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Indicators and assessment of the environmental impact of EU consumption

Consumption and Consumer Footprints for assessing and monitoring EU policies with Life Cycle Assessment

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The study underpinning the calculation of the 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 Life Cycle Assessment (LCA) to define the baseline of impacts due to consumption in Europe and to test eco-innovation and policy options against that baseline.

Contents

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This Science for Policy Report is complemented by a technical report presenting the results of the LC-IND2 project, where methodological details and assumptions as well as comparisons with other available studies are reported (Sala et al., 2019). The contribution of each author to the work performed in the LC-IND2 project is fully detailed in this technical report.

Executive summary

This report provides an overview of the result of the application of Life Cycle Assessment (LCA) to assess the environmental impacts of consumption in the European Union (EU) as a basis to support policies and to improve the appraisal of impacts and benefits thereof.

The content builds upon the results of the **Life Cycle Indicators** (LC-IND2) **project**[1], which aimed to develop two sets of Life Cycle Assessment-based indicators for the assessment of the environmental impact of EU consumption: the **Consumer Footprint** and the **Consumption Footprint**. The designed indicators aim to:

- monitor the evolution of environmental impacts of consumption over time in the EU and the Member States as well as the progress towards decoupling economic growth from environmental impacts;
- build an **LCA-based framework** for assessing impacts of consumption patterns and impacts and trade-offs related to eco-innovation policies. Environmental impacts are assessed from three different perspectives: **product group level**, **consumption areas** (Food, Mobility, Housing, Household goods, and Appliances) and **average EU consumer**;
- develop a **single headline indicator to monitor** the evolution of the overall environmental impacts of EU consumption and production at macro level. This includes the elaboration of a specific framework on which to build such indicator and complete time-series for each Member State and for the EU as a whole;
- test burden and benefits of **eco-innovation scenarios** along the supply chains, from extraction of raw materials, to consumer behaviour, up to end of life options.
- support the **future design of policy measures** which target the key sectors identified by this study

Moreover, since the Better Regulation (EC, 2015a), within its toolbox, foresees the enhanced application of LCA for the purpose of supporting policy impact assessments, this report is offering an overview of possible uses of LCA for supporting policies. This Science for Policy Report is complemented by a technical report[2], where methodological details and assumptions as well as comparisons with other available studies are reported.

Policy context

As part of its commitment towards more sustainable production and consumption, the European Commission has developed an LCA-based framework to monitor the evolution of environmental impacts associated to consumption in the EU (EC-JRC, 2012a). Within this framework, the calculation of two sets of indicators (Consumer Footprint and Consumption Footprint) are used to assess the environmental impacts due to consumption of goods and services. These indicators are relevant in the context of several policies and initiatives related to sustainable consumption and production:

- contributing to the **Better regulation** (EC, 2015a), unveiling the potential role of LCA for defining baseline scenarios to be used in policy impact assessment;
- supporting the **monitoring of progress towards the sustainable development goals** (SDGs) on responsible consumption and production (**SDG 12**), other SDGs related to environmental quality, such as **SDG 3** (Good health and well-being), **SDG 6** (Clean Water and Sanitation), **SDG 13** (Climate action), **SDG 14** (Life below water), **SDG 15** (Life on land), and highlighting the and **interlinkages between them**;
- benchmarking the efficiency of land, carbon, water, and material use and assessing the appropriateness of the inclusion of a lead indicator and targets, as foreseen in the

[1] 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

[2] Consumption and Consumer Footprint: methodology and results. Indicators and Assessment of the environmental impact of EU consumption (Sala et al., 2019)

7th Environment Action Programme (EAP) (European Parliament and Council, 2013);

- identifying **indicators of decoupling** of environmental impact from economic growth, serving both **SDG 8 on sustained, inclusive and sustainable economic growth** (target 8.4), the **Circular Economy Action Plan** (EC, 2015b), as well as the **Europe 2020 strategy** (EC, 2010), and its flagship initiative **A resource-efficient Europe** (EC, 2011a);
- contributing to the implementation of the **Beyond GDP Roadmap** (EC, 2009) which, foresees five actions, including one on complementing Gross Domestic Product (GDP) with highly aggregated environmental and social indicators;
- developing methodologies for measuring to which extent the EU is ensuring **living well within the limits of our Planet** (EAP) (European Parliament and Council, 2013)**.**

Key conclusions and main findings

Adopting LCA as reference methodology, the environmental impacts of EU consumption have been assessed for 16 impacts (e.g. climate change, ecotoxicity, land use related impacts, water use related impacts). Adopting normalisation and weighting, a single headline indicator is calculated as well. Modelling production and consumption in the EU, the calculated environmental impacts are basically expressing the impacts of SDG 12 (responsible production and consumption) in relation to SDGs (3, 6, 13, 14, and 15). The comparison with GDP trend allows to assess whether there is a decoupling of economic growth from environmental degradation (SDG 8). Results are expressed at different scales (at the overall EU level, at Member States level), per areas of consumption, per single products, per environmental impact, and ultimately, and as a single headline indicator.

Which are the main areas of consumption and products driving the impacts across the 16 impact categories considered?

Five areas of consumption (Food, Mobility, Housing, Household goods, and Appliances) have been assessed through the LCA of more than 130 representative products. **Consumption of food emerged as the main driver of impacts** generated by an average EU citizen, followed by Housing (especially for space heating) and Mobility (especially due to the use of private cars). The Consumer Footprint in the five areas of consumption increased by 6% from 2010 to 2015.

Which is the environmental impact of consumption at EU and country scales?

The EU can be considered a "**net importer of environmental impacts**": environmental impacts of imports are larger than those of exports. This implies that the Consumption Footprint (overall impacts related to consumption of good and services) is higher than the Domestic Footprint (impacts generated in the EU area).

Is there a decoupling of environmental impact from economic growth?

Between 2005 and 2014, environmental impacts in EU have decreased (-18% as weighted score) while GDP has increased by 8%, showing an absolute decoupling. Yet accounting for trade (Consumption Footprint), a more limited decoupling is observed. Moreover, a number of impacts cannot be fully captured so far, indicating the need of including in future more aspects to depict comprehensively the decoupling.

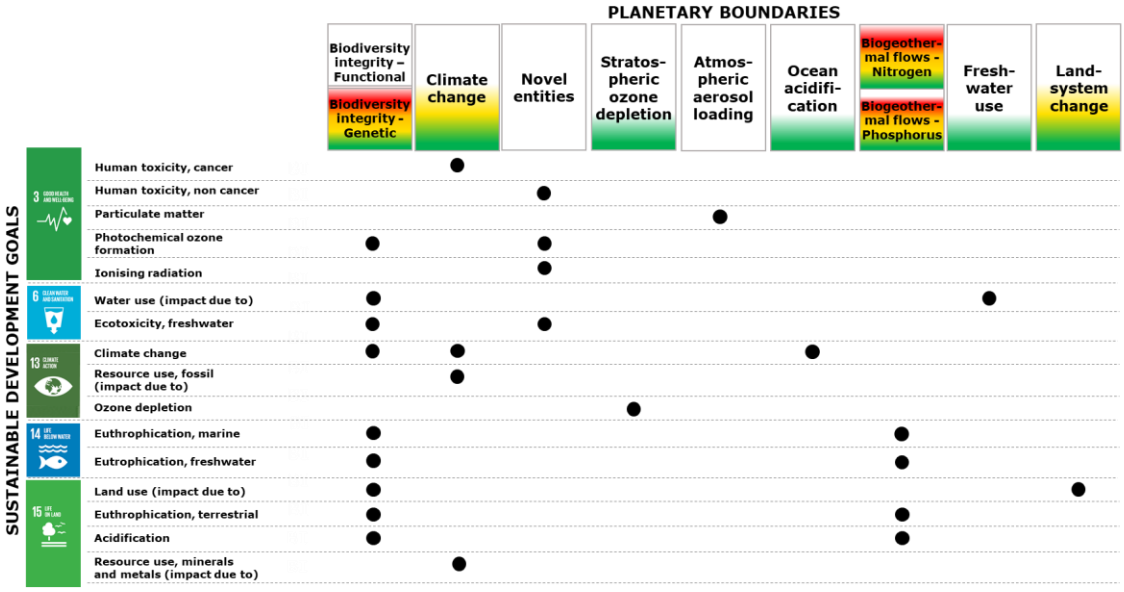
Is consumption in the EU environmentally sustainable and within the Planetary Boundaries?

Results show that the environmental impact of the **consumption of an average EU citizen is outside the safe operating space for humanity** for several impacts, namely climate change, particulate matter, resource use (fossils fuels, minerals and metals), freshwater eutrophication, and human toxicity-cancer.

Is it possible to evaluate in a systemic manner solutions and eco-innovations, towards SDGs goals?

The Consumer Footprint in a reference year could be considered a baseline scenario against which different policy options could be tested, from substituting a raw material, to changing a consumer behaviour or a waste management option. When adopting the LCA approach, trade-offs related to eco-innovation clearly emerge. In the LC-ind2 project, more than 50 scenarios on the different areas of consumption have been tested. Overall, results showed that **only an integrated action combining several interventions may ensure reducing significantly the environmental impacts**.

Figure 1. Overview of the links between the (midpoint) impact categories adopted in Life Cycle Impact Assessment, the Sustainable Development Goals, and the Planetary Boundaries.



Some impacts may fall into more than one SDG. For the sake of simplicity, each impact has been listed once.

Next steps: related and future JRC work

JRC is working on further developing LCA-based methodologies for supporting policy making in relation to the assessment of the environmental impact of consumption. Indeed, LCA can have a crucial role in ensuring a systematic approach to environmental impact assessment so as to unveil and assess trade-offs. However, currently, potential impacts are assessed according to the impact categories selected in the Environmental Footprint, which are not exhaustive of all environmental concerns. Future work may focus on improving the robustness of the assessment of the overcoming of Planetary Boundaries, and of impacts related to biodiversity loss and to additional environmental concerns, such as marine litter. In addition, specific tools dedicated to the assessment of the Consumer and Consumption Footprints may be further developed, enabling at the same time the modelling of scenarios, and more efficient visualisation and interpretation of the results.

Overview of the report

The report presents the results of the two sets of indicators (the Consumer Footprint and the Consumption Footprint), analysing the results for the whole EU, the Member States and the average EU citizen. Each chapter addresses a specific question.

Section 1	Why measure the environmental impacts of EU consumption?
Section 2	Why LCA is useful to evaluate environmental impacts of consumption?
Section 3	How to measure the environmental impacts of consumption?
Section 4	Consumer Footprint: what are the impacts of an average EU citizens?
Section 5	Consumption Footprint: what are the impacts of EU consumption at EU and country scales?
Section 6	Is consumption in EU environmentally sustainable and within Planetary Boundaries?
Section 7	Conclusion

1 Why measure the environmental impacts of EU consumption?

The protection of the environment is one of the core principles of the EU and has been integrated in an increasing number of policies. Within the activities impacting the global environment, consumption of goods and services is recognised as one of the main drivers. **Addressing the environmental impacts of consumption is therefore of utmost importance to meet environmental objectives and targets set by the EU**.

The **Agenda 2030**, with its 17 Sustainable Development Goals (**SDGs**), is the global key reference in the way towards sustainable development (EC, 2016). Responsible consumption and production are the core of SDG 12, and are as well addressed by other SDGs such as SDG 11 on sustainable cities and communities, and SDG 9 on industry, innovation and infrastructure. Furthermore, environmental impacts generated by consumption are related to a number of SDGs, e.g. on SDG 3 on good health and well-being, SDG 6 related to clear water on sanitation, SDG 13 dealing with climate action, SDG 14 and SDG 15 respectively related to life below water and on land. Comparing trends of environmental impacts and of GDP allows assessing the decoupling of economic growth from environmental degradation, a target embedded in sustained, inclusive and sustainable economic growth (SDG 8). Sustainability of consumption is central in many EU environmental policies. The **7th Environment Action Programme** (7th EAP) (European Parliament and Council, 2013), guiding EU environmental policies until 2020, establishes as general principle the need to live well within the ecological limits of our planet. In order to do so, resource efficiency needs to be improved and a decoupling of economic growth and wellbeing from environmental impacts is required (EC, 2011b; Sala et al., 2014). Measuring environmental impacts of consumption over time and the extent to which they are decoupling from economic growth is key to assess the success of the abovementioned environmental policies (European Parliament and Council, 2013). Moreover the **"Beyond GDP" initiative** highlights the importance of developing indicators as clear and appealing as GDP, but more inclusive of environmental and social aspects of progress (EC, 2009). The **Single Market for Green Products Initiative (EC, 2013)**, aims to remove market barriers that may limit the uptake of green products. The **Circular Economy Action Plan** (EC, 2015b) foresees a transition from a linear to a circular consumption paradigm, whereas the **bioeconomy strategy** (EC, 2018) aims to a transition towards a sustainable use of bio-based resources in substitution of fossil ones. The **Better Regulation,** with its toolbox n.64, foresees the enhanced application of life cycle analysis for the purpose of supporting policy impact assessments (EC, 2015a). The main linkages between such indicator framework and existing EU polices are summarised in Figure 2.

As part of its commitment towards more sustainable production and consumption, the European Commission has developed an **indicator framework to monitor the evolution of environmental impacts associated to consumption in the EU**. Indicators are based on Life Cycle Assessment (LCA), a methodology to assess the environmental impacts of products and services covering all their life cycle stages. The main advantages of LCA is that, thanks to its comprehensiveness, it allows assessing a multitude of environmental impacts (i.e. 16 in the Environmental Footprint (EC, 2013)) highlighting possible trade-offs and burdens shifting. LCA aims to assess impacts comprehensively and holistically, avoiding the transfer of impacts between life cycle stages, or environmental compartments (for more details, see Section 2).

