links the different environmental impacts quantified by the midpoint impact categories to three issues of concern or areas of protection (AoP) for human societies: human health, ecosystem quality (which addresses biodiversity loss), and natural resource availability (EC-JRC, 2010b) (Figure 73).

The endpoint modelling is helpful in decision-making as it concentrates the attention to a fewer areas of concern. In fact, through a science-based aggregation of the impact categories, it facilitates the comparison and interpretation of impacts to society values (UNEP, 2000). Although endpoint results are easier to understand by policy makers than midpoint, the endpoint modelling is still considered highly uncertain (Kägi et al., 2016). So far, no single endpoint method recommendation is included in the Single Market for Green Products (SMGP) communication with the EF methods (EC, 2013).

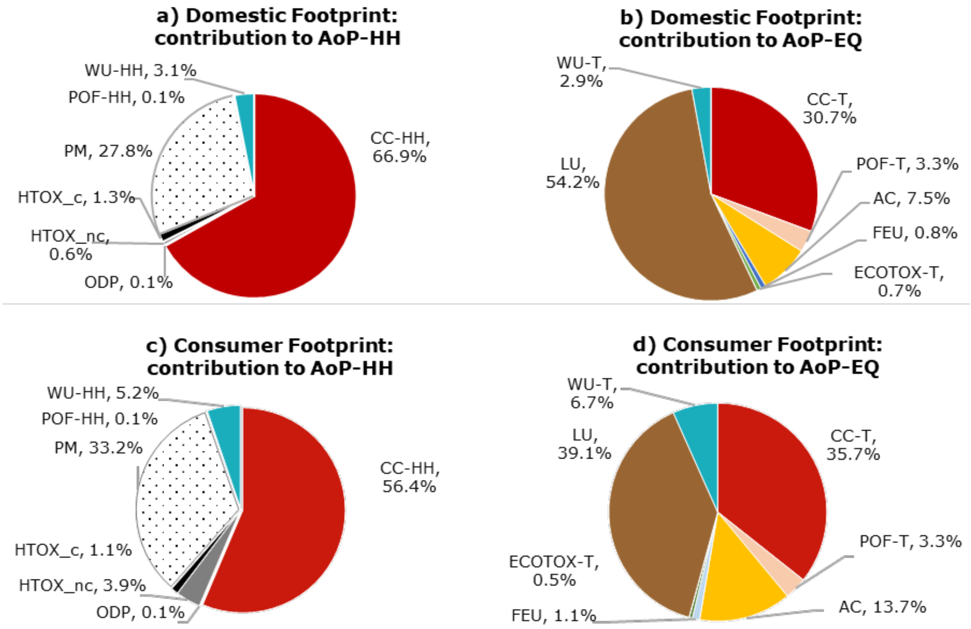
Figure 73. Environmental cause-effect chain linking the impacts quantified by the midpoint impact categories to the damages at the three areas of protection, through the endpoint modelling.



To explore how the different midpoint indicators affect human health and biodiversity (accounted by the area of protection of ecosystem quality), the endpoint method ReCiPe 2016 (Huijbregts et al., 2017) has been applied to the Domestic Footprint and Consumer Footprint results for the reference year 2010. The hierarchist cultural perspective[22], which is based on the most common policy principles with regards, for example, to the timeframe has been adopted (Goedkoop et al., 2008). According to the ReCiPe 2016, the damage to human health are measured in DALY, i.e. Disability-Adjusted Life Years, a measure of the overall disease burden that accounts for both the years lost due to premature death and the years lived with disability. While, the damage to ecosystem quality is expressed in terms of PDF, i.e. Potentially Disappeared Fraction of species over a certain area, during a certain period of time.

Climate change has a relevant contribution in affecting human health and ecosystem quality according to both the approaches (Figure 74). In fact, it is predominant in human health (ca. 67% and 56% respectively in the Domestic Footprint and Consumer Footprint), while it is second after land use in its contribution to affecting ecosystem quality (ca. 31% and 36%, respectively). This would reflect the need of persevere in the commitment to climate-related policies to meet the SDG 13. **Land use**, which does not play a role in damaging human health according to ReCiPe 2016, **is the impact category with the highest score in the area of protection of ecosystem quality** in both approaches, hence leading to the largest number of potential species lost as confirmed by the literature (e.g. MEA, 2005). In the specific case of the Consumer Footprint, this result is driven by the prevalence of BoP Food among the baskets of products.

Figure 74. Contribution of the midpoint impact categories to the damage to human health and ecosystem quality for the Domestic and the Consumer Footprint.



Note: The contribution is expressed as a percentage out of the overall environmental impact. If an impact category is not displayed in the charts, it means that its impact is below 0.1%. AoP-HH: Area of Protection-Human health; AoP-EQ: Area of Protection-Ecosystem quality; CC-HH: climate change human health; CC-T: climate change terrestrial ecosystem; ODP: ozone depletion; POF-HH: photochemical ozone formation human health; POF-T: photochemical ozone formation terrestrial ecosystem; HTOX_c: human toxicity, cancer; HTOX_nc: human toxicity, non-cancer; PM: particulate matter; WU-HH: water use human health; WU-T: water use terrestrial ecosystem; AC: terrestrial acidification; FEU: freshwater eutrophication; ECOTOX-T: terrestrial ecotoxicity; LU: land use.

[22] The other perspectives are based on a short-term interest (Individualist) or the most precautionary approach taking into account the longest time-frame (Egalitarian) (Goedkoop et al., 2008).

Actually, the BoP Food includes a number of products which present the heaviest impact on ecosystem quality and accounts for 57% of the impact of the overall consumption in the EU (see Annex 14 for further details). The land use-related impacts of BoP Food on ecosystem quality are mainly linked to the use of agricultural land for cultivation of crops and grass for feed production. After climate change, particulate matter represents the second most impacting category on human health in both the approaches, thus raising the need of intervening and ensuring better health conditions according to the SDG 3. Water use and photochemical ozone formation affect both human health and ecosystem quality, although at a very low level of impact compared with other impact categories.

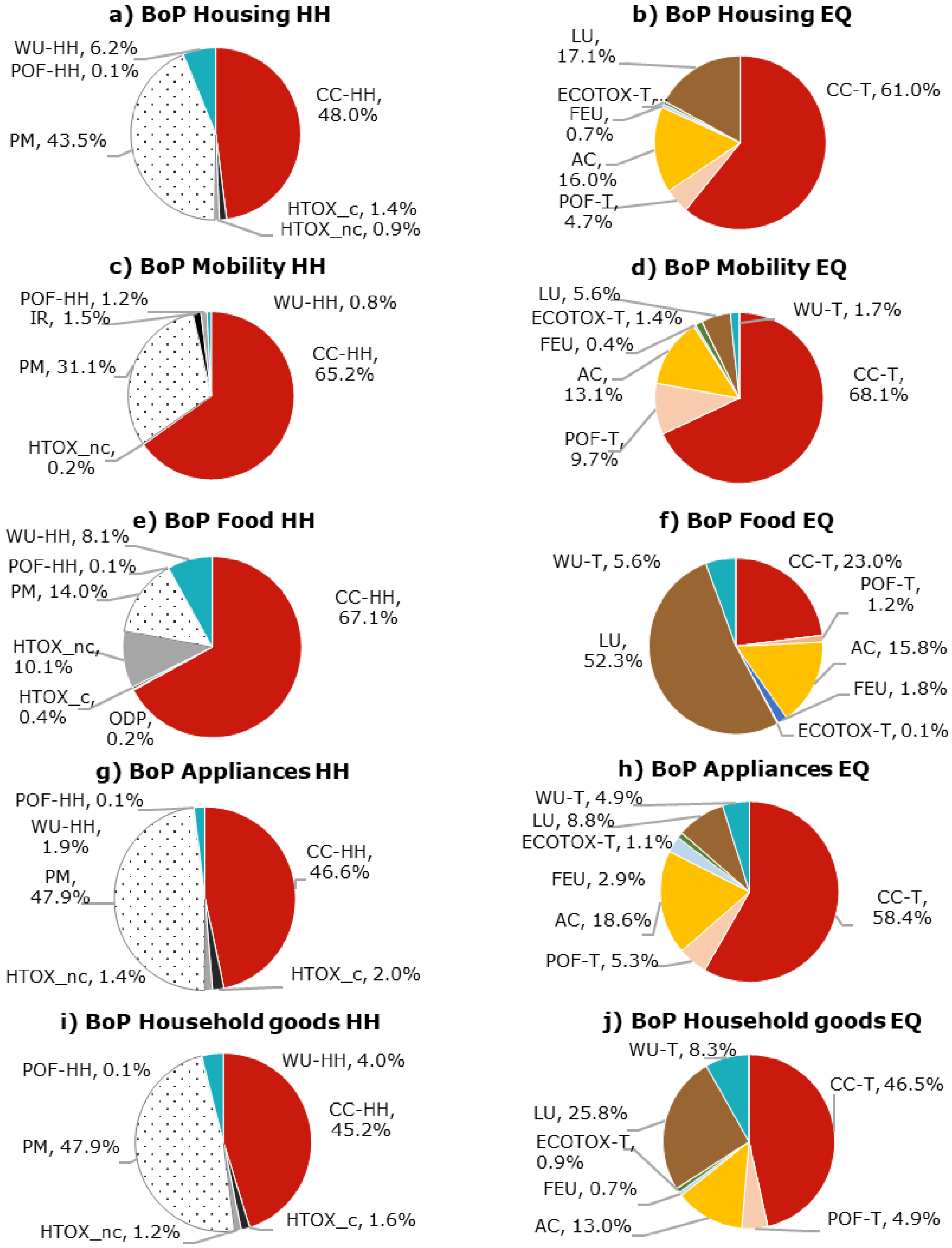
Looking more into details of the single baskets of products composing the Consumer Footprint (Figure 75), the situation slightly changes in accordance with the specific BoP considered. For instance, particulate matter prevails on climate change in damaging human health in those cases where electricity use is at high levels (e.g. BoPs Household goods and Appliances). In these cases, the most impacting products are respectively T-shirts (14%) and Washing machine (21%). On the other hand, climate change takes over land use in all BoPs but BoP Food, whose contribution to the damages to ecosystem quality stands between nearly 6% and 26%.

Specifically concerning the damages to ecosystem quality and on biodiversity, the necessary integration of biodiversity in life cycle-oriented methodologies has been recognized, since biodiversity represents a crucial aspect for policy makers and consumers. For instance, as detailed in Crenna et al. (2019b), many food products consumed in the EU are somehow linked to impacts on biodiversity (Table 28).

Table 28. Food products and their impacts on biodiversity.

<table>
<tr><th>Products</th><th>Pressures generated by human interventions</th><th>Impacts on natural environment and biodiversity</th></tr>
<tr><td>Beef/pork/poultry meat</td><td rowspan="6">Land use change, e.g. in Brazil or in Europe, from natural areas into monoculture of soybean</td><td rowspan="6">Loss of habitats suitable for endangered species, e.g. black-faced lion tamarin and ring-tail monkey, or for helpful insects, birds and bats as pollinators</td></tr>
<tr><td>Dairy products</td></tr>
<tr><td>Tofu</td></tr>
<tr><td>Salmon</td></tr>
<tr><td>Eggs</td></tr>
<tr><td>Oils</td></tr>
<tr><td>Biscuits</td><td>Land use change, e.g. in Indonesia, from natural areas into palm oil monoculture plantations</td><td>Loss of habitats suitable for endangered species, e.g. gibbons and Javan rhinoceros</td></tr>
<tr><td>Chocolate (cocoa beans)</td><td rowspan="5">Pesticides use</td><td rowspan="5">– Contamination of water courses leading to fish and amphibian populations' decline
– Habitat degradation, leading to birds and insect pollinators' loss</td></tr>
<tr><td>Tea</td></tr>
<tr><td>Tomato</td></tr>
<tr><td>Fruit cultivation, e.g. apples, oranges, grapes for wine</td></tr>
<tr><td>Coffee</td></tr>
<tr><td>Banana</td><td>Land use change, e.g. in Ecuador, from natural areas into monoculture banana plantations</td><td rowspan="5">Loss of habitats suitable for several species, from insects to mammals</td></tr>
<tr><td rowspan="2">Rice</td><td>Land occupation, e.g. in the EU and Mediterranean areas</td></tr>
<tr><td rowspan="2">Water use</td></tr>
<tr><td>Almond</td></tr>
<tr><td rowspan="2">Cod</td><td>Sea bottom trawling</td></tr>
<tr><td>Overfishing</td><td>Loss of wild cod stock and disruption of the trophic chain</td></tr>
<tr><td>Salmon</td><td rowspan="2">Nutrient emissions</td><td rowspan="2">Excessive algae blooms, eutrophicating marine and fresh water, thus leading to species composition change and disruption of the trophic chain</td></tr>
<tr><td>Shrimps</td></tr>
<tr><td>Agricultural commodities</td><td>Spread of invasive species due to commodities trade, e.g. pathogens from China and the USA</td><td>Loss of helpful insects (e.g. pollinators) and crops, affecting also food security</td></tr>
</table>

Figure 75. Contribution of the EF 2017 midpoint impact categories to the damage to human health (HH) and ecosystem quality (EQ) for the five Baskets of Products (BoP) of the Consumer Footprint.

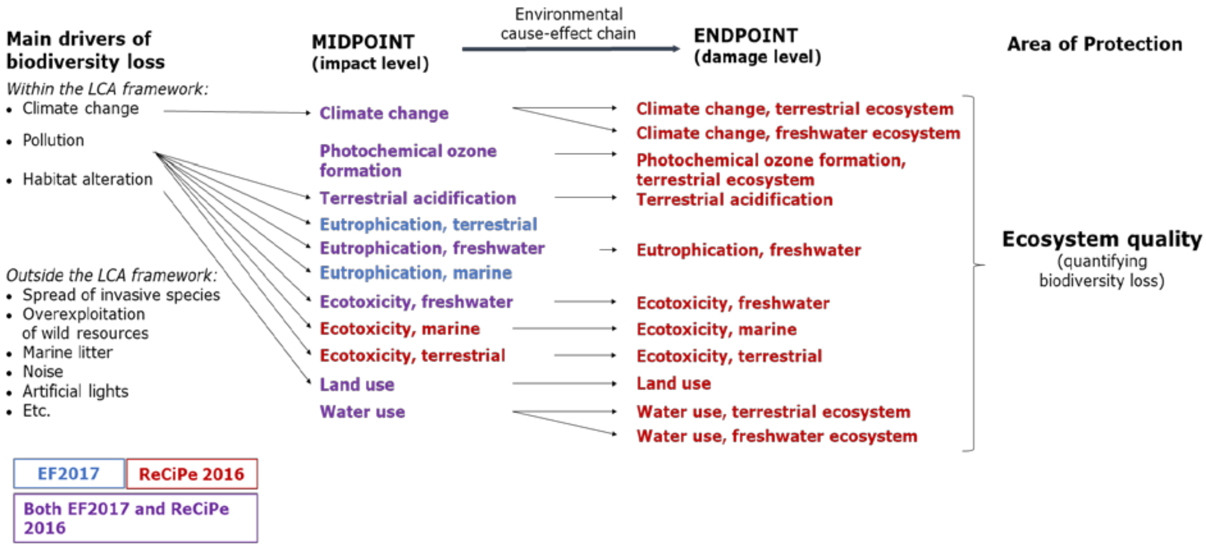


Note: The contribution is expressed as a percentage out of the overall environmental impact. If an impact category is not displayed in the charts, it means that its impact is below 0.1%. CC-HH: climate change human health; CC-T: climate change terrestrial ecosystem; ODP: ozone depletion; POF-HH: photochemical ozone formation human health; POF-T: photochemical ozone formation terrestrial ecosystem; IR: Ionising radiation; PM: particulate matter; HTOX_c: human toxicity, carcinogenic; HTOX_nc: human toxicity, non-carcinogenic; WU-HH: water use human health; WU-T: water use terrestrial ecosystem; AC: terrestrial acidification; FEU: freshwater eutrophication; ECOTOX-T: terrestrial ecotoxicity; LU: land use.

The most recent works in the LCA context (e.g. Winter et al., 2017) agree that only three out of the five drivers of biodiversity loss identified by the Millennium Ecosystem Assessment (MEA, 2005) (i.e. climate change, pollution, habitat alteration, spread of invasive species and resource overexploitation) are addressed in the existing midpoint/endpoint impact categories (Figure 76).

Some attempts have been made to cover the missing drivers. Hanafiah et al. (2013) and Emanuelsson et al. (2014) assessed respectively the impacts due to invasive species and overexploitation of wild fish. Crenna et al. (2018) identified the key aspects for developing a framework able to assess the impacts on biotic resources. However, these models are not yet operational in the common LCA practice. Additionally, other critical drivers are not yet reflected in the LCIA framework, including marine litter, noise, artificial lights and international trade, which is increasing the rate of habitat degradation and species loss in those areas where products have their origin (Lenzen, 2012; Moran et al., 2016).

Figure 76. Overview of the main drivers of biodiversity loss and their status in the LCA framework, according to EF 2017 and ReCiPe 2016, presented as an example.



8 Evaluating sustainable solutions: ecoinnovations and behavioural shifts

Box 16. Key messages on scenario analyses

— Results of scenario analyses highlighted that LCA can help to identify trade-offs associated to policy, technological and behavioural shift options.

— The effect of single actions is generally quite limited across all baskets. However, interesting results are obtained when several actions are combined together (e.g. in the case of energy-efficiency measures in the housing sector).

— The analysis showed that sometimes the intensity of consumption (affluence) could be more relevant than possible technical improvements. In the case of appliances, the combined effect of technological improvements and of the increase in the intensity of consumption (larger number of devices per household) generated diverging trends among impact categories (e.g. reduction of climate change and increase in mineral resources depletion).

— In scenarios related to consumer behaviour, the assumption on the uptake of the change at the EU scale (i.e. upscaling the effect from the single citizen to whole EU) can play a relevant role. Therefore, it is important to understand how to define it, especially because data sources on this topic are quite limited and sometimes uncertain (due to the inherent nature of surveys). The use of Eurobarometer surveys can be an option to be further explored, as suggested in section 5.2.

— As proved by the scenarios on food waste, results of scenarios on the BoPs can be an input for further analyses, combining environmental and economic evaluation (e.g. through linear programming models), in support to decision making.

— Future developments could include the rebound effect in the modelling of scenarios.

The results of the assessment of Consumer Footprint as presented in section 4, section 5 and section 6 represent a picture of the impacts generated by household consumption in the EU in the reference year chosen for the analysis (2010). The hotspot analysis conducted at the level of sectors, of products and of substances helped to identify the main drivers of impact for each of the five BoPs. Starting from those results, several actions could be identified in order to reduce the impact of household consumption and to reduce the Consumer Footprint in Europe. This was done through a review of scientific literature and technical documents in the field of the five areas of consumption considered in the BoPs (housing, mobility, food, appliances, and household goods).

The eco-innovation and pro-environmental consumer's behaviours identified through the review constituted a long list of possible scenarios to be tested on the BoPs' baseline scenarios (i.e. the situation in 2010), to assess potential benefits and to identify potential burden shifting.

For the selection of the scenarios developed for each BoP, priority was given to:

1. Scenarios that address the most relevant hotspots identified in the BoPs (e.g. for BoP food, priority is given to the scenarios on nutrients recovery, that are expected to reduce the impacts on eutrophication and human toxicity);
2. Scenarios able to simulate the effect of EU policies (e.g. for BoP Household Goods, a scenario on second-hand products can help to understand the effect of circular economy strategies);
3. Scenarios related to innovations that are at present a niche in the market but are expected to become relevant for one of the consumption sector (e.g. the growing market share of electric vehicles in the mobility sector).

The scenarios assessed in the context of the Consumer Footprint have several links to product policies. The most important ones are the Circular Economy package and the Roadmap to a resource efficient Europe. Other policies, related more specifically to each of the BoPs are: GPP on food, Urban Waste Water Directive, European strategy on nutrition, Bioeconomy Strategy (EC, 2018b), SDG 12.3 on food waste, EU Water Framework Directive, Energy efficiency directive, Ecolabel, Ecodesign directive, WEE Directive, Macro-objectives for the life cycle environmental performance and resource efficiency of EU buildings, Thematic Strategy on Air Pollution, European strategy for low emission mobility, GPP on Transport, Renewable Energy Directive, and Fuel Quality Directive.

Annex 15 reports a detailed correspondence between each scenario tested in the BoPs and the policies to which it is related, whereas section 10 discusses more in detail the links between the work done in the LC-IND2 project and existing and potentially upcoming policies.

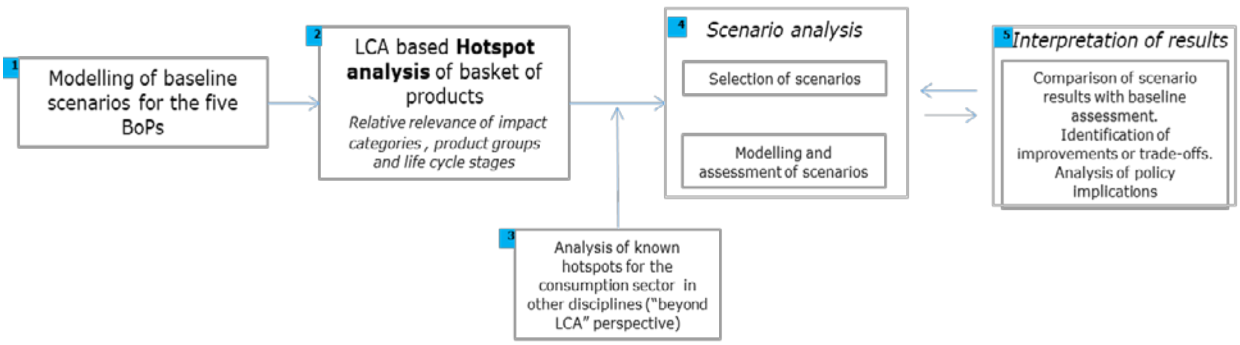
The scenarios developed in the context of the BoP indicators are built in the form of a "what if" analysis, i.e. testing the variation of one parameter at a time, assuming that all the others remain as they are in the baseline. If needed, scenarios can be combined to check the cumulative effects of several improvement options. When relevant, geographical variability (e.g. for cluster of MSs or climatic regions) can be modelled.