The **LCA-based framework** to assess the environmental of consumption may serve policies makers both in **analysing the effects of existing policies**, and in **identifying hotspots** in terms of the most critical areas of consumption and life cycle stages which should be prioritised by future policies. The indicator framework has been developed within an administrative arrangement (AA) between DG ENV and DG JRC entitled "Indicators and Assessment of the environmental impact of EU consumption (LC-IND2)". The present report summarises the main outcomes of the AA. More detailed results are described in the report by Sala et al. (2019).

Figure 2. Overview of the interlinkages between existing policies and the LCA-based indicators (Consumer Footprint and Consumption Footprint) described in this report

LCA-based indicators for supporting policies

- Assessing environmental impacts and decoupling of those impacts from economic growth
- Monitoring trends overtime
- Unveiling trade-offs
- Comparing alternatives
- Identifying interlinkages between SDGs

Better regulation

Assessing policy options against a baseline scenario considering life cycle-related implications of the options. Baselines may be based on Consumption Footprint, as this represent the intensity of environmental impact associated to EU consumption in a certain year.

SDGs

Assessing and monitoring SDG 12 on responsible consumption and production, as well as addressing SDG 9 on industry innovation and infrastructure, and SDG 11 on sustainable cities and communities, and their implications on other environmentally-relevant SDGs such as e.g. SDG 3, 6, 13, 14, and 15. Assessing decoupling of environmental impacts from economic growth (SDG 8).

Circular economy

Assessing circular economy options, unveiling possible trade-offs. Assessing impacts at macro-scale when implementing the options. Monitoring environmental benefits of circular economy overtime.

Bioeconomy

Assessing bioeconomy options, unveiling possible trade-offs. Assessing impacts at macro-scale when implementing a bio-based solution substituting a fossil-based or a mineral-based one. Monitoring environmental benefits of bioeconomy over time.

Product policies

Adopting life cycle thinking to assess and improve products, aiming at identifying hotspots of impact in terms of product life cycle stage or type of impact (e.g. climate change, ecotoxicity). Assessing implications of product policies at macro-scale, e.g. to which extent a shift in consumption patterns (choice or use of a product) may bring benefits or burdens at the macroscale.

2 Why LCA is useful to evaluate environmental impacts of consumption?

Life cycle thinking is a basic concept that refers to the need for assessing burdens and benefits associated to products, sectors, and projects adopting a life cycle perspective, from raw material extraction to end of life. Life cycle thinking can be applied to both economic, social, and environmental pillars. The environmental pillar of life cycle thinking is primarily supported by LCA methodology.

Compared to other methodologies with a more limited perspective, **LCA has the advantage of accounting for potential burdens shifting between life cycle stages and environmental impacts, allowing a comprehensive assessment**.

According to ISO (2006a,b), LCA is based on four main steps (Figure 3).

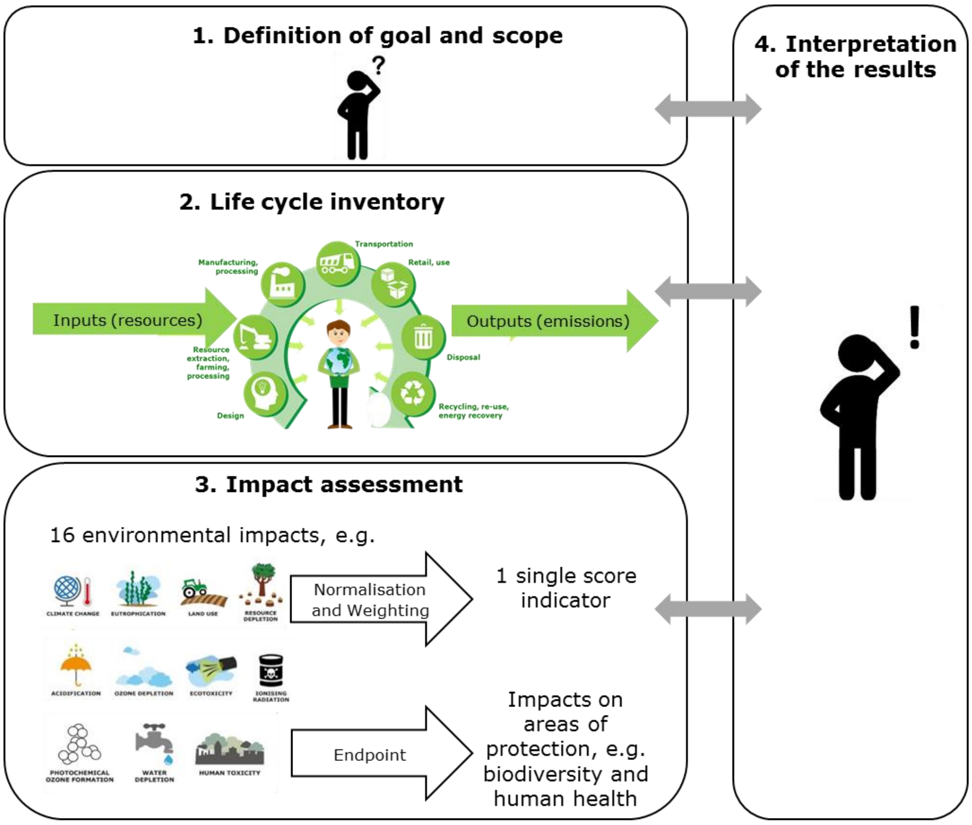
1. *Definition of goal and scope*. This step includes the overall design of the study, e.g. the definition of the specific objectives of the study, the description of the modelling assumptions, and the identification of the intended audience.
2. *Definition of the life cycle inventory*. In this step, data on inputs, i.e. resources, and outputs, i.e. emissions in the various environmental compartments, entering and leaving the system under study should be collected.
3. *Assessment of the environmental impacts*. In this step, the impacts of resources and emissions reported in the inventory are calculated through the use of impact models. Sixteen indicators are considered referring to different impacts, such as climate change, eutrophication of water bodies, and use of fossil, mineral and metal resources (EC, 2107). Furthermore, endpoint assessment models can be applied to assess effects of these 16 impacts on 3 areas of protection, i.e. human health, ecosystem health, and natural resources. In addition, these 16 indicators may be normalised by global impacts and weighted to be summarised in one "single score" indicator. Compared to the 16 indicators, the single score indicator has the advantage of being more effective for communication and for supporting the selection of alternatives, but at the same time "hides" part of the complexity of the different environmental impacts, and introduce a subjective element, i.e. weighting, which may affect the results.
4. *Interpretation of the results*. This step aims to fulfil the goal and scope of the study. Typical questions which may be answered at this stage are "which are the most impacting stages of the supply chain?", "what are the effects on the environment of a certain policy?". LCA results are characterised by different sources of uncertainty that should be considered in the interpretation of the results. The definition of the life cycle inventory is subject to the availability of average information describing the system. In addition, impact assessment models are characterised by uncertainties, which influence the robustness of the 16 indicators to different extents (details on the robustness of each indicator are given in Annex 1).

The EU Environmental Footprint

Performing an LCA implies making assumptions on the modelling of the analysed system, choosing sources for inventory data, and selecting the most suitable impact assessment models among the ones available. All these elements may affect the results of LCA and their comparability, thus limiting the effectiveness of environmental communication.

To enhance the comparability of LCA and remove potential market barriers due to the existence of different environmental communication schemes, the European Commission has proposed the Product Environmental Footprint (PEF) and the Organisation Environmental Footprint (OEF) methods (EC, 2013). The methodological approach was tested between 2013-2018 together with more than 280 volunteering companies and organisations. Results and reports of the pilot phase are currently available on the PEF and OEF website http://ec.europa.eu/environment/eussd/smgp/PEFCR_OEFSR_en.htm#final.

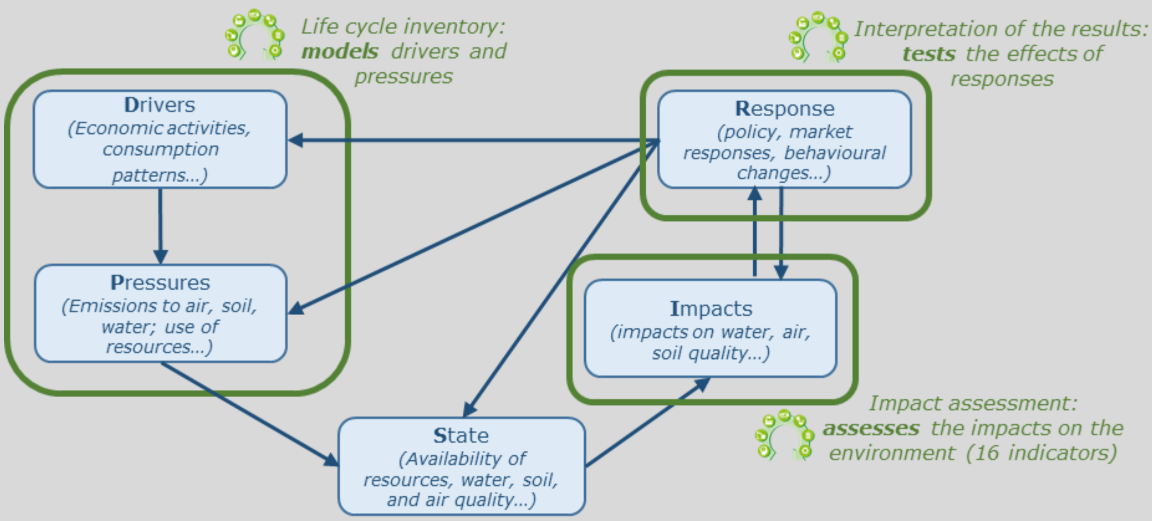
Figure 3. Steps of Life Cycle Assessment studies



LCA and the "Driver Pressure State Impact Response" framework (DPSIR)

The underpinning logic of LCA is linked with the framework "Drivers, Pressure, State, Impact and Response" (DPSIR) for reporting environmental issues (Smeets & Weterings, 1999). When defining the life cycle inventory of a product, sector or project, drivers of environmental issues should be identified and related pressures should be quantified. Impacts on the environment are then calculated through the use of impact assessment models. Finally, the interpretation of the results allows to test the effects of responses, such as policies, on the environmental impacts of products, sectors and services.

Overview of the linkages between the DPSIR framework and the LCA



Climate change

This indicator refers to the increase in the average global temperatures as result of greenhouse gas (GHG) emissions. The greatest contributor is generally the combustion of fossil fuels such as coal, oil, and natural gas. The global warming potential of all GHG emissions is measured in kilogram of carbon dioxide equivalent (kg CO_2 eq), namely all GHG are compared to the amount of the global warming potential of 1 kg of CO_2.

Particulate Matter

This indicator measures the adverse impacts on human health caused by emissions of Particulate Matter (PM) and its precursors (e.g. NO_x, SO_2). Usually, the smaller the particles, the more dangerous they are, as they can go deeper into the lungs. The potential impact of is measured as the change in mortality due to PM emissions, expressed as disease incidence per kg of $PM_{2.5}$ emitted.

Ionising radiation

The exposure to ionising radiation (radioactivity) can have impacts on human health. The Environmental Footprint only considers emissions under normal operating conditions (no accidents in nuclear plants are considered). The potential impact on human health of different ionising radiations is converted to the equivalent of kilobequerels of Uranium 235 (kg U235 eq).

Photochemical ozone formation

Ozone (O_3) on the ground (in the troposphere) is harmful: it attacks organic compounds in animals and plants, it increases the frequency of respiratory problems when photochemical smog ("summer smog") is present in cities. The potential impact of substances contributing to photochemical ozone formation is converted into the equivalent of kilograms of Non-Methane Volatile Organic Compounds (e.g. alcohols, aromatics, etc.; kg NMVOC eq).

Eutrophication, terrestrial

Eutrophication impacts ecosystems due to substances containing nitrogen (N) or phosphorus (P). These nutrients cause a growth of algae or specific plants and limit growth in the original ecosystem. The potential impact of substances contributing to terrestrial eutrophication is converted to the equivalent of moles of nitrogen (mol N eq).

Ozone depletion

The stratospheric ozone (O_3) layer protects us from hazardous ultraviolet radiation (UV-B). Its depletion increases skin cancer cases in humans and damage to plants. The potential impacts of all relevant substances for ozone depletion are converted to their equivalent of kilograms of trichlorofluoromethane (also called Freon-11 and R-11), hence the unit of measurement is in kilogram of CFC-11 equivalent (kg CFC-11 eq).

LCA and environmental impacts

With LCA, different environmental impacts may be assessed. The Environmental Footprint method allows assessing 16 impact categories.

Acidification

Acidification has contributed to a decline of coniferous forests and an increase in fish mortality. Acidification can be caused by emissions getting into the air, water and soil. The most significant sources are combustion processes in electricity, heating production, and transport. The contribution to acidification is greatest when the fuels contain a high level of sulphur. The potential impact of substances contributing to acidification is converted to the equivalent of moles of hydron (general name for a cationic form of atomic hydrogen, mol H^+ eq).

Eutrophication, freshwater

Eutrophication impacts ecosystems due to substances containing nitrogen (N) or phosphorus (P). If algae grows too rapidly, it can leave water without enough oxygen for fish to survive. Nitrogen emissions into the aquatic environment are caused largely by fertilizers used in agriculture, but also by combustion processes. The most significant sources of phosphorus emissions are sewage treatment plants for urban and industrial effluents and leaching from agricultural land. The potential impact of substances contributing to freshwater eutrophication is converted to the equivalent of kilograms of phosphorus (kg P eq).