Results of the scenarios can be presented according to the modularity of the BoP indicators: the effects of the proposed innovation can be reported per single citizen and for the whole EU. When calculating the results at the EU level, one or more assumptions on the foreseen uptake of the innovation or behavioural change tested are considered (e.g. the foreseen percentage of citizens willing to change their consumption's habits or the percentage of farms or firms that will implement a technical innovation). The following sections present a summary of the results obtained from the scenario analysis in each of the five BoPs considered (section 8.1) and a selection of scenarios that are described more in detail (sections 8.2.1, 8.2.2 and 8.2.3).

8.1 Scenario analysis of the five BoPs in the Consumer Footprint

Several scenarios have been assessed and compared to the baseline scenario of each BoP. The scenarios selected for the analysis included both technical innovations and behavioural changes. The framework of scenario analysis in the context of the Consumer Footprint is illustrated in Figure 77. It includes the selection of scenarios, their modelling and assessment and the interpretation of results in support to policy making.

Figure 77. Framework for scenario analysis in the Consumer Footprint.



Some general conclusions may be drawn from the scenario analyses conducted on the five BoPs. Results highlighted that LCA can help to identify trade-offs associated to some technologies (e.g. reduction of use of fossil resources combined with an additional use of mineral resources for PV panels and other appliances).

The effect of single actions is generally quite limited across all baskets. However, interesting results are obtained when several actions are combined together (e.g. in the case of energy-efficiency measures in the housing sector). The analysis showed that

sometimes the intensity of consumption could be more relevant than possible technical improvements. In some cases, the combined effect of technological improvements (e.g. improved energy efficiency of appliances) and of the increase in the intensity of consumption (as it is for future scenarios on mobility and use of appliances, presented in the following sections) generated diverging trends among impact categories (e.g. reduction of climate change and increase in mineral resource use).

In scenarios related to consumer behaviour, the assumption on the uptake of the change at the EU scale (i.e. upscaling the effect from the single citizen to whole EU) can play a relevant role. Therefore, it is important to understand how to define it, especially because data sources on this topic are quite limited and sometimes uncertain (due to the inherent nature of surveys). The use of Eurobarometer surveys can be an option to be further explored, as suggested in section 5.2.

On the one hand, the use of a bottom-up approach allows for having more detailed life cycle inventories, and it is more useful when modelling scenarios on specific characteristics of products. On the other hand, the use of representative products can be a limitation when modelling other types of scenarios, such as the ones looking at different types of diets in the BoP Food.

Finally, it has to be considered that the scenarios show the environmental effects of the improvement actions analysed. In real conditions, other aspects (and especially economic sustainability) would be considered in the decision making process. As proved by the scenarios on food waste, results of scenarios on the BoPs can be an input for further analyses, combining environmental and economic evaluation (e.g. through linear programming models), in support to decision making.

The following paragraphs present the results of scenario analysis for each of the five BoPs. Annex 16 provides a summary of the results for all the scenarios assessed in all the BoPs.

8.1.1 Scenarios on housing

The Consumer Footprint BoP Housing baseline has been assessed against nine scenarios, referring to improvement options related to the main drivers of impact. The nine scenarios covers both technological improvements and changes in consumers' behaviour. The scenarios are:

1. night attenuation of setting temperature for space heating;
2. external wall insulation with an increased thickness;
3. external wall insulation comparing conventional or bio-based materials;
4. use of a solar collector to heat sanitary water;
5. floor finishing with timber instead of ceramic tiles;
6. a building structure in timber compared with concrete frame;
7. implementation of smart windows for improved energy efficiency (two options about the refurbishment rate for the substitution of old windows);
8. a combination of some of the above-mentioned energy-related scenarios;
9. production of electricity through a photovoltaic system installed on the roof.

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

The same applies for all the scenarios evaluated. **Therefore, a combination of several actions, both for energy saving and for material efficiency, is needed to achieve a significant reduction in environmental impact of the overall BoP Housing.** Hence, it can be concluded from the assessment that an integrated policy is important in order to achieve significant impact reductions of the EU building stock. A preliminary modelling of combination of energy-related measures (scenario 8) proved to be a good way to enlarge the potential benefits coming from the selected improvements of the building stock. The same approach could be adopted for different kinds of improvements, combining also energy-related and non-energy-related measures.

8.1.2 Scenarios on mobility

The Consumer Footprint BoP Mobility baseline has been assessed against five scenarios. The scenarios developed for the BoP mobility refer to:

1. the evolution of fleet composition and mobility demand in 2030;
2. the use of eco-driving measures, including technical and behavioural changes (two extreme options considered: gentle driving style with tyre class A and aggressive driving style with tyre class G);
3. increased use of biofuels in substitution of the current diesel blend;
4. expected evolution of batteries for hybrid and electric mobility (three parameters considered: mass, lifetime, and consumption of the battery);
5. changes in the lifestyle of European citizens, namely the shift of a portion of their mobility habits from private cars to public transport, for what concern the mobility in urban areas.

What emerged from the scenarios is that most of the measures tested have a positive effect on the reduction of impacts for the vehicles to which they are applied. However, the impact reduction expected from the single solutions explored in the scenarios has a limited effect on the overall impact of the BoP, especially because the factor that influences most the results is the amount of kms travelled by European citizens. Indeed, the number of person*km (pkm) travelled yearly by an average European citizen is constantly growing over time. This is reflected in the larger impact (over all the impact categories considered) of the baseline for the reference year 2015 over the baseline 2010. A similar result is obtained for the scenario on the expected situation in 2030 (presented in section 9.2.2) over the baseline scenario for year 2010 and year 2015. The increase of the pkm travelled, and the relative increase of the share of air transport over the total mobility, offset the reduction of the impact per km travelled achieved through the introduction of cars compliant to the new emission standards (Euro 6) and through the increase of electric and hybrid vehicles.

To maximize the results of all the possible improvement measures for the mobility sector, a combined implementation of all possible options to optimize the use of transport means and to reduce the associated burden should be planned. This should include both the **technological advancement in the field of fuel efficiency and alternative fuels** (biofuels or electricity produced from renewable sources), but also a **behavioural change towards more sustainable lifestyles, with a less intensive use of private cars as far as possible** (e.g. in urban areas). A reduction of the total kms travelled by road, rail or air (e.g. by increasing the kms travelled by bicycle or by walking, when possible), is needed, to avoid that the reduction of impact achieved through technological improvements is offset by the continuous increase in the amount of pkm over time.

8.1.3 Scenarios on food

The Consumer Footprint BoP Food baseline has been assessed against five scenarios, referring to improvement options related to the main drivers of impact:

1. improved nutrients cycle: food waste to animal feed;
2. improvement of the efficiency of the waste water treatment in the EU;
3. reduced amount of meat consumed (benefits of behavioural changes);
4. improved nutrients cycle: recovery of nutrients from urine;
5. food waste prevention, entailing a number of prevention measures, acting at different stages of the food supply chain, including the use phase.

Among the scenarios assessed, the options that allow for a higher reduction of impacts are the ones acting on the drivers of freshwater eutrophication, such as recovery of nutrients form urine or improvement of the wastewater treatment. A general comment valid for all the scenarios refers to the relevance of the level of uptake of the improvement measure modelled in the scenario. Some options can have a high potential in terms of the reduction of impacts, but can also be difficult to implement at large scale. This can limit their potential effect on the overall impact of the BoP Food (i.e. on the impacts of food consumption in Europe).

The combination of several actions could be a good way to cover a wider range of impacts and to maximize the potential of impact reduction, both at the scale of the single citizen and of the whole Europe. One example has been already provided by summing a selection of actions for food waste prevention. The same approach could be applied to all the scenarios presented (and others to be eventually developed in the future), if the single actions are not overlapping and can be implemented in parallel (e.g. improvement of wastewater treatment and food waste reduction). Furthermore, the combination of mathematical programming and LCA can help to prioritize measures within the limited budget available for the implementation of policies, as proved in Cristóbal et al. (2018).

8.1.4 Scenarios on appliances

A set of twelve scenarios was developed to be tested in the BoP Appliances:

1. more renewable electricity mix;
2. improved energy efficiency of appliance: dishwasher and washing machine;
3. improved energy efficiency of appliance: refrigerator;
4. improved energy efficiency of appliance: TV;
5. use of less harmful refrigerants for the air conditioning units;
6. reduction of leakages from the air conditioning units;
7. development (increase) of the number of devices per household until 2030;
8. improvement at the EoL, with three options: a) increased reuse of products (via second-hand markets), b) increased collection rate of Waste Electrical and Electronic Equipment (WEEE), and c) increase of the material recovery rates during the various recycling processes for the different fractions (metals, plastics, etc.);
9. increased use of LED lighting, in substitution of other light sources that are planned to be phased out in the future;
10. “devices-related potential”: sum of all more energy efficient devices as well as devices less harmful for ozone layer (scenario 10a); adding to this all the increased “reusability” scenarios (scenario 10b); and, finally, combining all this with the changing amount of devices in use (scenario 10c);

11. “overall potential” scenario in the field of appliances: combination of all the previous scenarios together;
12. to analyse the effect of “domotics” (home automation).

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 saving 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), show 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 possible forecast of the 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. Among them, 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.** Further details on the scenarios regarding the BoP appliances are provided in Hischier et al. (2020).

8.1.5 Scenarios on household goods

Four scenarios of ecoinnovation and six scenarios on the implementation of Ecolabel criteria have been selected and modelled in the context of the BoP Household goods:

1. larger use of Totally Chlorine Free (TCF) pulp in paper and sanitary products;
2. options for reducing the impact of electricity use in the textile sector;
3. improved reuse (buying second-hand products);
4. use of textiles with recycled input materials;
5. purchase and use of products compliant with Ecolabel criteria: liquid soap;
6. purchase and use of products compliant with Ecolabel criteria: shampoo;
7. purchase and use of products compliant with Ecolabel criteria: dishwasher detergent;
8. purchase and use of products compliant with Ecolabel criteria: laundry detergent;
9. purchase and use of products compliant with Ecolabel criteria: upholstered seat;
10. purchase and use of products compliant with Ecolabel criteria: overall potential coming from Ecolabel products, by analysing the effect of having 100% Ecolabel product on the market, for the five product groups analysed before, combined with the average products (i.e. no Ecolabel) for the remaining product groups in the BoP Household goods.

Among the scenarios assessed, the options that allow for a higher reduction of impacts are the ones related to the use of less impacting electricity mixes and to the reuse of products. Results of the hotspot analysis for the baseline scenario and results of scenario 2 show that for products that are largely imported from outside Europe, impacts due to the use of electricity in the production phase, which happens in country that have an electricity mix with lower share of renewable sources compared to Europe, is more relevant than the impact associated to the transport from overseas. Results of scenario 3b, where 100% reuse is assumed for furniture and textile products, show a reduction of impact that is generally higher than 10% for all the impact categories. Furthermore, the potential of this action could be even higher if other product categories could be considered (e.g. footwear). Finally, the scenarios on Ecolabelled product show that, even if the environmental profile of Ecolabelled products is generally better than the one of the average products in the market, the effect that the choice of Ecolabelled products can have on the overall impact coming from purchase and use of household goods could be relatively limited and highly dependent on the share of Ecolabel products bought by European consumers. When interpreting these results, it has to be considered that the present study investigated the effect of Ecolabel criteria only on some of the product groups considered in the BoP household goods. Therefore, the study could be enlarged to have a wider assessment of the potential coming from the application of the Ecolabel criteria.

8.2 Examples of results of the ecoinnovation scenarios tested against the Consumer Footprint

8.2.1 Overall potential improvement in the appliances sector in the EU

This scenario refers to the BoP Appliances and it is aimed at exploring the combined effect of technical improvements of devices (e.g. in terms of energy efficiency or recyclability of materials at the end of life) and of expected future behaviour of consumers (in terms of the number of devices owned and their intensity of use). It can be considered as an overall summary of the effects of all the innovations and the behavioural changes tested on the BoP appliances.

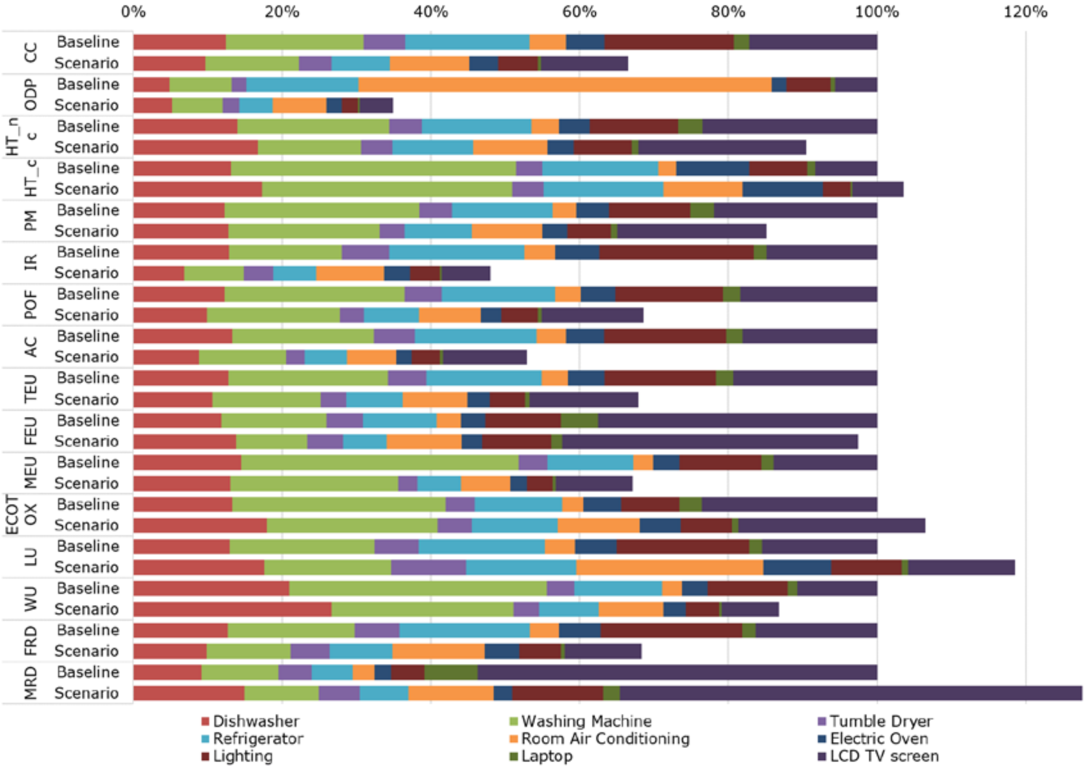
The scenario explores the effect of the following changes to the baseline scenario:

- improvements in energy efficiency of devices (dishwasher, washing machine, refrigerator and TV screen);
- change in the composition of the electricity mix in the use phase of products (with 35% of the electricity produced from renewable energy sources[23]);
- specific improvements for products groups (less harmful refrigerants for the air conditioning and increase share of LED for lighting);
- increased remanufacturing and reuse of products and increased recycle of materials;
- expected change in the composition of the stock (i.e. increased number of appliances per household) and change of users' behaviour (intensity of use of the appliances owned).

Results of the scenario show that the analysed changes could generate some trade-offs: the impact of the scenario is lower than the impact of the baseline in most of the impact categories. However, for some impact categories the future scenario would imply higher impacts than the baseline, mainly due to the increase of the number of devices per person (Figure 78).

[23] Based on the EC's report "EU Reference Scenario 2016 – Energy, transport and GHG emissions Trends to 2050" (EC, 2016b)

Figure 78. Results of scenario on overall potential in the appliances sector in comparison with the baseline scenario of BoP Appliances (with total from the baseline set as 100%).



The highest reduction (63%) is obtained for ODP, thanks to the substitution of refrigerants and the reduction of refrigerant leakages. The effect of those measures are so important that they can offset the potential increase of the impact coming from the relevant increase in the number of air-conditioners owned by EU citizens (+53% compared to the baseline scenario). The impact on ionising radiation in the scenario is half of the one in the baseline (mainly because of the assumed phasing-out of nuclear power plants in Europe, when using the future European electricity mix). The new electricity mix has a positive effect also on acidification, because the reduction of the amount of coal-based electricity reduces the release of those substances contributing to AC. Thanks to the combined effect of improved efficiency of devices and the increased use of a renewable electricity sources, the impact on climate change and fossil resource depletion is reduced by 34% and 23% respectively.

On the contrary, for some impacts – namely human toxicity cancer effects, ecotoxicity, land use and mineral and metals depletion – the results of the scenario show an increase compared to the baseline. This can be mainly 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 increased use of more renewable electricity sources (e.g. the increase of the impact on land use is due to a larger use of wood as energy source).

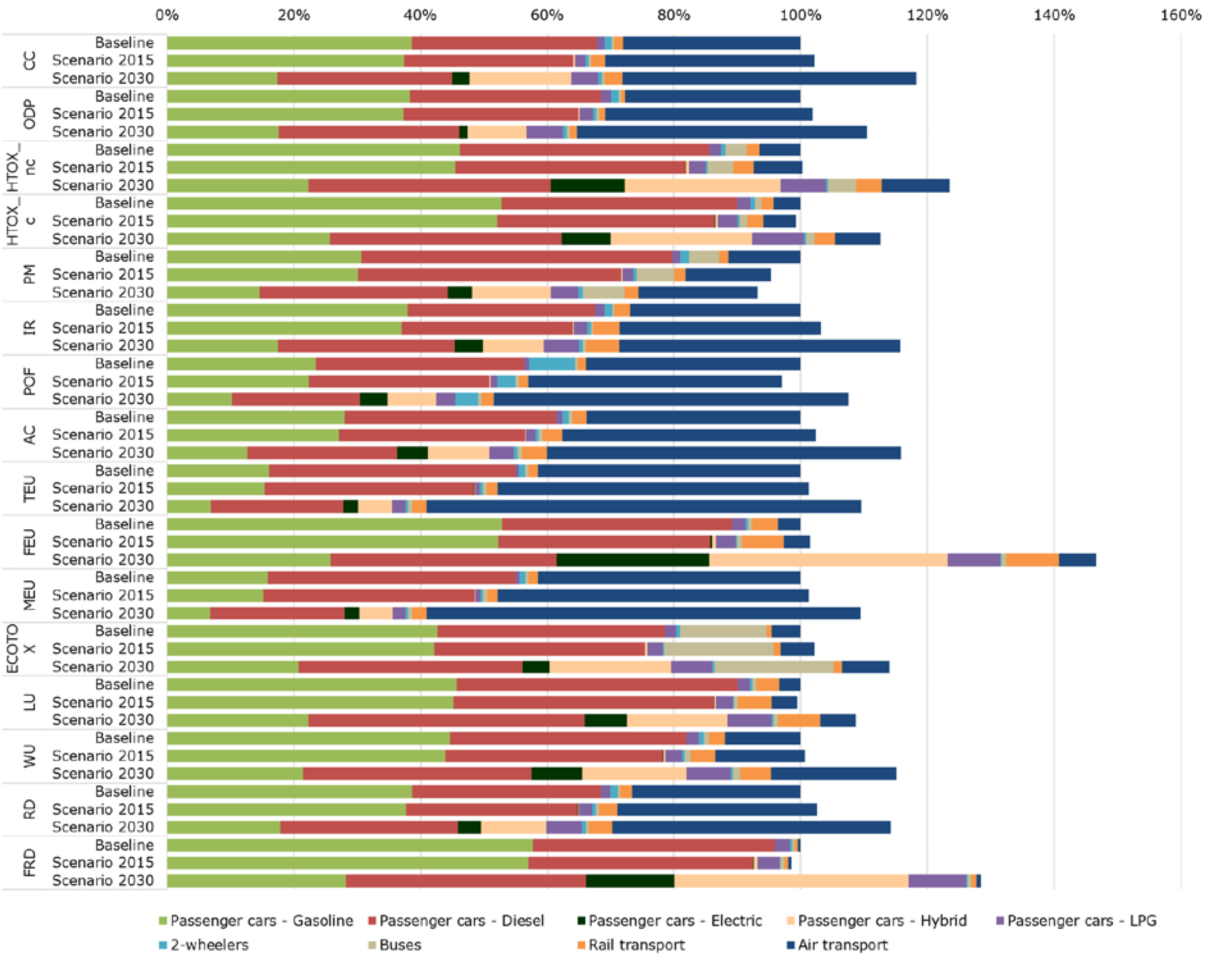
As a conclusion, it could be noted that the technical reduction potential is still quite high, but a further increase of the number of devices per household could offset substantial parts of this potential. Therefore, actions for the future improvements of the sector should consider also user behaviour and consumption patterns.

8.2.2 Expected evolution of EU mobility in 2030

This scenario is related to the BoP Mobility and it considers the expected evolution of EU mobility (in terms of fleet composition and mobility demand) in the future (reference year 2030). The scenario is based on the projections for the year 2030 adopted in the EU Reference Scenario 2016 approach (EC, 2016b), which provides simulations on future trend of EU energy, transport and climate change given certain conditions. It has been modelled by updating the fleet composition in terms of types and number of vehicles and the mobility demand (as passenger-kilometres – pkm - travelled) for each of the means of transport considered in the BoP Mobility. The most relevant change between the baseline year 2010 and the future scenario 2030 is the increase in the number of km travelled by an average citizen with the different means of transport and the expected increase of European population, partially due also to the enlarged geography (from EU-27 in 2010 to EU-28 in 2015 and 2030). This is reflected in a 10% increase of pkm from 2010 to 2015 and a further 25% increase from 2015 to 2030 (leading to 37% increase of pkm from 2010 to 2030). Other relevant differences regard the composition of the EU fleet. The scenario takes into account the expected increase of electric vehicles (EVs) and hybrid vehicles (HEVs) in the future and also the effect of regulations with tighter emission standards, i.e. the larger share of Euro 6 vehicles. Similarly, considering that in 2030 the Euro 3 vehicles would be from 26 to 30 years old, it has been assumed that in 2030 passenger cars compliant with emission standard lower than Euro 4 will be phased out.