Eutrophication, marine

Eutrophication impacts ecosystems due to substances containing nitrogen (N) or phosphorus (P). As a rule, the availability of one of these nutrients will be a limiting factor for growth in the ecosystem, and if this nutrient is added, the growth of algae or specific plants will be increased. For the marine environment this will be mainly due to an increase of nitrogen (N). Nitrogen emissions are caused largely by the agricultural use of fertilisers, but also by combustion processes. The potential impact of substances contributing to marine eutrophication is converted to the equivalent of kilograms of nitrogen (kg N eq).

Human toxicity, non-cancer

This indicator refers to potential impacts on human health caused by absorbing substances through the air, water, and soil. Direct effects of products on humans are currently not measured. The unit of measurement is Comparative Toxic Unit for humans (CTUh). This is based on a model called USEtox.

Water use

The withdrawal of water from lakes, rivers or groundwater can contribute to the 'depletion' of available water. The impact category considers the availability or scarcity of water in the regions where the activity takes place, if this information is known. The potential impact is expressed in cubic metres (m^3) of water use related to the local scarcity of water.

Resource use, minerals and metals

The basic idea behind this impact category is the same as the one behind the impact category resource use, fossils (namely, extracting a high concentration of resources today will force future generations to extract lower concentration or lower value resources). The amount of materials contributing to resource depletion are converted into equivalents of kilograms of antimony (kg Sb eq).

Ecotoxicity, freshwater

This indicator refers to potential toxic impacts on an ecosystem, which may damage individual species as well as the functioning of the ecosystem. Some substances have a tendency to accumulate in living organisms. The unit of measurement is Comparative Toxic Unit for ecosystems (CTUe). This is based on a model called USEtox.

Human toxicity, cancer

This indicator refers to potential impacts on human health caused by absorbing substances through the air, water and soil. Direct effects of products on humans are currently not measured. The unit of measurement is Comparative Toxic Unit for humans (CTUh). This is based on a model called USEtox.

Land Use

Use and transformation of land for agriculture, roads, housing, mining or other purposes. The impacts can vary and include loss of species, of the organic matter content of soil, or loss of the soil itself (erosion). This is an indicator of loss of soil organic matter content, expressed in kilograms of carbon deficit (kg C deficit).

Resource use, fossils

The earth contains a finite amount of non-renewable resources, such as fossil fuels like coal, oil and gas. The basic idea behind this impact category is that extracting resources today will force future generations to extract less or different resources. For example, the depletion of fossil fuels may lead to the non-availability of fossil fuels for future generations. The amount of materials contributing to resource use, fossils, are converted into MJ.

Impact affecting the environment on a global scale

Impact affecting the environment mainly at local/regional scale

3 How to measure the environmental impacts of consumption?

Environmental impacts generated by consumption and, more generally, by people's 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. They differ from the **production-based approach**, which instead allocates the impacts to the producer of goods (Hertwich and Peters, 2009; Davis and Caldeira, 2010; Wiedmann et al., 2013). The two major methods for estimating the footprint of EU households and governments are:

- the **top-down** method, which builds on **Environmentally Extended Input-Output Tables (EEIOTs)**, essentially compiled from **statistical data** on monetary, environmental and resource exchanges at **a macro- (country-) scale**;
- the **bottom-up** method, based on **LCA** studies for specific representative **products** which are then up-scaled to overall consumption figures through several up-scaling techniques (e.g. EC-JRC, 2012b; Frischknecht et al., 2013).

In this study, the assessment framework for assessing the environmental impact of EU consumption considers a number of key principles. Firstly, the modelling approach is **consumption-oriented**, namely it assesses impacts of final consumption. Secondly, the framework applies **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.

The environmental impact of EU consumption is calculated considering two indicators:

- **Consumer Footprint**: this indicator aims to assess the environmental impacts of **consumption** in EU, considering an **average EU citizen**. In this report, results relative to the Consumer Footprint are based on a **bottom-up** approach;
- **Consumption Footprint**: this indicator aims to track the overall environmental impact of apparent consumption in the EU, corresponding to the mathematical sum of domestic production plus imports minus exports. It refers to the environmental impact exerted by the **whole economy**, including all the economic activities, and is assessed both for the **entire EU and at Member State level.** Both **top-down and bottom-up** approaches are implemented in this study.

LCA has been performed following the **Environmental Footprint** impact assessment method (EF 2017) (EC, 2017) as EF reference package 2.0 (EC-JRC, 2018)). Three steps have been implemented: 1) the calculation of the impacts, for **16 impact categories;** 2) their **normalization** against a reference system (environmental impacts at global level as calculated by Crenna et al., 2019a); 3) their **weighting**, in order to derive a single weighted score with using the weighting factors developed in the context of the Environmental Footprint (Sala et al., 2018).

Figure 4. Consumer Footprint and Consumption Footprint: 2 indicators, 5 key features

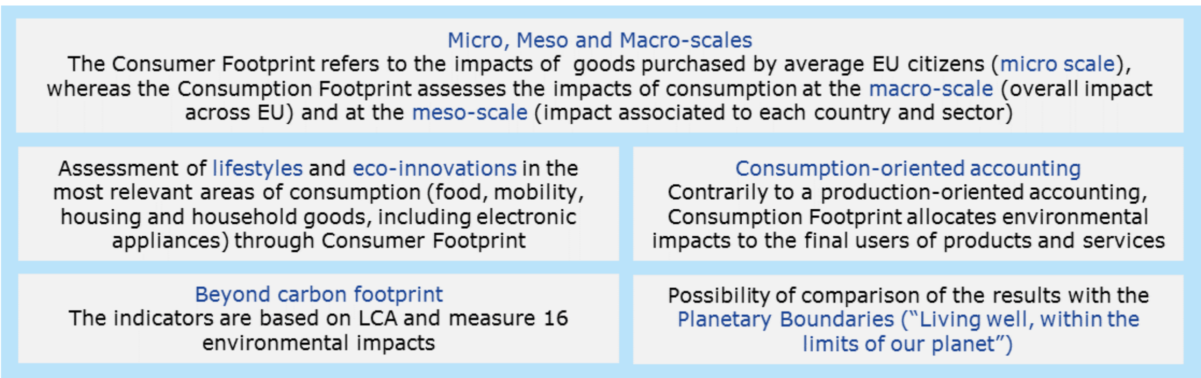


Figure 5. Overview of the methodological steps for calculating life cycle-based indicators for assessing the impacts of EU consumption.

	The Consumer Footprint	**The Consumption Footprint**

Goal and scope

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

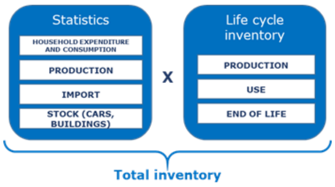
The Consumption Footprint: Economy-wide assessment of apparent consumption in the EU

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.

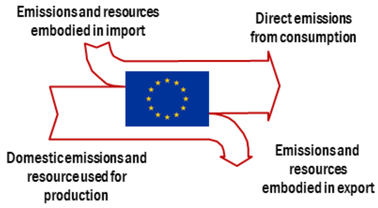
The Consumer Footprint:

- 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 SDGs

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.

3 Good health and well-being
- Human toxicity, cancer
- Human toxicity, non-cancer
- Particulate matter
- Photochemical ozone formation
- Ionising radiation

6 Clean water and sanitation
- Impact due to water use
- Ecotoxicity
- Eutrophication

13 Climate action
- Climate chance
- Impact due to resource use
- Ozone depletion

14 Life below water
- Eutrophication marine and freshwater
- Ecotoxicity

15 Life on land
- Impact due to land use
- Eutrophication terrestrial
- Acidification
- Impact due to mineral and metal resource use
- Ozone depletion

Normalization: comparing results with global references

The normalization helps understanding 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 (Sala et al., 2018).

Planetary Boundaries

Alternative to normalization and weighting, the results could be compared with environmental sustainability thresholds, as those developed in the context of the Planetary Boundaries assessment.

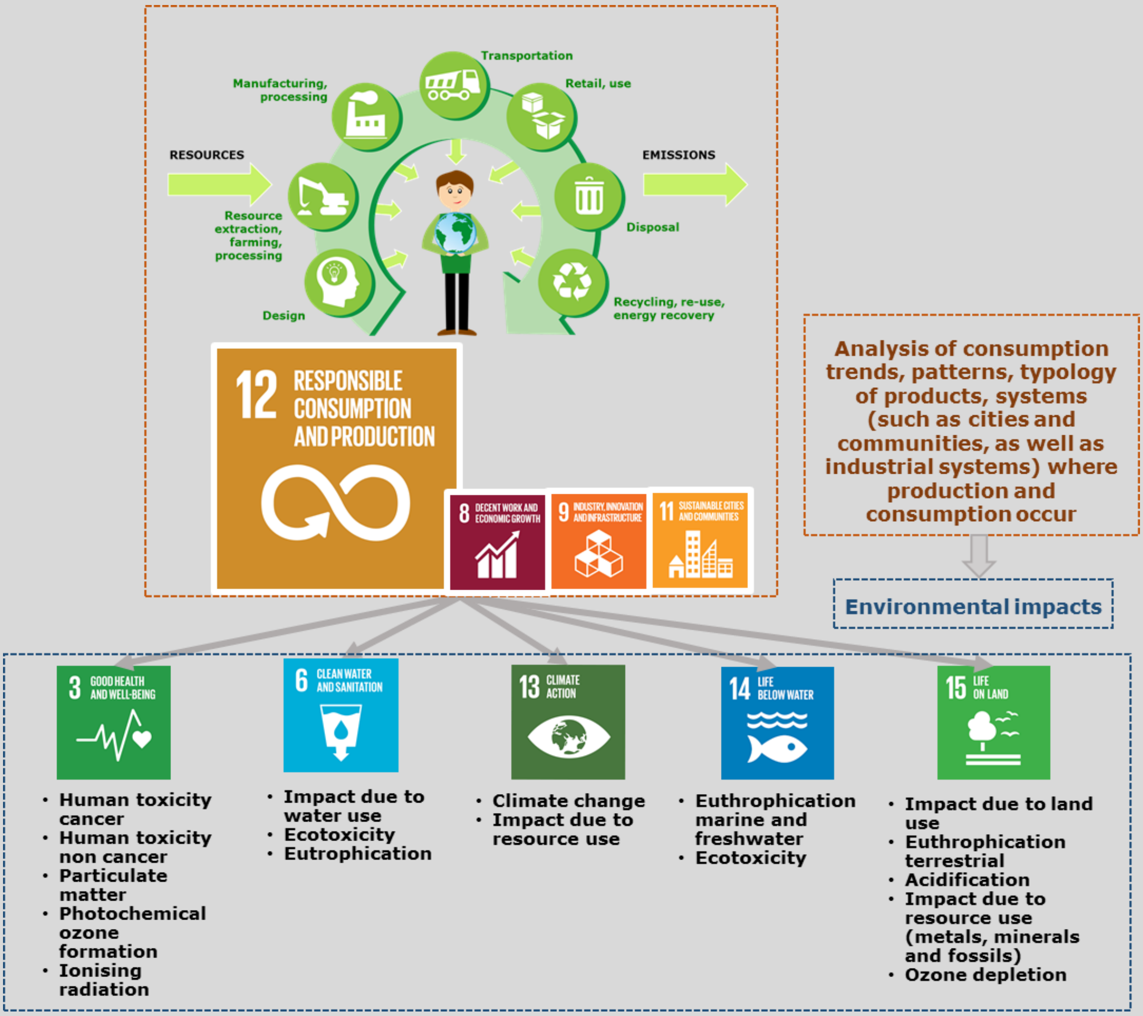
Consumer Footprint, Consumption Footprint, and SDGs

The Consumer Footprint and the Consumption Footprint are sets of LCA-based indicators that aim to quantify the environmental impacts of consumption in EU considering respectively an average EU citizen and the overall economic activities associated to consumption. LCA is a comprehensive methodology meant to assess the environmental impacts of products, sectors, and projects. These two elements create several connections between Consumer Footprint, Consumption Footprint, and SDGs.

Fist of all, Consumer and Consumption Footprints provide an overall picture of the environmental impacts of consumption that can support the assessment and monitoring of decoupling of economic growth from environmental impacts, as foreseen by SDG 12 "Ensure responsible production and consumption patterns" and SDG 8 "Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all." Moreover, the objectives of SDG 9 "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation" and SDG 11 "Make cities and human settlements inclusive, safe, resilient and sustainable" are as well partially addressed by the Consumer and the Consumption Footprints.

In addition, by addressing different types of environmental impacts, Consumer and Consumption Footprints have several connections with SDGs focused on specific impacts, such as SDG 3, SDG 6, SDG 13, SDG 14, and SDG 15. For example, Consumer and Consumption Footprints assess the impacts on water use, water eutrophication, and water ecotoxicity, which are closely linked with the objectives of SDG 6 "Ensure availability and sustainable management of water and sanitation for all".