Notwithstanding the expected improvement of emission standards and the notable share of EVs and HEVs in the car fleet, the scenario on European mobility in 2030 (Figure 79) shows higher impacts for all the assessed impact categories, compared to the baseline scenario (reference year 2010) and the updated baseline for the year 2015. This is mainly due to the expected increase in the amount of passenger-kilometres travelled and the number of vehicles of each mobility product. The increase in freshwater eutrophication is also due to the increased emissions from sulfidic tailings in the extraction process of gold, used in the printed wiring boards. Printed wiring boards are used in all types of cars, but their quantity is higher in electric and hybrid vehicles.

Figure 79. Results of scenario on mobility 2030 in comparison with the baseline scenario of BoP Mobility (with total from the baseline set as 100%) and the scenario 2015– split into the contributions of the various product groups.



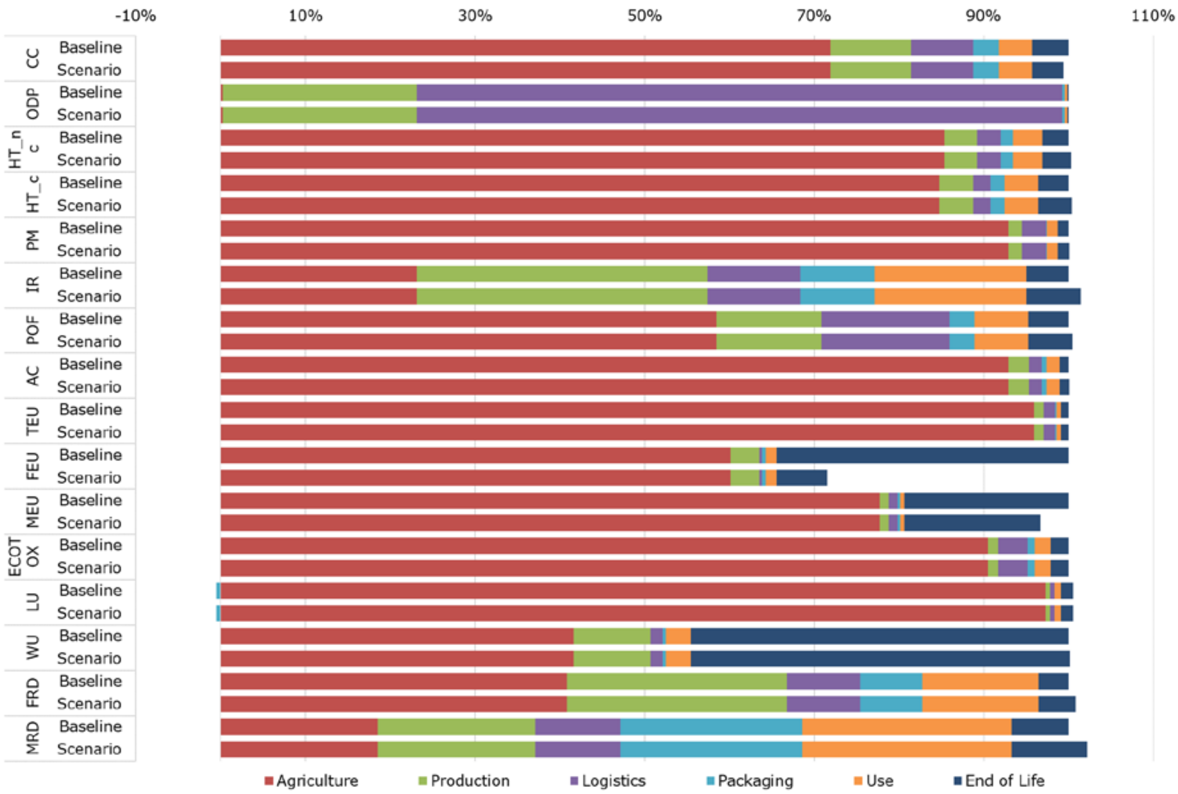
8.2.3 Improvement of European wastewater treatment facilities

This scenario is developed in the context of the BoP Food and it is aimed at testing the effects of an improvement in nutrients removal at the wastewater treatment stage, by assuming that tertiary treatment (i.e. an additional step for the removal of nutrients such as phosphorus and nitrogen) is applied to all the wastewater generated by the ingestion of food in the BoP.

The treatment of wastewater at the end of life of the BoP Food was found to be a hotspot for freshwater and marine eutrophication, due to the human metabolism of food, i.e. the emissions of nutrients in sewage from human excretion (and related treatment). Moreover, the Urban Waste Water Directive has specific targets on tertiary treatment, with the aim of increasing the number of pants in which tertiary treatment is performed. The BoP Food baseline assumes 46% secondary treatment and 54% secondary and tertiary treatment. The scenario is built by moving to 100% tertiary treatment for all the wastewater generated by the ingestion of food in the basket, modifying inputs and emissions for the wastewater treatment process accordingly.

According to the results obtained with the scenario (Figure 80), the implementation of tertiary treatment for all the wastewater generated from food consumption in the EU would determine a reduction of the impact of freshwater eutrophication potential (–28%) and, to a lesser extent, of marine eutrophication and climate change. The performance of some impact categories would instead be worse compared to the baseline scenario, because of the additional inputs the tertiary treatment requires (electricity and additives, such as chlorine). However, such increase of the environmental burden of this alternative scenario compared to the baseline can be considered negligible as the increase in impacts is below 5%. Hence, the implementation of a tertiary treatment step in all the wastewater treatment plants in the EU could be considered overall positive to reduce the impact on freshwater and marine eutrophication.

Figure 80. Results of scenario on wastewater treatment in comparison with the baseline scenario of the BoP Food (with total from the baseline set as 100%).



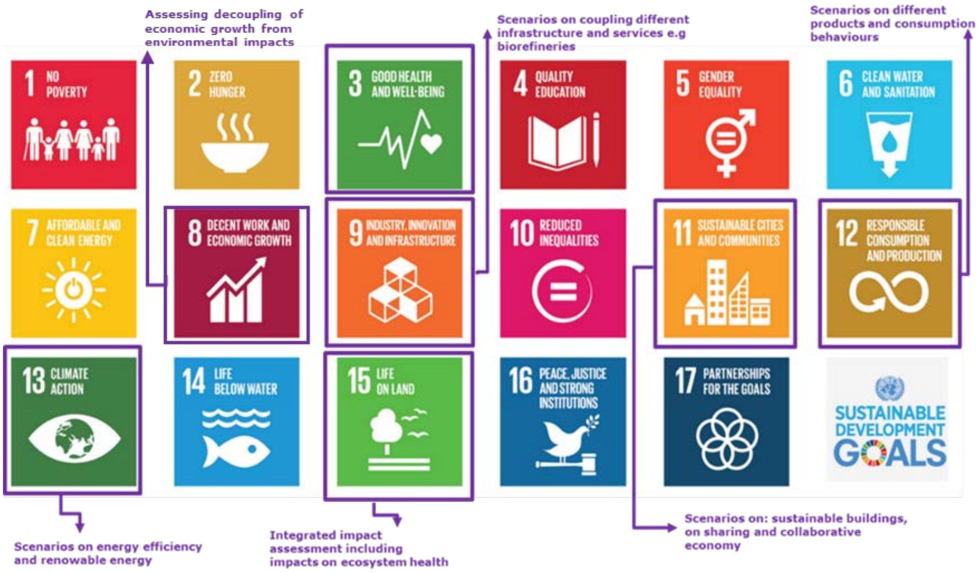
9 Life cycle based indicators and their support to policies

Through a Life Cycle Thinking approach, Consumption and Consumer Footprints provide an integrated view of the links between consumption and production, as well as the resource use and the associated environmental impacts. Therefore, they are relevant in monitoring progress towards the goals set by the flagship initiative, i.e. decoupling economic growth from the use of resources, supporting the shift towards a low carbon economy, increasing the use of renewable energy sources, modernising our transport sector and promoting energy efficiency (EC, 2011b). The Consumption Footprint and the Consumer Footprint have a clear link with policies for **Sustainable Consumption and Production (SCP)**, which aim at improving "the use of services and related products, which respond to basic needs and bring a better quality of life while minimizing the use of natural resources and toxic materials as well as the emissions of waste and pollutants over the life cycle of the service or product so as not to The two set of indicators has also crucial link with the "*Building the Single Market for Green Products - Facilitating better information on the environmental performance of products and organisations*" communication (EC, 2013). Some examples of policies and initiatives that may be supported by the set of indicators is reported in next sections.

9.1 Supporting SDGs

In the context of the SDGs (UN, 2015), **specific support** could be envisaged in relation to the **SDG 12** "Ensure sustainable consumption and production patterns", both **for monitoring impacts due to consumption patterns** and **for assessing options towards SDGs achievements**. Sustainable consumption and production aim at "doing more and better with less", thus increasing net welfare gains from economic activities by reducing resource use, degradation and pollution along the whole lifecycle, while increasing quality of life. The SDG 12 also requires a **systemic approach** and cooperation among actors operating in the supply chain, from producer to final consumer. Moreover, several scenarios related to intervention towards reaching an SDGs may be tested in term of environmental impacts and benefits, as well as trade-offs associated to implementation thereof. Conclusively, the two newly developed indicators the EU Consumer Footprint and the EU Consumption Footprint are proposed to be used for monitoring EU progress on SDG 12. Moreover, the life cycle based indicators are helping to assess the level of decoupling of economic growth from environmental impacts (SDG 8.4) which is essential in the Beyond GDP discussion. A specific study on the use of Consumer footprint for SDGs is reported in Sala and Castellani, 2019.

Figure 81. Sustainable development goals and examples of links with this project, through the possibility of testing several scenarios aiming at the transition toward sustainable development.



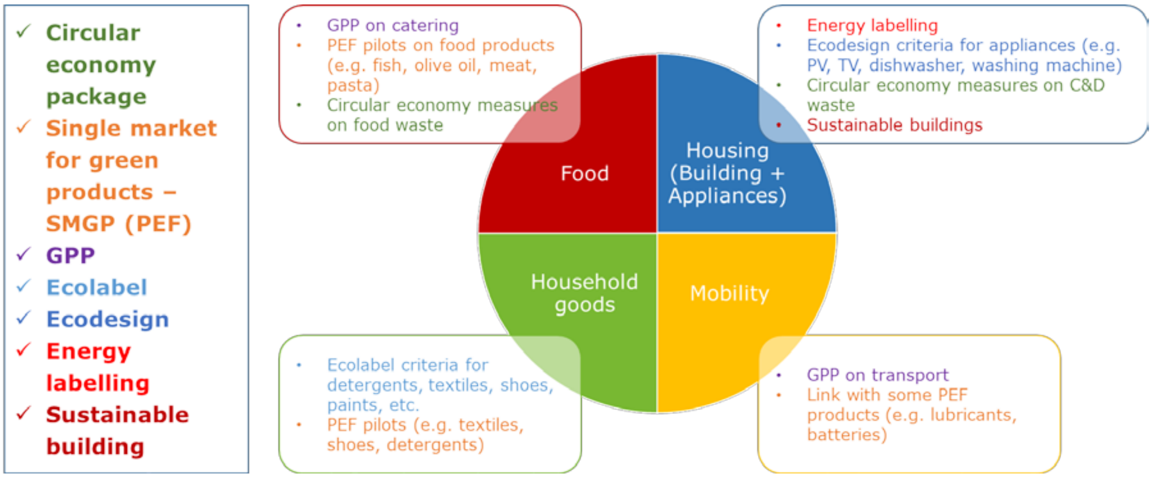
9.2 Relevance in support to the circular economy and the bioeconomy

The Consumption Footprint and the Consumer Footprint are relevant in the context of specific policies affecting production and consumption patterns, such as the circular economy (EC, 2014b) and the Bioeconomy (EC, 2018b). The set of indicators may be used both for **assessing the benefits associated to possible more circular and or bio-based scenarios** as well as for **monitoring environmental trends related to the implementation of those policies**.