Overview of the connections between Consumer Footprint, Consumption Footprint and SDGs



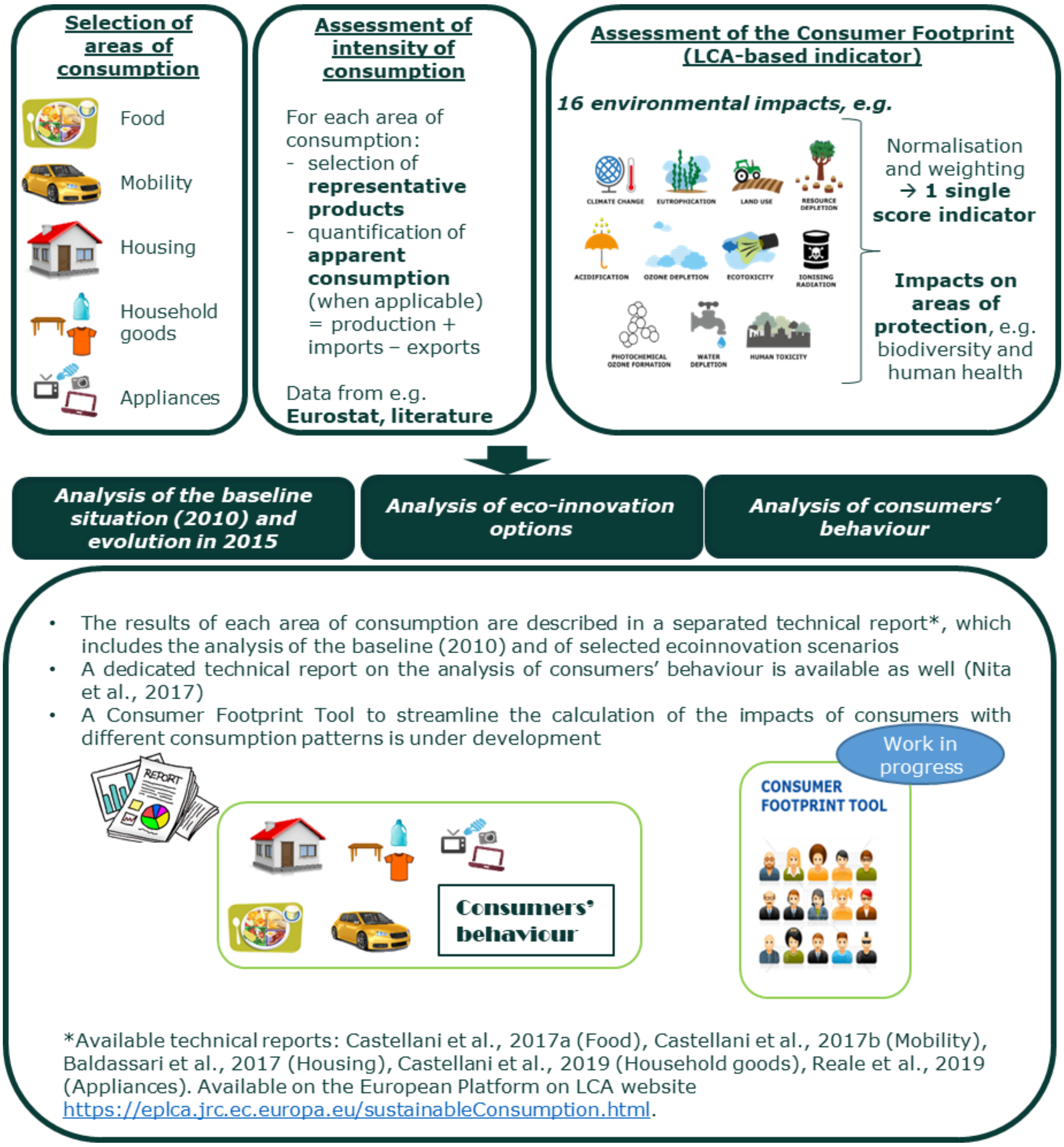
4 Consumer Footprint: what are the impacts of an average EU citizen?

The **Consumer Footprint** is a **set of 16 LCA-based indicators (also available as single score)**, whose purpose is to quantify the **environmental impacts of an average EU citizen**, based on the consumption of goods in 5 areas (Food, Mobility, Housing, Household goods, and Appliances).

The Consumer Footprint encompasses the **5** most impacting **areas of consumption**, i.e. Food, Housing, Mobility, Household goods, and Appliances. For each of them a "Basket of representative Products" (BoP) has been defined and the environmental impacts of each BoP have been calculated through LCA.

The Consumer Footprint **serves multiple purposes**. It **allows for the identification of the most impacting areas of consumption, products, life cycle stages, and substances**. In addition, it **can be used to estimate the impacts of possible future scenarios,** including an increased spread of eco-innovation options, and changing consumer behaviours.

Figure 6. Overview of the Consumer Footprint structure and outputs

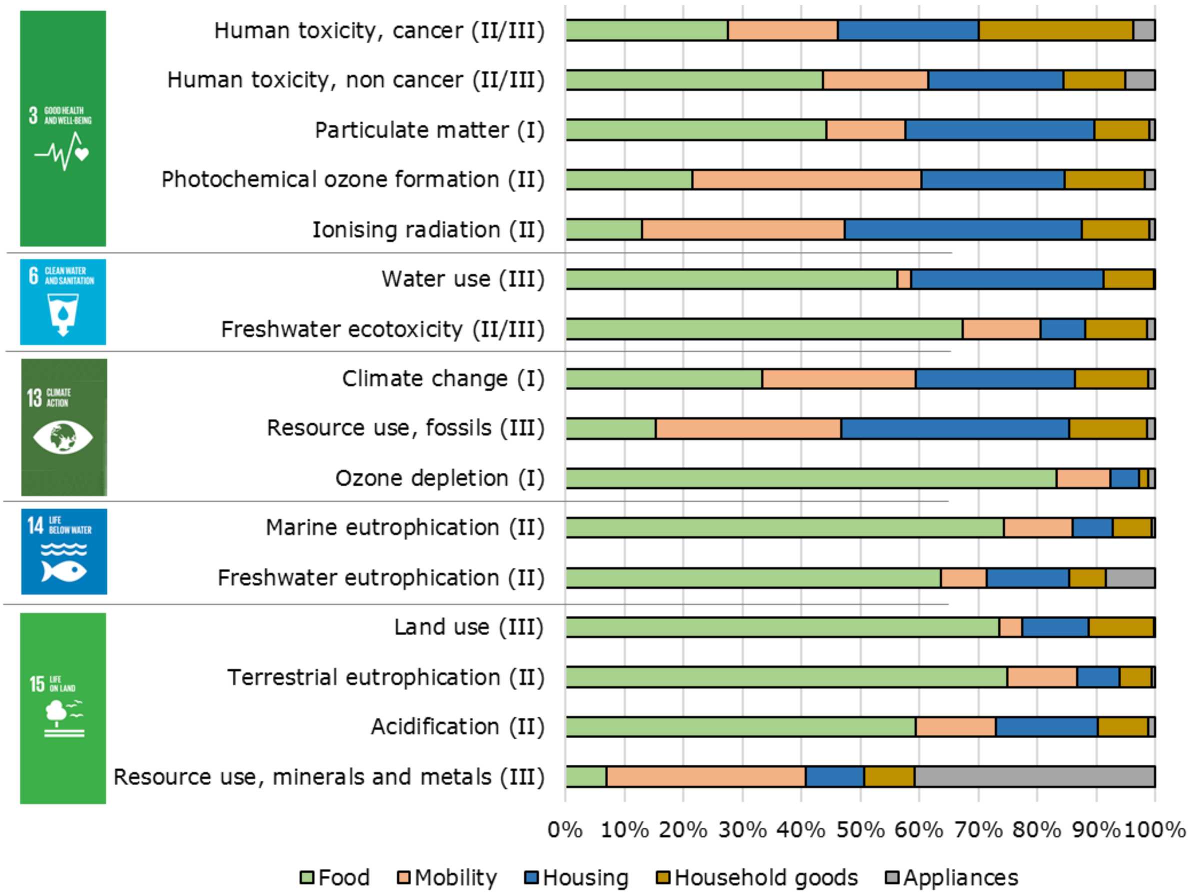


4.1 What are the main areas of consumption driving the impacts in Consumer Footprint?

Daily activities, such as eating food and driving a car, appear to be the highest contributors to the Consumer Footprint. Indeed, **Food, Mobility, and Housing** are, in the reported order, the **most impacting areas of consumption**, as well as the ones characterised by the less durable products and higher use intensity. On average, an EU citizen eats more than 3 kg of food and beverages every day, travels 16 km by car, and uses more than 20 kWh of energy at home[3].

The contribution of food is predominant on impacts notably influenced by agricultural production, such as acidification, eutrophication, ecotoxicity, and land use, mainly related to SDG 6, SDG 14, and SDG 15. The contribution of the three most relevant areas of consumption is more balanced for the impacts associated with energy production, e.g. climate change, fossil resources use, and ionising radiation that closely link with SDG 3 and SDG 13. Appliances are the main hotspot for minerals and metals resources use because of the utilisation of raw materials (including critical raw materials) in their inner components. In Figure 7, the numbers in brackets reflects the robustness impact assessment model underpinning the assessment of the impact category: the higher the number, the lower the robustness, and the higher the uncertainties of the results (i.e., higher caution should be adopted in their interpretation).

Figure 7. Contribution of the areas of consumption to the Consumer Footprint (2010)



The roman numbers in brackets refer to the robustness of the model used to asses environmental impacts (EC, 2017). The lower the number, the higher its robustness. This information is key for the interpretation of the results (see Annex 1).

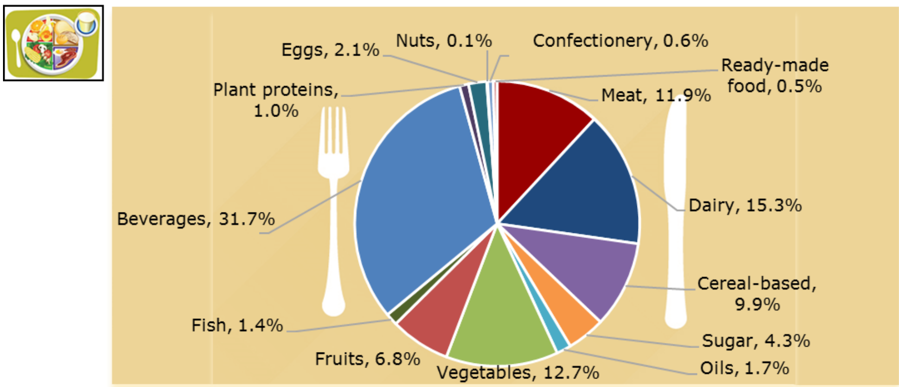
[3] To avoid double counting, the energy used for energy appliances is here accounted under the area of consumption "Housing". Hence, Appliances includes all the life cycle stages, except the use phase.

4.2 What are the main products driving the Consumer Footprint within each area of consumption?

4.2.1 Food

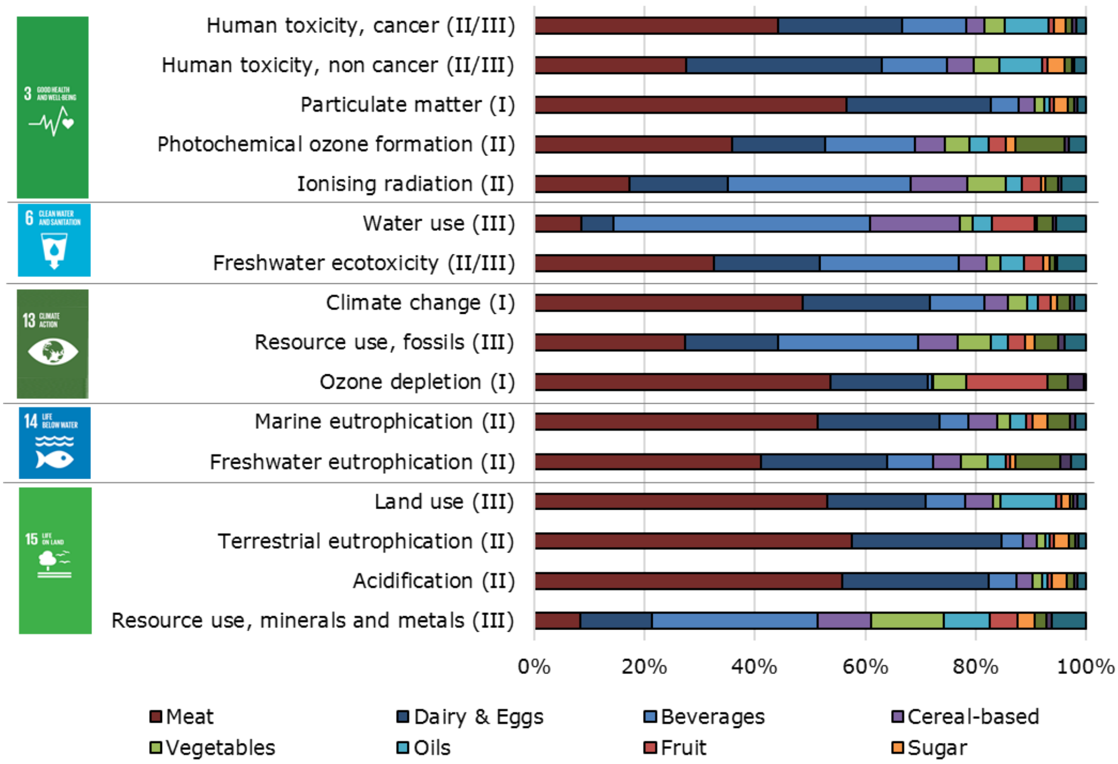
Thirty-two representative food products (Figure 8) have been selected based on their level of consumption in the EU. LCA has been applied to the representative products to identify those that are impacting the most and in which life cycle stage.

Figure 8. Share of the mass of food products consumed by an average EU citizen (2010)



Animal-based products, i.e. meat, dairy, and eggs, **contribute for more than 50% to most of the environmental impacts**, despite being consumed in lower quantities compared to vegetable-based products. The underpinning motivation is essentially the lower efficiency of the animal production systems, which, when compared to vegetable-based systems, requires more inputs to deliver the same quantity of product. Therefore, a reduced consumption of animal-based products would be beneficial to the reduction of the overall impacts associated to food consumption.

Figure 9. Contribution of product groups to the impacts of food consumption in EU (2010)

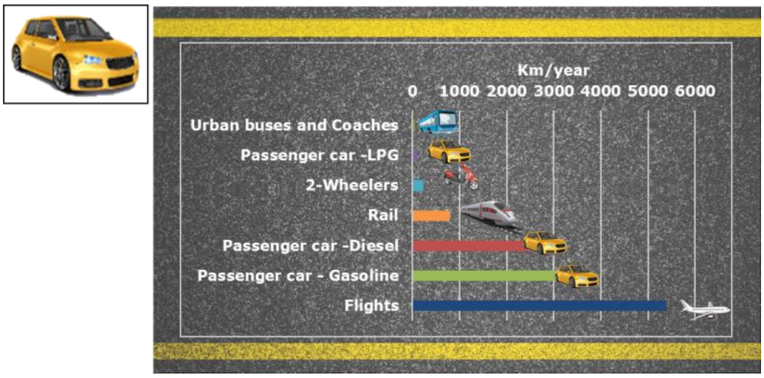


The roman numbers in brackets refer to the robustness of the model used to asses environmental impacts (EC, 2017). The lower the number, the higher its robustness. This information is key for the interpretation of the results (see Annex 1).

4.2.2 Mobility

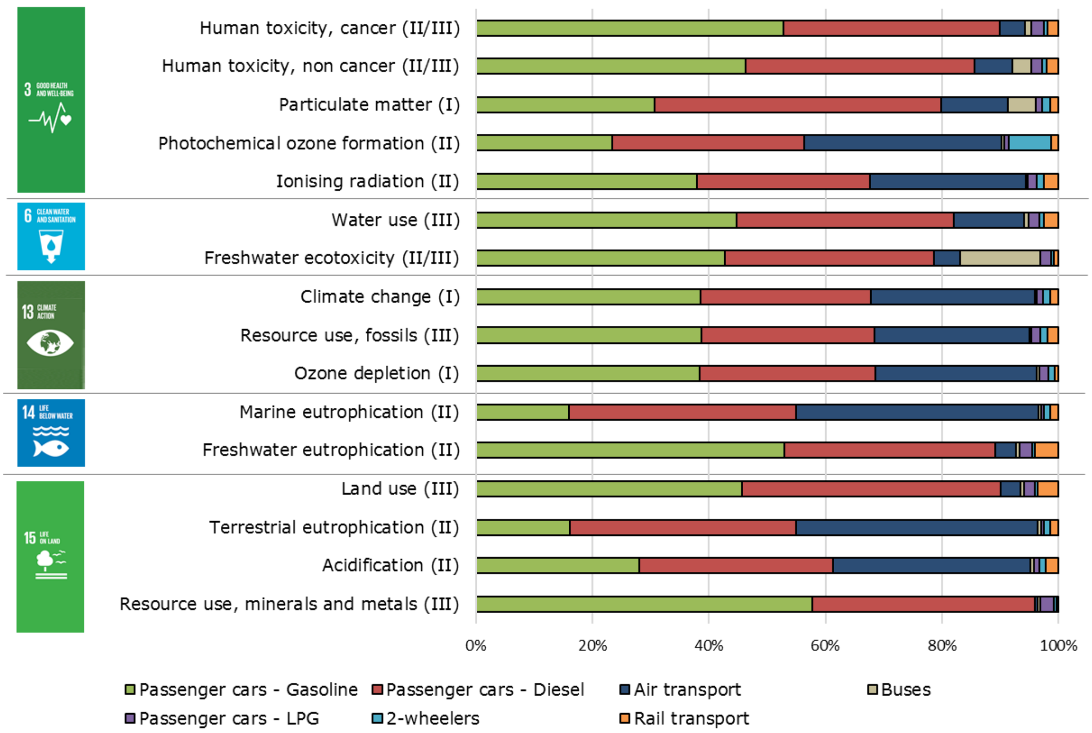
Based on available statistics, the area of consumption Mobility has been modelled considering the kilometres travelled by an average EU citizen by means of transport (Figure 10). The LCA has been then applied to assess the environmental impacts associated to mobility.

Figure 10. Kilometres travelled yearly by an average EU citizen (2010)



Passenger cars, followed by aircrafts, are the most used means of transport in EU and are **responsible for the majority of the environmental impacts of mobility**. When looking at the impacts of the analysed means of transport expressed per person and per km travelled, cars have on average the highest impacts, whereas trains have the best environmental performance. The share of the overall impacts associated to gasoline cars is generally higher than for diesel cars mainly because of the longer distance travelled. Exceptions are observed for some impacts, where the higher emission factors of diesel cars offset the differences in the distance travelled: particulate matter, due to the emissions of $PM_{2.5}$; terrestrial and marine eutrophication, mostly affected by nitrogen oxides (NO_x) emissions.

Figure 11. Contribution of means of transport to the impact of Mobility in EU (2010)



The roman numbers in brackets refer to the robustness of the model used to asses environmental impacts (EC, 2017). The lower the number, the higher its robustness. This information is key for the interpretation of the results (see Annex 1).

4.2.3 Housing

The housing stock in the EU has been modelled with LCA by means of 24 building archetypes, representative of building in three climatic zones and different period of construction (Figure 12).

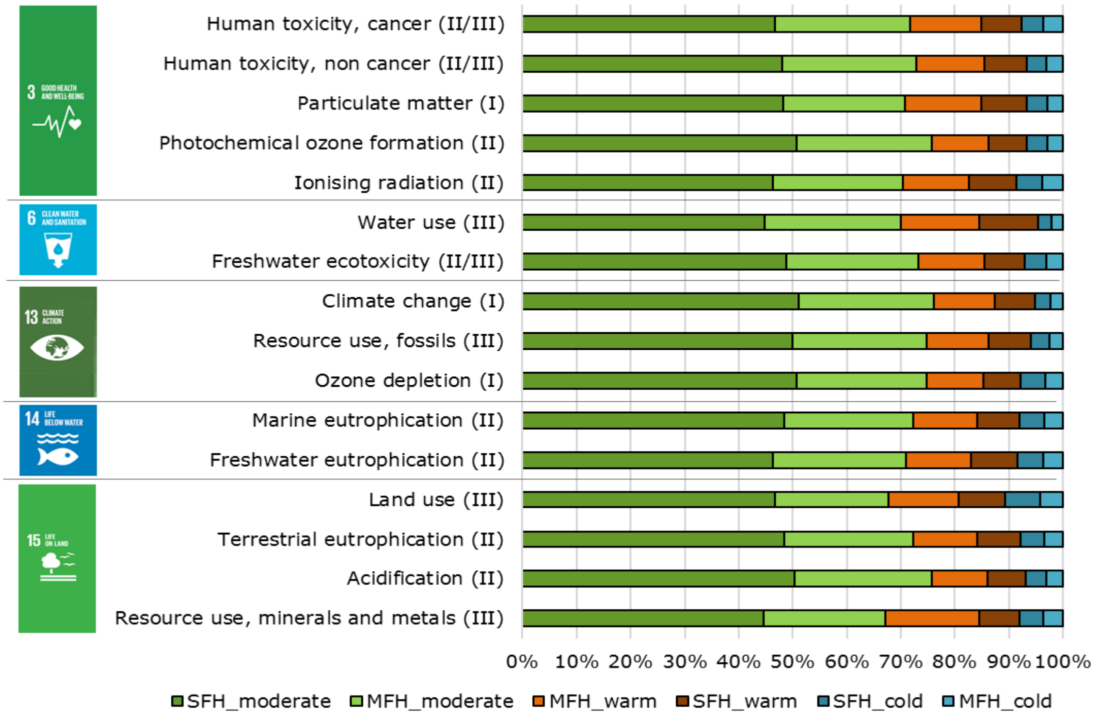
Figure 12. Share of the number of different types of dwellings in the EU (2010)

	<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)

The share of the impacts of each different dwellings to the overall impact of Housing in the EU depends on two factors: the impact per dwelling, and the number of dwellings in the EU. The **higher contribution** is **from the buildings in moderate climates**, which represent about 70% of the EU building stock and contribute to about 70-80% of the overall impacts. When analysing the impact per single dwelling, the single family houses in cold climate are those with the highest impact per dwelling per year for all the analysed impacts, mainly due to higher energy demand, except for climate change and resource depletion impacts. The main reason for this countertendency is the higher impact of concrete and bricks used in the moderate climate compared to the timber frame used in cold climate.

Figure 13. Contribution of different dwellings to the impacts of Housing in EU (2010)

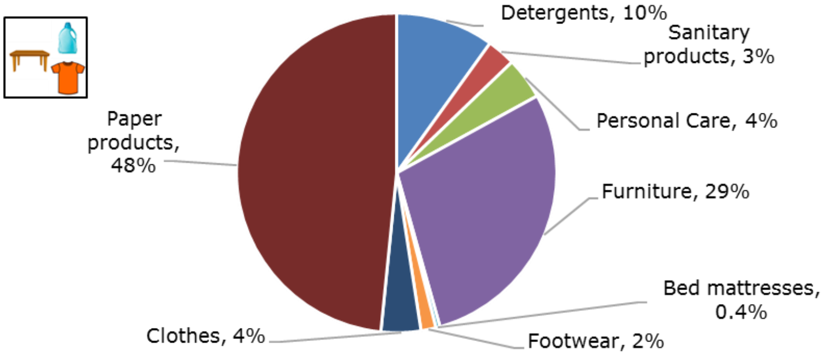


SFH= single family house, MFH=Multi family house.
The roman numbers in brackets refer to the robustness of the model used to asses environmental impacts (EC, 2017). The lower the number, the higher its robustness. This information is key for the interpretation of the results (see Annex 1).

4.2.4 Household goods

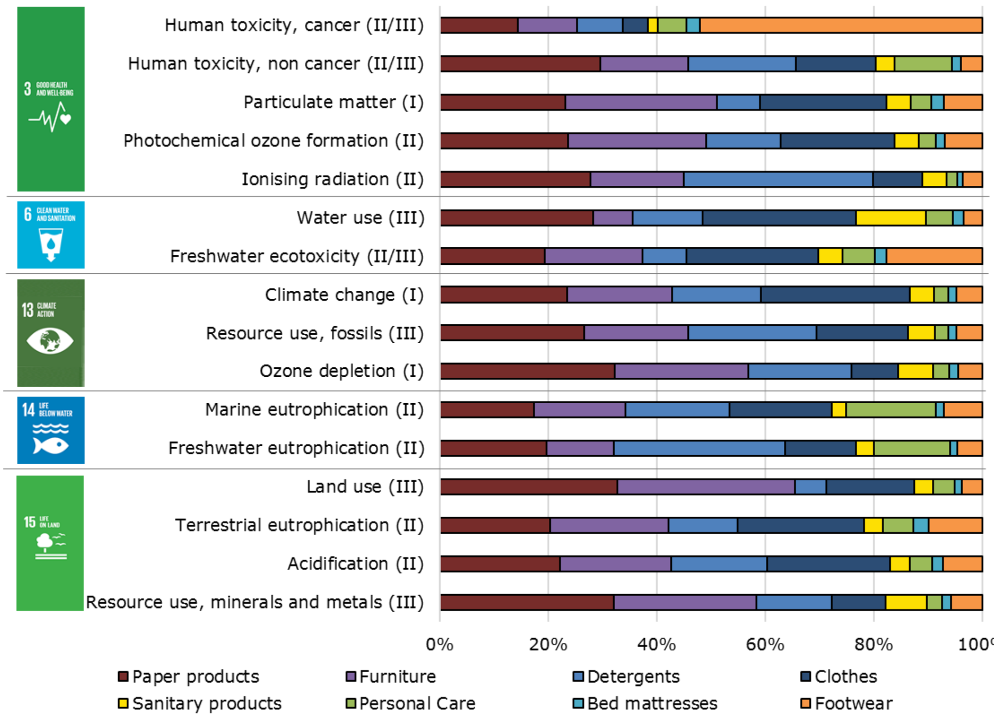
Households are consuming a huge variety of products encompassing paper-based products, detergents, textiles, furniture, detergents, etc. A selection of representative products has been done based on statistics, capturing products which large shares in mass, and on the presence of products in the EU Ecolabel scheme (Figure 14).

Figure 14. Share of the mass of household goods consumed by an average EU citizen (2010)



Paper products, detergents, furniture, and clothes are the main contributors to the impacts of Household goods, due to the relevant amount of products consumed, mainly for paper products and clothes, and high impacts per unit of product, especially for furniture and detergents. Hence, the reduction of the impacts of this area of consumption should encompass a decrease in the use of most diffused products, and improvements in the production processes. The main environmental hotspots of the production phase are the use of electricity to transform raw fibres in textile, happening mainly outside EU, impacting importantly on climate change, particulate matter, acidification, and water use, the tanning of leather used for shoes, responsible for the emissions of chromium into water, causing a large share of the impact on human toxicity cancer, and the use of coal to produce flame retardants used in sofas, which contributes significantly to particulate matter emissions.

Figure 15. Contribution of different products to the impacts of Household goods in EU (2010)

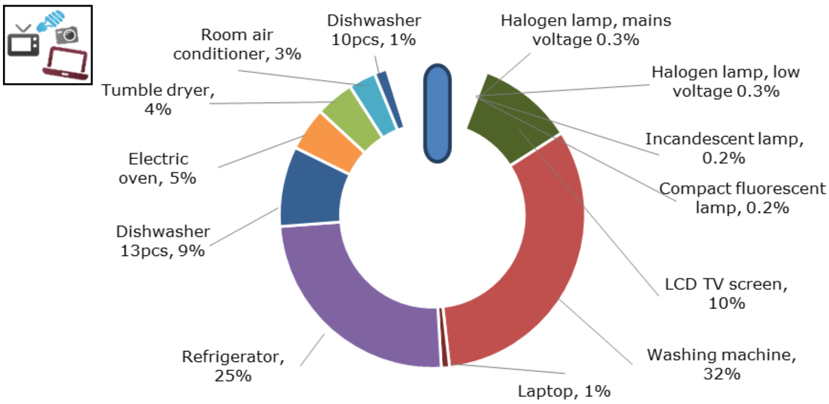


The roman numbers in brackets refer to the robustness of the model used to asses environmental impacts (EC, 2017). The lower the number, the higher its robustness. This information is key for the interpretation of the results (see Annex 1).