9.3 Relevance in support to product policies

The life cycle indicators project may represent an ideal framework for testing the potential benefit associated to product policies, including ensuring that environmental burdens do not shift from a life cycle stage to another or from one impact category to another. More specifically, in relation to a wide range of product policies, in Figure 82, we report an overview of the possible synergies between different thematic BoPs and existing/future product policies.

Figure 82. Basic overview of the potential synergies between the different thematic Basket of products indicators and existing/future product policies.



Concerning the links between the Consumer Footprint indicator and the existing product policies, the **Consumer Footprint could be seen as a baseline scenario**, reflecting average EU consumption, on which to test: i) benefits associated to improved products (e.g. an Ecolabel product or a product with a high energy class) against the burden of the overall consumption, and ii) benefits associated to the introduction of specific criteria (e.g. GPP criteria).

Regarding possible future policies, the link with the Environmental Footprint (both product and organisation) (EC, 2013a) is related to both the Consumption Footprint, which represents the basis for calculating normalisation factors, as well with the Consumer Footprint, which could be used to test scenarios in which PEF products are assessed. The current models in the Consumer Footprint are not fully aligned with PEF modelling, as the project has run in parallel with the PEF pilot phase 2013-2018.

Regarding existing product policies such as the Communication on Resource Efficiency Opportunities in the Building Sector (EC, 2014c) and the EF, again the Consumer Footprint indicators may have several roles: testing assumption and criteria towards more sustainable products; creating a basket of PEF products; assessing products within their average EU systems (in terms of infrastructure, manufacturing etc.).

10 Conclusion and outlook

This study has proposed the implementation of different LCA-based approaches to estimate environmental pressures and impacts due to EU consumption. The assessment has been performed at different scales: entire EU, 28 Member States, sector and product, and individual citizens. Namely, two indicators have been assessed along this report:

- the **Consumption Footprint**, tracking the overall environmental impacts of consumption in the EU (taking into account both the burdens associated with domestic activities and trade);
- the **Consumer Footprint**, assessing the environmental impacts of household consumption in EU.

Along the study, different accounting perspectives (respectively domestic, consumption-based top-down and consumption-based bottom-up) have been implemented, either in combination to each other or as a matter of comparison for evaluating the robustness of results and subsequent conclusions. The different approaches undertaken have led to several key converging results with respect to the environmental impacts of consumption in the EU:

— An absolute **decoupling of environmental impacts from economic growth is observed** in the period 2000-2014 for both Domestic Footprint and Consumption Footprint. On average, from 2000 to 2014, the total Domestic Footprint decreased by 21%, despite an increase in the GDP of 19%. The extent of decoupling observed for the Consumption Footprint is different depending on the accounting approach adopted, i.e. top-down or bottom-up. Between 2005 and 2014 the GDP increased by 8%, whereas the Consumption Footprint Top-down remained quite stable, and the Consumption Footprint Bottom-up decreased by 23%. Robustness of the data is not the same in the approaches, and differences are present in terms of country coverage, emission and resource coverage, time coverage, reliability of sources;

— **In the case of the Consumption Footprint Bottom-up**, beneficial to the negative trend are the concomitant reduction of the Domestic Footprint (-19%), the reduction of the Import Footprint Bottom-up (-5%), and the considerable increase of the Export Footprint Bottom-up (+27%) (the so-called "**export effect**");

— Within the Consumption Footprint, both the top-down and the bottom-up approaches highlighted an **overall predominance of the environmental impacts due to imports compared to exports for almost all the impact categories**. This means that a share of the environmental impacts associated with EU consumption are generated outside EU borders and **EU can, therefore, be mainly considered a "net importer" of environmental impacts**. This is despite the increase in the Export Footprint (+40% and +27% from 2005 to 2014, considering results respectively from the top-down and the bottom-up approaches);

— The **impact of import is dominated by "fuels and mineral oils"** according to the bottom-up approach. The top-down approach identifies a broader range of contributors depending on the impact category: i) **food products** (in particular meat) and food-related services ii) **basic and intermediate products** (in particular basic iron and steel, and rubber and plastic products) and iii) **raw materials** (fossil, mineral and metal resources). The impact of export is dominated by manufactured products in both approaches, with some exceptions for the bottom-up approach (including fuels and mineral oils, and iron and steel);

— According to the **Consumer Footprint** by basket of products (BoP), the main drivers of impact from citizens' apparent consumption of goods and services are **meat and dairy products**, **space heating for housing** (especially in cold climate) and **the use of private cars**, especially diesel ones;

— Looking specifically at the areas of consumption leading the impacts, **food appears to be the main driver for impacts** on acidification, terrestrial, freshwater and marine eutrophication, land use and water use in the two approaches undertaken (the bottom-up Consumer Footprint and top-down Household Footprint). In particular, food contributes to more than 70% of the impact on terrestrial and marine eutrophication and on land use for the Consumer Footprint. Yet, the lower contribution of food sector in Household Footprint compared to the Consumer Footprint is observed as a recurrent difference. Fossil resource depletion is driven by housing and mobility in both approaches;

— Based on the Consumer Footprint and Household Footprint the impact of **particulate matter** is **generated mainly by food and secondly by housing**, yet with different shares depending on the approach. These two modelling approaches had also diverging results in determining the most contributing sectors for the impact categories human toxicity, non-cancer effects, ecotoxicity and mineral resource use;

— The **comparison of different approaches for calculating Consumption Footprint and Consumer Footprint showed that generally top-down approaches are overestimating impacts**, which is in line with the fact that they cover more broadly the areas of consumption (e.g. including services). On the contrary, for specific impact categories, additional modelling effort is needed, e.g. for what concern toxicity related impact categories and resource use;

— It is evident that **reducing the environmental impacts of production of goods**, for example **by improving technological efficiency, is not enough to guarantee a reduction in the overall footprint**. The use phase plays a central role in the overall environmental burdens exerted by an average EU-citizen, particularly in certain areas of consumption, e.g. for most of the impact categories use phase is responsible of 80% of the impact per year in the BoP Housing and 50% in the BoP Appliances;

— Example of **different consumer profiles showed that food consumption is still the main driver of impact in many impact categories**, also for people with a semi-vegetarian or vegetarian diet. In the case of a family with two private cars, mobility becomes relevant as well. In case of single persons, housing is second contributor in addition to food;

— A **Consumer Footprint tool has been developed** based on the results of the different basket of products for enabling the assessment of specific consumer profiles, addressing main differences in consumption patterns (e.g. a diet or housing could be changed);

— When assessing trends in the different areas of consumption **over the period 2010-2015**, data show that **household consumption per person generally increased from 2010 to 2015**, e.g. food consumption increased by 6%, the kilometres travelled by European citizens increased by 10%, etc. This determines an increase of Consumer Footprint, due also to the extension of the geography from EU-27 to EU-28 (and the consequent increase in the population by 1%). BoP Housing is an exception to this trend. The impact in 2015 was around 10% less compared to 2010 for most of the impact categories, mainly driven by a general reduction of energy use in the buildings (especially for space heating);

— A **systemic perspective is** therefore required **to reduce the overall environmental burdens of EU consumption patterns.** It should encompass both the production and the consumption sides and, specifically regarding production, it should include both domestic activities and activities taking place outside EU boundaries;

— Regarding the contribution of the **different areas of consumption in the EU over key areas of concerns**, i.e. "**human health**" and "ecosystem quality"/"**biodiversity**": **climate change** and **particulate matter** drive the impacts on **human health** while **climate change**, **land use** and **acidification** lead to impacts on **biodiversity**;

— When **comparing the impact generated in the EU with the impacts generated globally** (global impact references), **the impact of the EU spans** from about 2%

regarding impact on mineral and metals resource extraction to 63% of ionising radiation for the Domestic Footprint and, **on average, from 2% of impact on ozone depletion to 51% of ionising radiation for the Consumption Footprint and the Consumer Footprint**;

— Adopting a per-capita perspective in assessing the extent to which Planetary Boundaries are overcome, **the environmental impact of the consumption of an average EU citizen is outside the safe operating space for humanity for several impact categories**, namely climate change, particulate matter, resource use, human toxicity, photochemical ozone formation and land use. The level to which the thresholds are overcome change in the different modelling approaches. However, there is a clear result that for most of the impact categories the impacts are close to the threshold when not overcome.

10.1 Limitation, research needs, and outlook

The study on the environmental impact of EU consumption is the first study exploring systematically different approaches to model the impact of EU consumption, comparing their results, including assessment to the Planetary Boundaries and aiming at a single headline indicator (a weighted score of the 16 environmental impact categories covered) for communicating these results. However, while exploring the assessment of the environmental impact of consumption from different modelling approaches and point of view, this study has also identified key limitations in the methods and corresponding databases, but also (and sometimes, subsequently) key perspectives for developments and further applications areas.

Domestic Footprint

The inventory underpinning the Domestic Footprint has been compiled by means of different types of data (i.e. raw data from statistical sources, estimated data and extrapolated data). The difference in the data sources may introduce some uncertainties, and the hierarchical approach applied in case of multiple sources for the same type of data plays a role as well. Additionally, data coverage is not the same for all Member States. All these aspects have an important role in determining the overall robustness of the results by country, year, and impact category. It is noteworthy to take into consideration that the linear extrapolation of some missing data for the most recent years could influence the decreasing trend registered in some impact categories showing the decoupling (e.g. ozone depletion, eutrophication). In addition, the uncertainties associated to the characterization model adopted could introduce other elements of uncertainty. Another key feature is the consistency between the level of detail for both the inventory and the characterization factors (CFs) underpinning the calculation. For example, since the Domestic Footprint allows for the assessment of the decoupling of economic growth from the overall impacts in EU as a whole and at the Member State level, the regionalisation of impact assessment could be quite important. At present average CFs are used in the calculation, while data in the inventory are country-specific. Therefore the use of country-specific CFs may lead to differences in results (e.g. in land use and water use impact categories).