4.2.5 Appliances

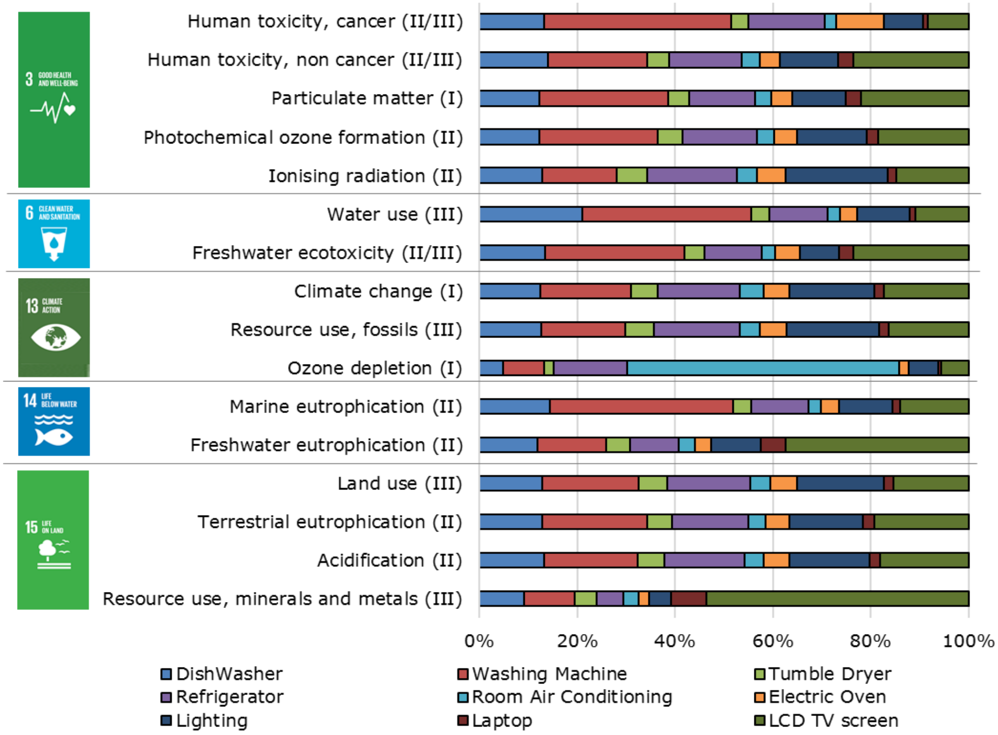
Appliances are increasingly used in EU households, serving multiple purposes, from lighting to washing, from storing to cooking. A selection of representative products has been performed considering the most relevant appliances in terms of energy consumption and market share in EU, and the appliances prioritised in the Ecodesign directive (European Parliament and Council, 2009).

Figure 16. Share of the mass of household appliances owned by an average EU citizen (2010)



The **larger contribution** to the overall impacts generated by the purchase and use of appliances in EU comes from **washing machines, and refrigerators**, mainly for the large amount owned, and from **dishwater, lighting, and TV screen**, especially for the inherent properties of their life cycles. Main environmental hotspots are the production of electricity for the use of the appliances, reflected, for example, in the impacts on climate change, particulate matter, and ionising radiation; refrigerants leakages from air conditioning, which influence ozone depletion, the use of detergents which impacts on marine eutrophication, and the use of gold in the printed circuited boards of TV screens, main hotspots for the use of mineral and metals resources.

Figure 17. Contribution of different products to the impacts of Household goods in EU (2010)



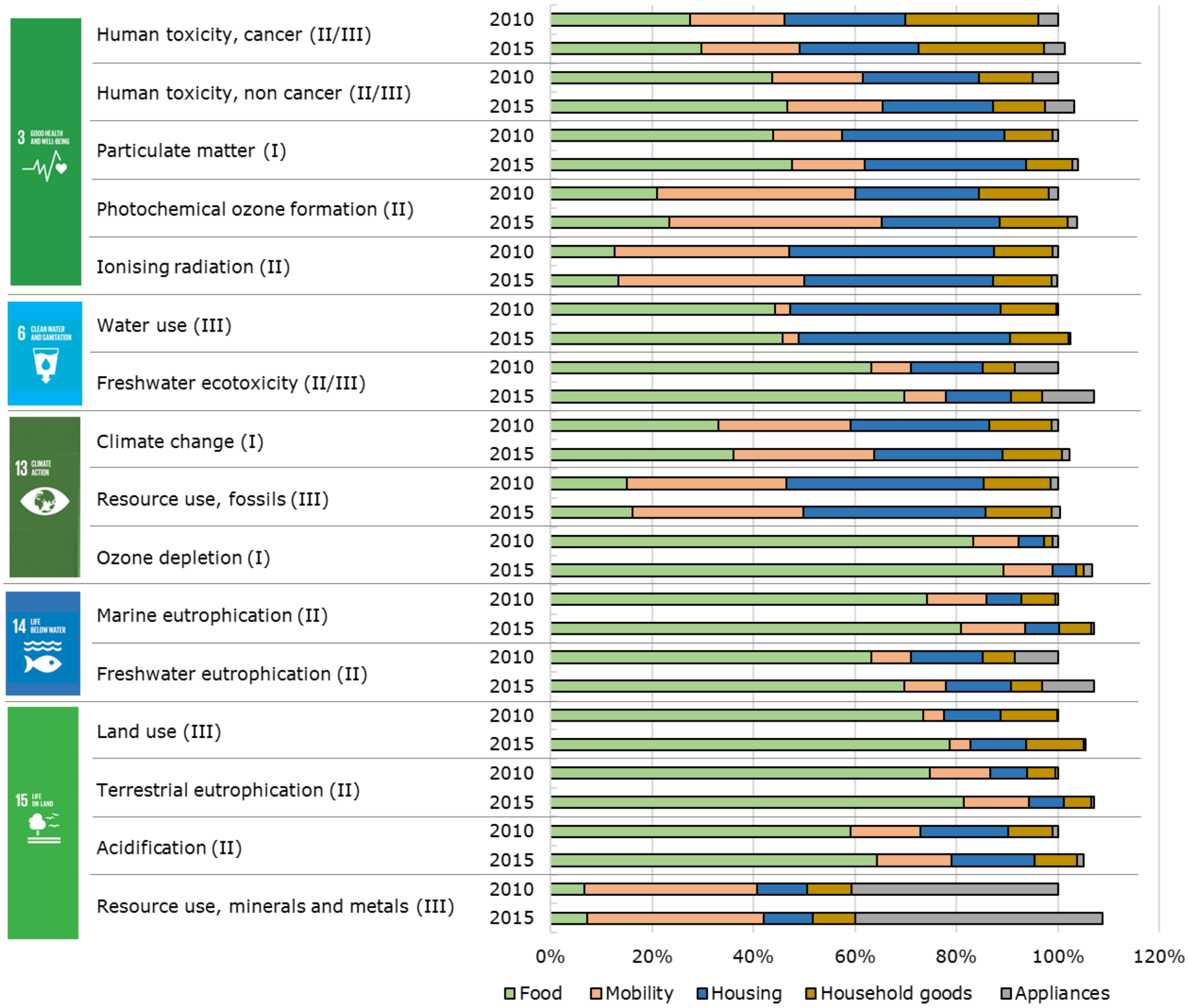
The roman numbers in brackets refer to the robustness of the model used to asses environmental impacts (EC, 2017). The lower the number, the higher its robustness. This information is key for the interpretation of the results (see Annex 1).

4.3 How is the Consumer Footprint evolving over time?

In the timeframe 2010-2015, the **amount of consumed goods increased** in all the areas of consumption, with the exception of some food products and household goods. The most important rise was observed for the number of kilometres travelled (+10%) and the amount of appliances owned (+29%, with +53% for air conditioning).

The growth of consumption, coupled with a slight rise in the population (+1%), results in an **overall increased environmental impact**, **reflected in all the analysed areas of consumption with the exception of Housing**. This countertrend (about -5% for all the impacts) is mainly driven by a general reduction of energy use in the buildings especially for space heating, and to energy efficiency regulations introduced since 2010 (European Parliament and Council, 2010). The benefits of other policies affecting the other areas of consumption, e.g. the progressive reduction of car emissions (EC, 2008), were instead partly offset by the increased use of cars (so called "rebound effect"), highlighting the importance of putting in place policies aimed at enhancing more responsible consumption patterns.

Figure 18. Contribution of the areas of consumption to the Consumer Footprint in 2010 and 2015 (set as 100%)



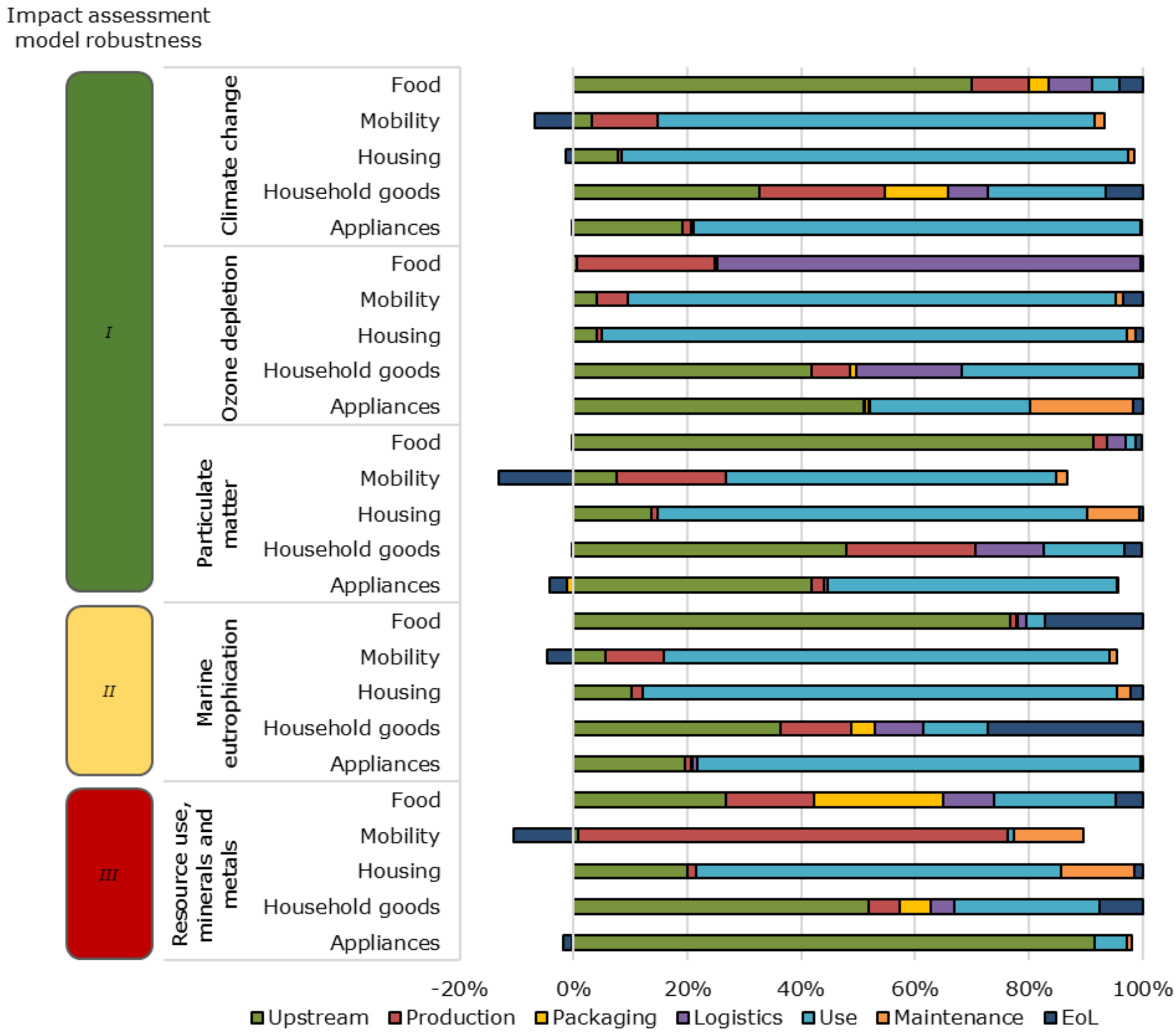
The roman numbers in brackets refer to the robustness of the model used to asses environmental impacts (EC, 2017). The lower the number, the higher its robustness. This information is key for the interpretation of the results (see Annex 1).

4.4 What are the life cycle stages driving the Consumer Footprint?

Life cycle stages are characterised by different activities and, therefore, by different impacts. In addition, products included in each area of consumption have different supply chains, which are reflected in different impact patterns, in light of the area of consumption analysed. Overall, there are some impacts that are strictly connected with the combustion of fossil fuels, e.g. climate change and particulate matter, and therefore are mainly associated to energy-intensive life cycle stages, e.g. the use of a car and appliances. Other impacts, e.g. use of minerals and metals resource, are mainly associated to the production of goods, except the ones of biological origin, such as food.

At a first sight (Figure 19), it is evident that **upstream activities and use phase are generating the highest impacts in the life cycle stages**. When looking into more detail to areas of consumption, it is noted that upstream activities, i.e. primary production, are the hotspot for almost all the impacts generated by Food. On the contrary, the impacts of Mobility and Housing are driven by the use phase, except for minerals and metals resource use in case of Mobility, which is dominated by the production phase of the vehicles. For Household goods and Appliances, the share of the impact associated to one life cycle stage or the other is more balanced according to the impact considered.

Figure 19. Impacts due to EU consumption in 2010, per area of consumption and per life cycle stage



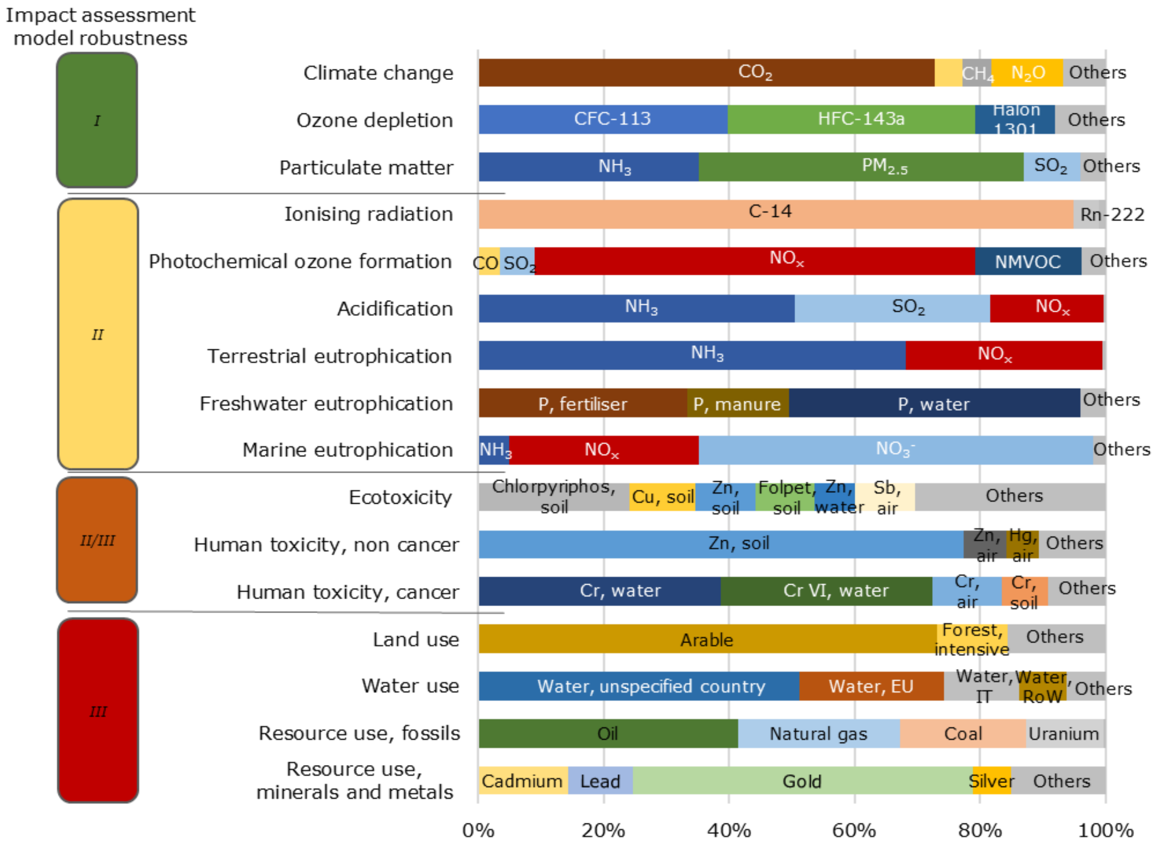
Selected impact categories are reported as example. Results for all the impacts are reported in Sala et al. (2019). Model robustness of the impact assessment model used to assess each indicator is taken from EC (2017).

4.5 What are the main contributors (pollutants and resources) driving the impacts of Consumer Footprint?

Environmental pressures taken into account in the Consumer Footprint include both emissions in the three environmental compartments air, water, and soil, and the use of natural resources, i.e. land, water, fossils, and minerals and metals. It has to be highlighted that the impacts generated by the use of resources, i.e. the last four in Figure 20, are characterised by the less robust impact assessment models, meaning that results should be interpreted with caution, and further developments are needed to improve their robustness.

Climate change is mainly influenced by carbon dioxide (CO_2) emissions into the atmosphere, which is primarily originated by the combustion of fossil fuels to drive vehicles and to produce electric and thermal energy. Biogenic methane emissions (CH_4) contribute to about 10% and are produced by animal rearing, i.e. due to animals' enteric fermentation and manure management. **Emissions of nitrogen compounds to the atmosphere** (nitrogen oxides (NO_x), ammonia (NH_3)) **and to water** (nitrates (NO_3^-)) are **responsible for** various type of impacts, such as **photochemical ozone formation and marine eutrophication**, but not only. The combustion of fossil fuels is, again, the primarily responsible for NO_x emissions, whereas NH_3 emissions are mainly associated to agricultural activities. Agriculture is mainly responsible for emissions of **phosphorous compounds**, which cause an impact on **freshwater eutrophication**, and of **pesticides** (Chlorpyrifos and Folpet) in the soil, which contribute to more than 30% to the impact on **freshwater ecotoxicity**. **Impacts on human toxicity**, and partly ecotoxicity, are mainly generated by **emissions of heavy metals in environment**, due to different activities, e.g. agriculture and industrial. However, these results have been calculated with a version of the characterisation factors which is in the process of being updated (Saouter et al. 2018).

Figure 20. Percentage contributions (pollutants and resources) to the Consumer Footprint (2010)



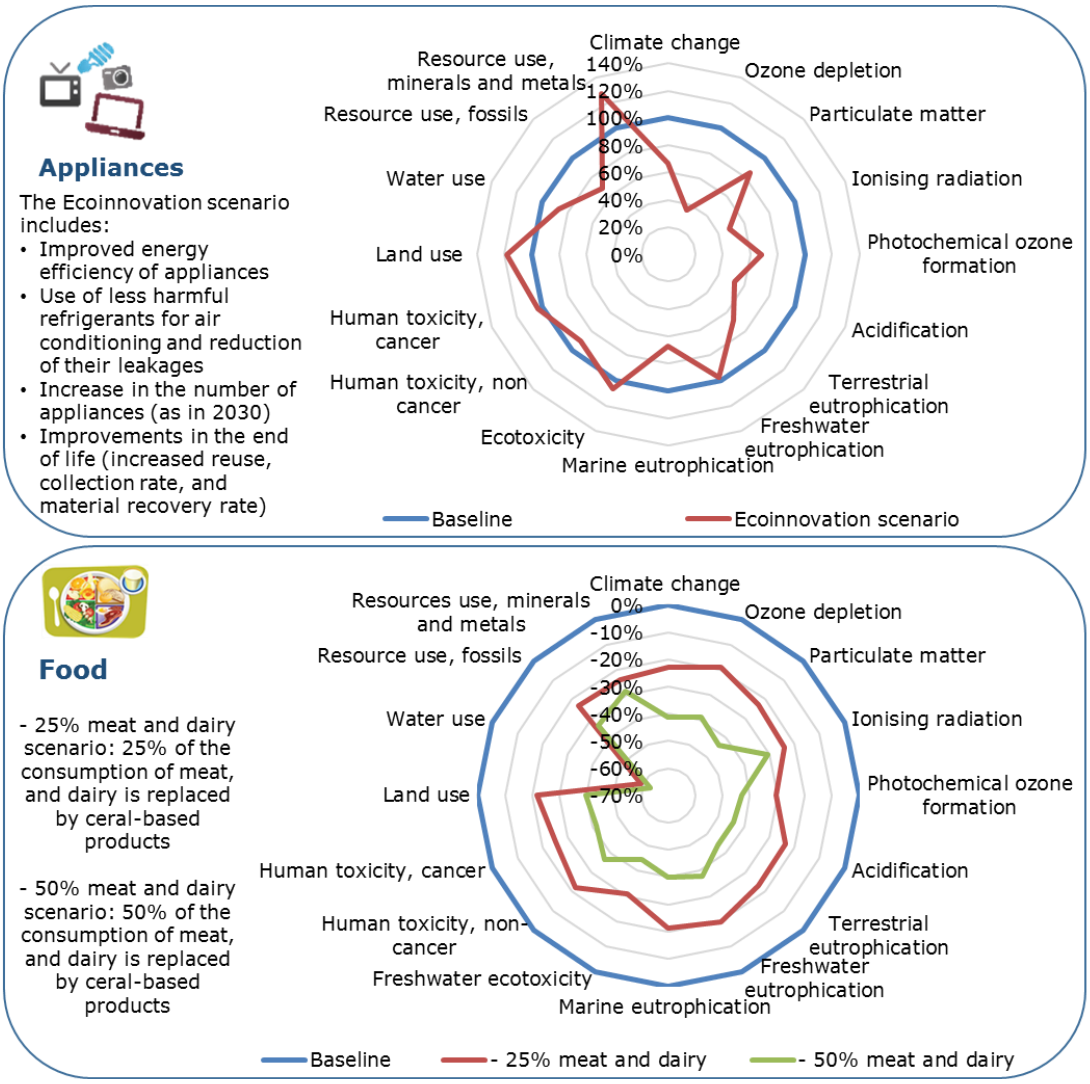
Model robustness of the impact assessment model used to assess each indicator is taken from EC (2017) and reported in Annex 1.

4.6 To which extent could eco-innovation and behavioural changes reduce the Consumer Footprint?

In Section 4.2, two recurrent drivers are identified for the investigated areas of consumption, i.e. the specific impact per unit of mass of products, and the amount of purchased or consumed products. Hence, the strategy to reduce the impacts of consumption needs to take into account peculiar features and criticalities of the products in each areas of consumption. In the technical report by Sala et al. (2019), more than 50 scenarios on the different areas of consumption have been tested. Here the results of two scenarios are presented (Figure 21): the first analyses the combined effects of a set of eco-innovation measures adopted for the goods consumed in the area of consumption Appliances (listed in Figure 21), whereas the second one focuses on the effects of a change in the average diet, considering that 25% and 50% of meat and dairy products are replaced with cereal-based products.

The eco-innovation scenario shows possible trade-offs, e.g. for the use of mineral and metals resources, for which the production of appliances is a hotspot (Section 4.1). The reduction in the consumption of meat and dairy, instead, has a positive effect on all the analysed impacts. In general, assessing different types of impact allows to have a broad picture of the effects of scenarios and to identify possible trade-offs.

Figure 21. Comparison between the impacts of the eco-innovation and the behavioural change scenarios and the baseline (set as 0%) on the areas of consumption Appliances and Food



4.7 How Consumer Footprint may capture different consumption patterns and lifestyles?

The Consumer Footprint is referred to an average EU citizen. However, individual lifestyles may diverge importantly from the average, resulting in different types of impacts and of different intensity**. The Consumer Footprint approach can be applied to consumption patterns and lifestyles different from the average one, to highlight environmental hotspots and possible areas for improvement.** JRC is currently developing a "Consumer Footprint Calculator", aimed to offer the possibility to EU citizens to assess the impacts and identify the most impacting activities of their own consumption patterns. Here an example on how the Consumer Footprint can be applied to calculate the impacts of specific consumers' profile is reported (Figure 22 and Figure 23).

Figure 22. Description of three exemplary consumers' profiles

	Anne (23 years old)	**Paul (25 years old)**	**Maria (32 years old), Evan (35), Ana (7)**
	Vegetarian	Semi-vegetarian (non –vegetarian options only when he eats outside)	Mediterranean diet
	Public transport/bike to go to the university. Trains to travel to nearby cities occasionally planes to go to other EU countries	Gasoline car to go to work (15 km). Trains to travel to nearby cities, often planes to go to distant places for vacations	Maria: Diesel car, carries Ana to school every day. Evan: LPG car, travels a lot for work.
	Shared flat with 2 friends, Gratz (Austria)	Flat, 15 km outside Gothenburg (Sweden)	Detached house with a small garden, small town in Italy
	Shared dishwasher, washing machine, and dryer with 2 flat-mates	Shared washing machine and dryer with other 6 tenants	Dishwasher, washing machine, 2 air conditioning