Consumption Footprint Top-down

The implementation of EXIOBASE 3, as any MRIOTs, enables to account not only for products but also for services in the assessment of the footprint of EU consumption. In addition, EXIOBASE 3 has been built considering specific modules for calculating and representing the EXIOBASE 3 environmental extensions of the agriculture and energy sectors (Merciai and Schmidt, 2017), which appear key in the evaluation of the environmental impacts of EU consumption. However, at this stage of development of the EXIOBASE 3 environmental extensions, three of their features imply that the impact assessment step adds a layer of uncertainty, potentially significant but still unexplored:

— a number of elementary flows, generally modelled in process-based LCA, are absent from the environmental extensions, so that part (especially regarding human toxicity and ecotoxicity) or even the entirety of impacts (regarding ozone depletion and ionizing radiation) cannot be properly assessed;

— details are missing regarding some properties of emissions (e.g. speciation of metals emitted to the environment), whereas they may significantly affect the impact assessment step;
— some flows are reported in an aggregated manner compared to their counterpart in impact assessment methods, while largely contributing to impacts (e.g. other industrial minerals with respect to minerals and metals resource use).

These features could be considered a basis for completing the environmental extensions in order to improve the robustness of any impact assessment performed using EXIOBASE 3, specifically regarding human toxicity (cancer and non-cancer), freshwater ecotoxicity, minerals and metals resources and to a lower extent particulate matter and land use. Moreover, the on-going development of new MRIOT databases (such as under the frame of the project FIGARO) could also be considered a basis for complementing the use of EXIOBASE 3 in future studies.

Consumption Footprint bottom-up

The selection of imported and exported products in the bottom-up approach was based on mass and economic criteria, which may be not sufficient to comprehensively identify the representative products which bear significant environmental impacts. An integration of different perspectives is, hence, needed. In addition, life cycle inventories of representative products may not properly reflect actual production practices in different countries. Options to improve the modelling of the Trade Footprint Bottom-up include: i) additional selection criteria for representative products, e.g. environmental relevance coming from specific studies; ii) a larger number of representative products, iii) and improvements in the life cycle inventories.

Consumer Footprint

Regarding the Consumer Footprint, the bottom-up approach, by means of process-based LCA of representative products, has covered five areas of consumption. However, the use of representative products may limit the possibility to fully represent the whole range of products on the market, and their variability in terms of features, and, consequently, of impacts (e.g. the difference between an average product and a more environmentally friendly one). The Consumer Footprint proved to be useful for modelling scenarios acting on specific features of the products composing the baskets (e.g. future energy efficiency improvement, or changes in the use of products). Moreover, it was possible to model consumption scenarios based on consumer choice and behaviours, in particular thanks to the Consumer Footprint calculator. The calculator enables users to take benefit of the process-based LCA framework to model the consumption of EU citizens, considering specific features of consumption at the product-level. For both macro and micro scale scenarios, it should be noted that such modelling of future scenarios could necessitate complements regarding the way some products are currently modelled, while some of their specific features may change in the future and their share in the total consumption may significantly increase or decrease compared to today. The use of existing studies entirely focused on future scenario analysis for specific topics (as the EU Reference scenario on energy and transport, used as input for modelling scenarios on mobility and appliances) proved to be a good way to complement the Consumer Footprint framework in the definition of scenarios taking into consideration both the technological development and the expected trends of consumer behaviours. In addition, it is to be noted that IO analysis (for example, using EXIOBASE 3) could also fit well to the modelling of future consumption scenarios, and could be considered a point of comparison of interest despite the limits on environmental extensions above-mentioned. Finally, a future improvement of the work on scenarios could be focused on including rebound effects generated by the innovation or by the behavioural changes assessed in scenario analyses.

Planetary Boundaries

The environmental impacts of EU consumption have been put in perspective with Planetary Boundaries. The knowledge of Planetary Boundaries can improve environmental policy relevance, by measuring the sustainability gap between the current human-driven impacts and their related carrying capacity thresholds. However, at the current state of knowledge, a crucial point is usually linked to the difficulties and the consequent uncertainties in defining the boundaries, due both to the underpinning ecological complexity of their evaluation and the need of translating the boundaries metrics in those used in Life Cycle Assessment. For example, this is particularly relevant for land use as the underneath inventory is poor in coverage (i.e. its calculation is based on four land use, occupation flows only), thus leading to a potential underestimation of the planetary boundary. Moreover, the inclusion of impacts on human health is still controversial, leading to possible significant underestimation of impacts such those due to particulate matter.

Calculation of impacts by means of endpoint modelling

Concerning the contribution of EU consumption to the impacts on key areas of concerns, such as “human health” and “ecosystem quality”, this study provides results based on the application of one among various endpoint methods currently available in the literature (Recipe). A sensitivity analysis with additional impact assessment models at the endpoint level would enable to achieve a better assessment of the impacts of EU consumption. Moreover, additional work is needed on deepening the assessment of the link between consumption and its impact on biodiversity loss due to drivers beyond those addressed by the current adopted impact categories (e.g. addressing impacts due to marine litter).

Calculation and visualisation of results

Additionally, this study has led to the development of specific tools enabling the calculation of the above-mentioned indicators and a more efficient visualisation and interpretation of the results. Both a Consumer Footprint calculator and a Consumption Footprint platform have been developed. The latter it is mainly dedicated to the visualisation and the communication of Consumption Footprints (regarding domestic, trade and apparent consumption) considering the 28 EU Member States. The Consumption Footprint platform is based on a navigable website and allows for data management and data checking as well as the visualization of several typologies of charts according to users’ needs.

Contingency plan

This study has focused on the environmental pressures and impacts due to European Consumption in the recent past years, covering the period 2000-2015 depending on the indicator at stake (e.g. 2000-2014 for the Domestic Footprint, and years 2010 and 2015 for the Consumer Footprint). The way in which the indicators are built allows for future updates of the assessment over time. However, this may be faced with some challenges, specific to each indicator.

Regarding the Consumer Footprint, the calculation of apparent consumption (used to define the amount of each representative product in the BoPs) has been built so that it fits the format of Eurostat statistics on consumption for most BoPs. The potential future update of the Consumer Footprint will be feasible through the Consumer Footprint calculator in a very direct manner, in case the format of Eurostat data on consumption remains similar to that of previous years. Yet, in the case of the BoP Housing, the model of the European building stock relies on several data sources, different from Eurostat. A discrepancy in data has already been observed from 2010 to 2015, due to the discontinuation of some of the sources used to model the year 2010. The use of the EU Building Observatory database (as it has been done for 2015) should allow for continuity in the future assessment, but this cannot be ensured at the moment. Moreover, the life cycle inventories that are used as a basis for calculations should as well be updated to account for the changes in the environmental impacts of products over time (e.g. regarding the energy efficiency of appliances). With this respect, the use of the EF database represents a key opportunity for updating the future Consumer Footprint.

Moreover, regarding footprints obtained entirely or partly by use of the EXIOBASE 3 database (i.e. Consumption Footprint Top-down and Household_I/O Footprint) their update will be related to updates of the database (and therefore depends on the developing team). It should be noted that the previous updates of EXIOBASE (e.g. from version 2 to version 3) was accompanied by a larger level of disaggregation, regarding products as well as environmental extensions. In case the framework of environmental extensions is modified in the future, then the mapping from emissions and resources to impacts (that is, the approach undertaken to translate elementary flows into impacts) will have to be updated as well.

In particular, for what concerns the Domestic Footprint, an increase in the level of coverage in order to have the same level for all the countries involved is needed to enhance the robustness of the results. This could be done by involving directly providers of statistical data to ensure a steady and prompt provision of raw data, for example. Additionally, the use of regionalised characterization factors could improve as well the Domestic Footprint.

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List of abbreviations

AC	Acidification, terrestrial
AoP	Area of Protection
BGS	British Geological Survey
BoP	Basket of Products
B-up	Bottom-up
BS	Behavioural Science
CF	Characterization factors
CFC	Chlorofluorocarbons
CN8	Eight-digit combined nomenclature
CNG	Compressed natural gas
COICOP	Classification of Individual Consumption According to Purpose
DALY	Disability-adjusted life years
DMC	Domestic material consumption
EEA	European Environmental Agency
EF	Environmental footprint
EoL	End of Life
EQ	Ecosystem quality
EU	European Union, considering the 28 Member States in 2018
EU-27	European Union, included EU Member States
EU-28	European Union, included EU Member States
EV	Electric vehicle
EXP	Expenditures
FAO	Food and Agricultural Organization of the United Nations
FBS	Food Balance Sheets
FCE	Final Consumption Expenditure
FU	Functional Unit
GDP	Gross Domestic Product
GHG	Greenhouse gas
GPP	Green Public Procurement
HDI	Human Development Index
HEV	Hybrid electric vehicle
HH	Human health
HS2	Two-digits harmonized system
IAEA-PRIS	International Atomic Energy Agency – Power Reactor Information System
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
LPG	Liquid petroleum gas
MFH	Multi-Family House
MS	Member States
nec	not elsewhere classified
NF	Normalisation factors
OECD	The Organisation for Economic Co-operation and Development
PB	Planetary boundary
PDF	Potentially disappeared fraction of species
PEF	Product Environmental Footprint
pkm	Passenger-kilometres
RME	Raw Material Equivalent
RPA	Risk and Policy Analysts
SDG	Sustainable Development Goals
SFH	Single-Family House
TCF	Totally Chlorine Free
UNFCCC	United Nations Convention on Climate Change
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
USGS	United States Geological Survey
WEEE	Waste Electrical and Electronic Equipment
WF	Weighting factors
WFr	Reversibility-based weighting factors
WWTP	Wastewater treatment plant

Abbreviations for Member States

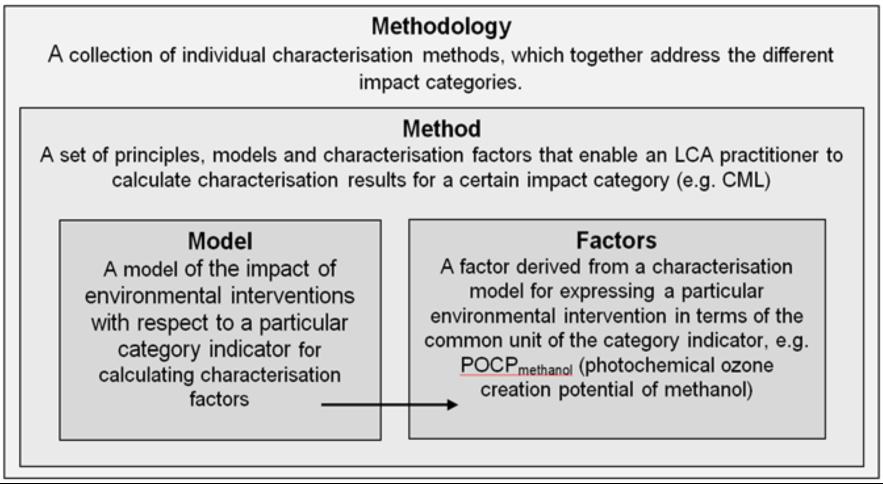
AT	Austria
BE	Belgium
BG	Bulgaria
CY	Cyprus
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
EL	Greece
ES	Spain
FI	Finland
FR	France
HR	Croatia
HU	Hungary
IE	Ireland
IT	Italy
LT	Lithuania
LU	Luxemburg
LV	Latvia
MT	Malta
NL	The Netherlands
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia
UK	United Kingdom

Abbreviations for impact categories

AC	Acidification
CC	Climate change
CC-HH	Climate change human health (for endpoint only)
CC-T	Climate change terrestrial ecosystem (for endpoint only)
ECOTOX	Ecotoxicity, freshwater
ECOTOX-F	Ecotoxicity, freshwater (for endpoint only)
ECOTOX-M	Ecotoxicity, marine (for endpoint only)
ECOTOX-T	Ecotoxicity, terrestrial (for endpoint only)
FEU	Eutrophication, freshwater
FRD	Resource use, fossils (impacts due to)
HTOX_c	Human toxicity, cancer
HTOX_nc	Human toxicity, non-cancer
IR	Ionising radiation
LU	Land use (impacts due to)
MEU	Eutrophication, marine
MRD	Resource use, minerals and metals (impacts due to)
NMVOC	Non-methane volatile compounds
ODP	Ozone depletion
PM	Particulate matter
POF	Photochemical ozone formation
POF-HH	Photochemical ozone formation, human health (for endpoint only)
POF-T	Photochemical ozone formation, terrestrial ecosystem (for endpoint only)
TEU	Eutrophication, terrestrial
WU	Water use (impacts due to)
WU-HH	Water use, human health (for endpoint only)
WU-T	Water use, terrestrial ecosystem (for endpoint only)

List of definitions

Definiendum	Definition
Absolute decoupling	The environmental impact is stable or decreasing while the economic growth is increasing.
Apparent consumption	It is the mathematical sum of domestic production plus imports minus exports (APPARENT CONSUMPTION = IMPORTS + DOMESTIC – EXPORTS). It differs from "real" consumption because it does not take into consideration changes in stocks.
Area of protection (AoP)	A cluster of category endpoints of recognisable value to society, viz. human health, natural resources, natural environment and sometimes man-made environment (Guinée et al., 2002).
Bottom-up inventory	It refers to a technique for modelling inventories. Elements of level *n-1* are used to model a system of level *n* e.g. LCIs of some representative products (level n-1) in import are up-scaled so to quantify the LCI of the overall import in one country (level n).
Carrying capacity	The carrying capacity of a biological species in an environment is the maximum population size of the species that the environment can sustain indefinitely, given the food, habitat, water and other necessities available in the environment. In population biology, carrying capacity is defined as the environment's maximal load, which is different from the concept of population equilibrium (Hui, 2006; Sayre, 2008).
Cause-effect chain	or environmental mechanism. System of physical, chemical and biological processes for a given impact category, linking the life cycle inventory analysis result to the common unit of the category indicator (ISO 14040) by means of a characterisation model.
Characterisation	A step of the Impact assessment, in which the environmental interventions assigned qualitatively to a specific impact category (in classification) are quantified in terms of a common unit for that category, allowing aggregation into one figure of the indicator result (Guinée et al., 2002).
Characterisation factor	Factor derived from a characterisation model which is applied to convert an assigned life cycle inventory analysis result to the common unit of the impact category indicator (ISO 14040).
Characterisation methodology, methods, models and factors	Throughout this document an "LCIA methodology" refers to a collection of individual characterisation "methods" or characterisation "models", which together address the different impact categories, which are covered by the methodology. "Method" is thus the individual characterisation model while "methodology" is the collection of methods. The characterisation factor is, thus, the factor derived from characterisation model which is applied to convert an assigned life cycle inventory result to the common unit of the category indicator.



Consumption Footprint	This indicator aims at tracking the overall environmental impacts of apparent consumption in the EU-28. Consumption Footprint = Domestic Footprint + Import Footprint – Export Footprint The Consumption Footprint is calculated according to two modelling approaches: Bottom-up and Top-down.
Consumption Footprint Bottom-up	Consumption Footprint calculated by implementing a bottom-up modelling approach, namely process-based LCA.
Consumption Footprint Top-down	Consumption Footprint calculated by implementing a top-down modelling approach, namely Environmentally Extended Input-Output analysis with EXIOBASE 3 as the supporting database.

Definiendum	Definition
Domestic Footprint	Overall environmental impact of European Union (EU-28) and ultimately of each Member State with a production-based approach. It is calculated by characterizing the domestic inventory.
Domestic inventory	Inventory of emissions to air, soil and water and resource extraction which takes place within boundaries of a country (or territory).
Domestic Material Consumption (DMC)	Environmental accounting tool that covers flows of resources by accounting for their mass, adopting the 'apparent consumption' perspective. Products in import and export do not take into account materials used in their production.
Driver	A natural or human-caused forcing that causes change in an ecosystem. Drivers can be direct (proximate) or indirect (ultimate) depending on the perspective or scale. For example, deforestation is a proximate driver of habitat fragmentation, whereas economic demand for timber is an ultimate driver of deforestation and therefore fragmentation (Brook et al., 2013).
Elementary flow	Material or energy entering the system being studied that has been drawn from the environment without previous human transformation (e.g. timber, water, iron ore, coal), or material or energy leaving the system being studied that is released into the environment without subsequent human transformation (e.g. CO_2 or noise emissions, wastes discarded in nature) (ISO 14040).
Endpoint method/model	The category endpoint is an attribute or aspect of natural environment, human health, or resources, identifying an environmental issue giving cause for concern (ISO 14040). Hence, endpoint method (or damage approach)/model) is a characterisation method/model that provides indicators at the level of Areas of Protection (natural environment's ecosystems, human health, resource availability) or at a level close to the Areas of Protection level.
Environmental Footprint (EF) – PEF/OEF	Life cycle based methodology for the assessment of the environmental profile of products (PEF) or organisations (OEF).
Environmentally-extended input-output (EEIO) analysis	Accounting method which builds on economic input output tables, complemented with environmental extensions, so to attribute emissions to the environment or resource use from the production stages to final demand in a consistent framework.
Environmental impact	A consequence of an environmental intervention in the environment system (Guinée et al., 2002). Potential impact on the natural environment, human health or the depletion of natural resources, caused by the interventions between the technosphere and the ecosphere as covered by LCA (e.g. emissions, resource extraction, land use).
Environmental profile	The result of the characterisation step showing the indicator results for all the predefined impact categories, supplemented by any other relevant information (Guinée et al., 2002).
EXIOBASE	"EXIOBASE is a global, detailed Multi-regional Environmentally Extended Supply and Use / Input Output (MR EE SUT/IOT) database" developed within the EU projects EXIOPOL, CREEA, and DESIRE (see http://www.exiobase.eu/ and Stadler et al., 2018). Version 3 of EXIOBASE (project DESIRE) "builds upon the previous EXIOBASE version with a focus on extending the time resolution to yearly MRIO tables ranging from 1995 to 2011. [...] In terms of countries, the focus remains on the EU and major economies, but with the inclusion of the new EU member state Croatia" (Stadler et al., 2018). The hybrid version of EXIOBASE 3 (Merciai and Schmidt, 2017) has been used in this study.
Export Footprint Bottom-up	Environmental impact of EU-28 exports calculated with a bottom-up approach, expressed as weighted score.
Final Consumption Expenditures (FCE)	Expenditure by resident institutional units - including households and enterprises whose main economic centre of interest is in that economic territory - on goods or services that are used for the direct satisfaction of individual needs or wants or the collective needs of members of the community.
Final consumption expenditure of households (also referred as "household consumption"	Household final consumption expenditure consists of the expenditure, including imputed expenditure, incurred by resident households on individual consumption goods and services, including those sold at prices that are not economically significant (Eurostat, 2008).
Footprint	A "footprint" is a quantitative measurement describing the appropriation of natural resources by humans. A footprint describes how human activities can impose different types of burdens and impacts on global sustainability (Čuček et al., 2012).
Impact category	Class representing environmental issue of concern (ISO 14040). E.g. Climate change, Acidification, Ecotoxicity etc.
Impact category indicator	Quantifiable representation of an impact category (ISO 14040). E.g. kg CO_2-equivalents for climate change.

Definiendum	Definition
Import Footprint Bottom-up	Environmental impact of EU-28 imports calculated with a bottom-up approach, expressed as weighted score.
ISO 2-digits code	ISO 3166-1 alpha-2 codes defined as two-letter country codes.
Life Cycle Assessment (LCA)	LCA is a methodology for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle.
Life cycle impact assessment (LCIA)	"Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a given product system throughout its life cycle." (ISO 14040) The third phase of an LCA, concerned with understanding and evaluating the magnitude and significance of the potential environmental impacts of the product system(s) under study. LCIA is the phase in which the emission and the resources associated to each life cycle stage of a products are evaluated in terms of environmental impacts, covering a wide variety of impact categories (e.g. climate change, acidification, eutrophication etc.). It allows understanding and evaluating the magnitude and significance of the potential environmental impacts of the product system(s) under study. EC-JRC has developed a guidance for LCIA (EC-JRC, 2011), identifying models and indicators for 14 impact categories.
Life cycle inventory (LCI)	It is an inventory of input/output data with regard to the system being studied (ISO 14044).
Life-Cycle-Thinking	Life Cycle Thinking (LCT) is about going beyond the traditional focus and production site and manufacturing processes to include environmental, social and economic impacts of a product over its entire life cycle.
Midpoint method and midpoint indicator	The midpoint method is a characterization method that provides indicators for comparison of environmental interventions at a level of cause-effect chain between emissions/resource consumption and the endpoint level.
Normalisation	According to ISO 14044, normalisation is an optional interpretation step of a complete LCA study. Normalisation allows the practitioner to express results after characterization using a common reference impact and it may be particularly of help if results need to be communicated to policy makers. Using normalisation references in combination with weighting factors, the relative magnitude of an impact may be related to other impacts in the life cycle with a common unit.
Normalisation factors	In the context of LCA, normalisation factors represent reference quantity (in terms of overall emission and used resources) related to production or consumption either at global scale or at country scale.
Overall environmental impact	Total of impacts on human health, natural environment and resource depletion for the considered impact categories. It can be calculated either as normalised and weighted overall LCIA results of the analysed process/system, or assuming an even weighting across impacts, i.e. for each and any of the impact categories.
Planetary Boundaries	A framework concept developed by Rockström et al. (2009) to define a desired operating range for essential Earth-system features and processes. Transgressing a terrestrial planetary boundary implies a risk of damaging or catastrophic loss of existing ecosystem functions or services across the entire terrestrial biosphere.
Relative decoupling	The environmental impact increases but without exceeding the economic growth.
Representative products	Products that well represents average properties of some particular product groups.
System and system boundaries	The system boundaries define which parts of the life cycle and which processes belong to the analysed system, i.e. are required for providing its function as defined by its functional unit. They hence separate the analysed system from the rest of the technosphere as well as to the ecosphere.
Top-down inventory	It refers to a technique for modelling inventories. Elements of level *n* are allocated so to model a system of level *n-1* e.g. emissions of CO_2 associated to economic sectors (level n) are allocated by means of mass or economic value and expenditure statistics so to quantify the emissions associated to products (level n-1) purchased by consumers.
Trade Footprint Bottom-up	Referring to both Import Footprint Bottom-up and Export Footprint Bottom-up.

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