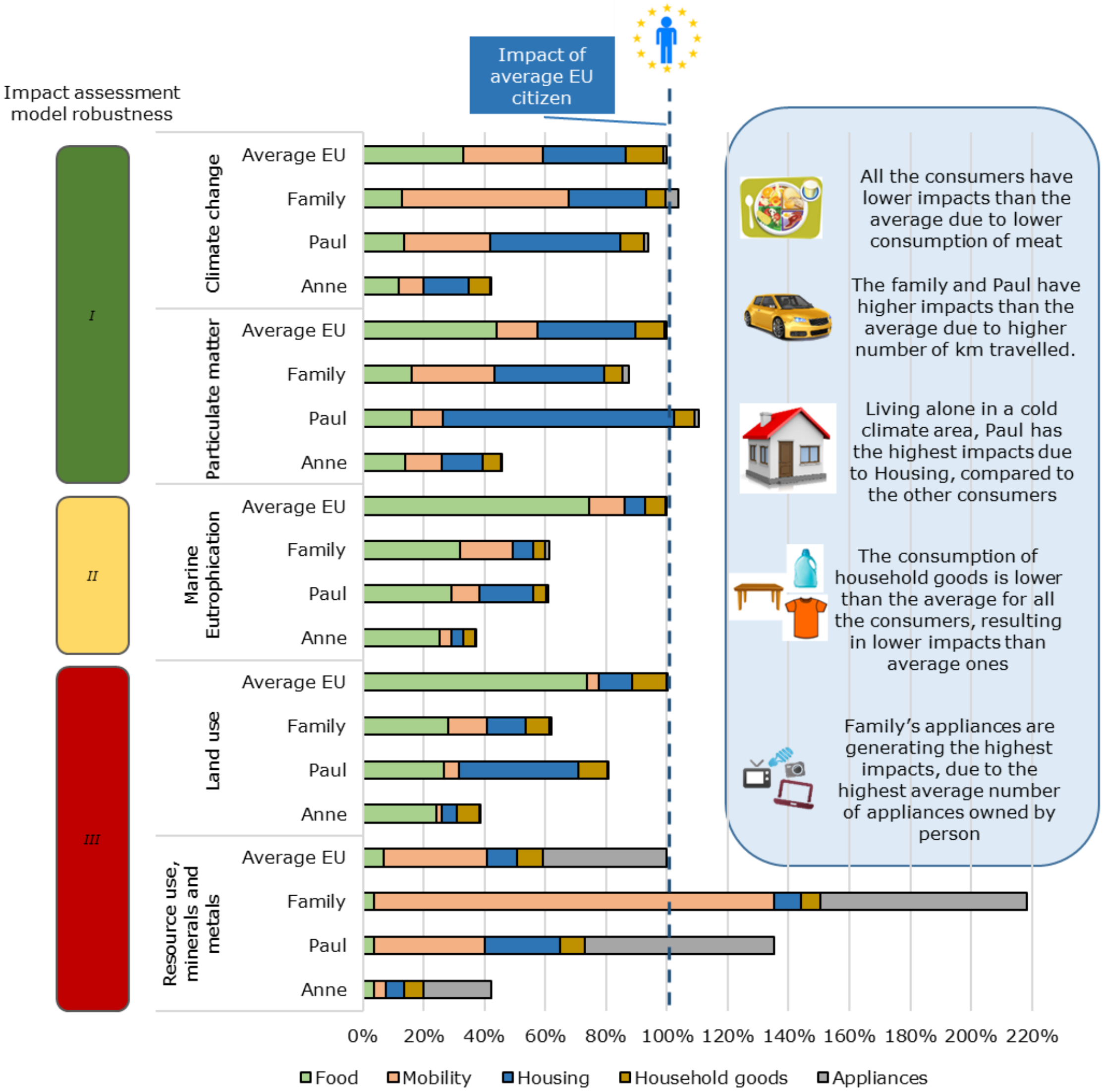
Significant differences are observed between the impacts of the analysed consumers' profiles and the one of an average EU citizen (Consumer Footprint).

Lower impacts than the average are observed for Anne in all the areas of consumption. Indeed, she adopts a series of environmentally friendly behaviours in the different areas of consumption, such as using public transportation, avoiding the consumption of meat, sharing the apartment and the appliances.

The impacts of the lifestyles of other consumers, instead, can be lower or higher than the average situation depending on the area of consumption considered. This highlights that positive effects due to the adoption of low-impact behaviours in a certain area of consumption may be to different extents offset by the impacts associated to other consumption areas. This is the case, for example, of the impact on climate change generated by Paul. His choice of being semi-vegetarian resulted in a 60% reduction of the impact of Food compared to the average. However, the fact that he is living alone and has to drive every weekday at least 30 km by car increases his impact in the areas of consumption Housing and Mobility, partially offsetting the positive effect of being semi-vegetarian. Indeed, Paul's overall impact of climate change is only 5% lower than the impact of an average EU citizen.

The analysis of consumers' profiles points out the need of adopting a comprehensive perspective, including all the areas of consumption, when assessing the impacts of consumption patterns.

Figure 23. Impacts of consumers' profiles compared with the average EU citizen (set as 100%)



Model robustness of the impact assessment model used to assess each indicator is taken from EC (2017) and reported in Annex 1. Results for the Family are expressed per person. Only few impacts reported as example. Results for all the impacts are reported in Sala et al. (2019).

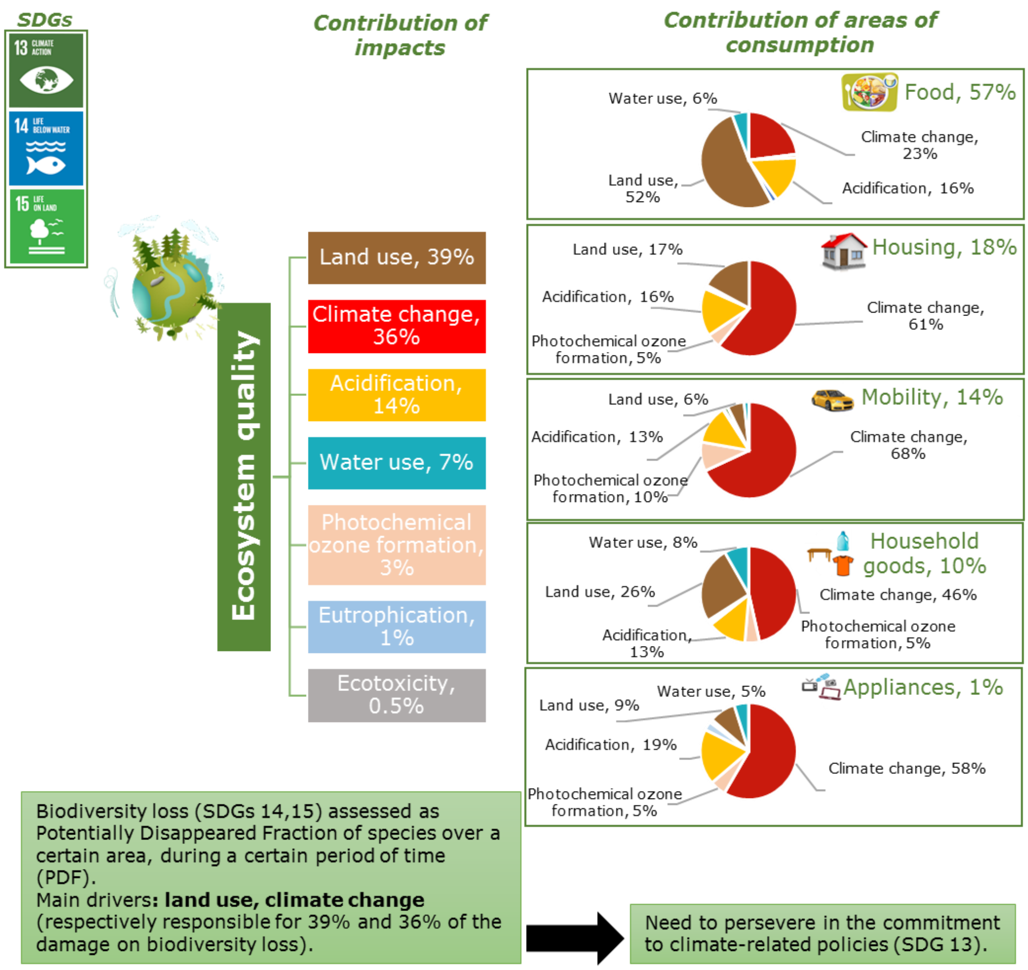
4.8 Which is the impact of Consumer Footprint on biodiversity and human health?

The 16 analysed LCA-based impact indicators assess changes in the aspect of the natural environment caused by environmental pressures. Estimating the impacts at the endpoint means modelling more broadly the effects of the environmental pressures, assessing the **damage effects** that may be generated on areas of protection, such as **ecosystem quality and human health**.

By focusing the evaluation of the damage provoked by environmental pressures on a few areas of protection, the endpoint modelling may facilitate the interpretation of the Consumer Footprint results in light of the objectives of SDGs, as well as reveal potential connections between them. Indeed, the quality of aquatic and terrestrial ecosystems and the conservation of biodiversity are within the focus of SDGs 14 "Life below water" and 15 "Life on land", whereas human health is at the core of SDG 3 "Good health and well-being".

Land use and climate change are responsible for the largest share of the damage on ecosystem quality in terms of biodiversity loss caused by consumption in EU. These results are coherent with the findings already reported in the Millennium Ecosystem Assessment (MEA, 2005; WWF 2017), which identify climate change and land use among the main drivers of biodiversity loss. Food is the area of consumption that mostly affects ecosystem quality, especially due to the environmental impacts caused by primary production. A specific study addressing the drivers of biodiversity impacts due to food consumption has been recently published (Crenna et al. 2019b)

Figure 24. Damage on ecosystem quality generated by EU consumption (2010)



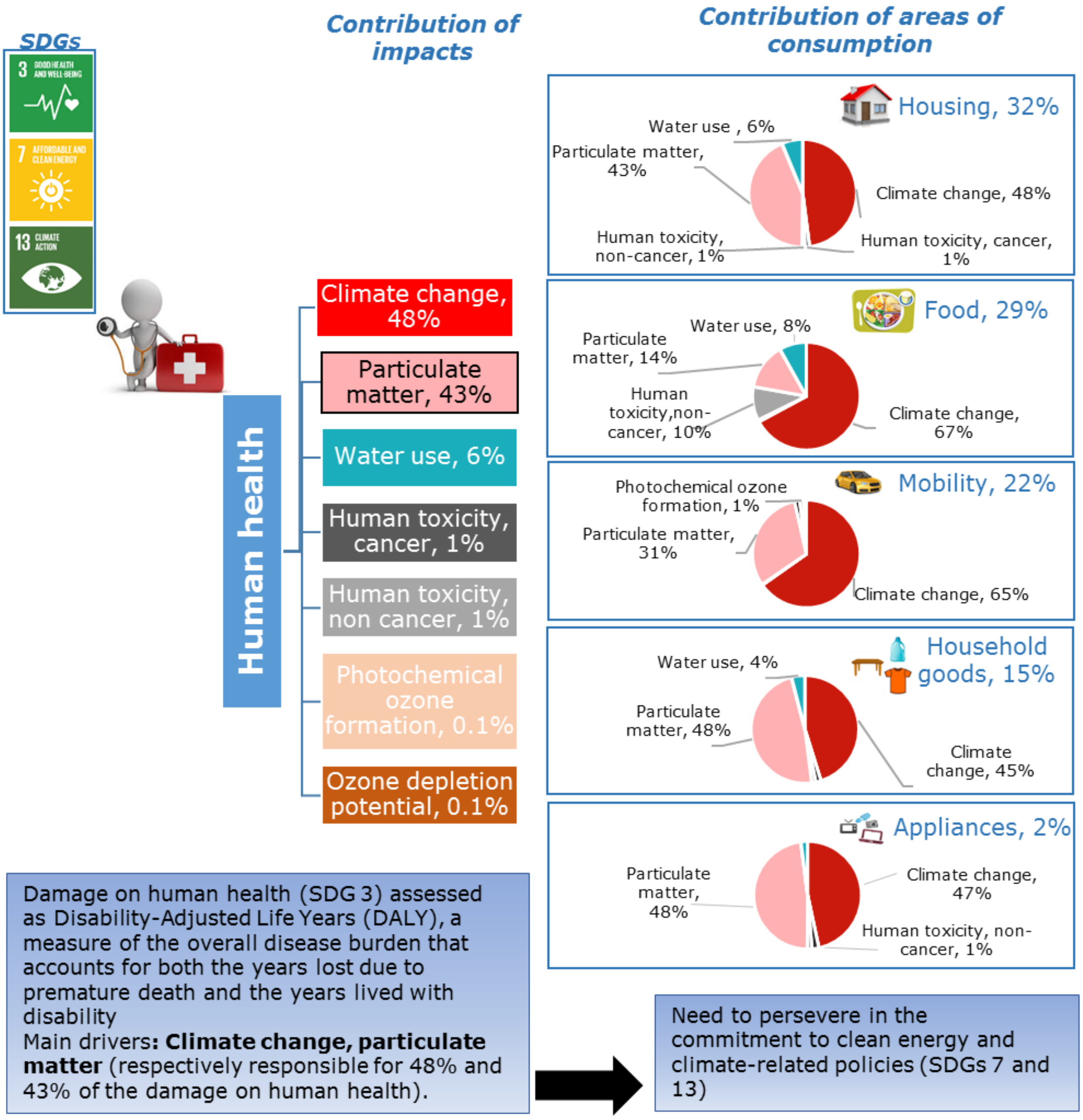
Endpoint assessment model: ReCiPe 2016 (Huijbregts et al., 2017), hierarchist perspective.

Particulate matter and climate change are the main drivers of the effects on human health due to consumption in EU. This result is in line with statistics on mortality by WHO that report illnesses associated with respiratory apparatus as third cause of mortality in the EU in 2010 (WHO, 2018). Particulate matter prevails on climate change in damaging human health in those areas of consumption where electricity use is at high levels, i.e. Housing and Household goods.

As general conclusion, it is possible to say that climate change is one of the main contributors to the endpoint damage on both ecosystem quality and human health. The damage on ecosystem quality is driven by land use associated to food production, whereas electricity production, being responsible of a large share of particulate matter emissions, is the main driver for the impact on human health.

These considerations highlight the existing **interconnections** between **SDG 13** "climate action", **SDG 7** "Affordable and clean energy", and respectively **SDGs 14 and 15, and SDG 3.**

Figure 25. Damage on human health generated by EU consumption (2010)



Endpoint assessment model: ReCiPe 2016 (Huijbregts et al., 2017), hierarchist perspective.

5 Consumption Footprint: what are the impacts of EU consumption at EU and at country scales?

> The **Consumption Footprint** is a set of **LCA-based indicators (also available as single score)** whose purpose is to quantify the **environmental impacts of apparent consumption in the EU**.
>
> Consumption Footprint = Domestic Footprint + Import Footprint – Export Footprint
>
> The Consumption Footprint is calculated according to two modelling approaches: bottom-up and top-down

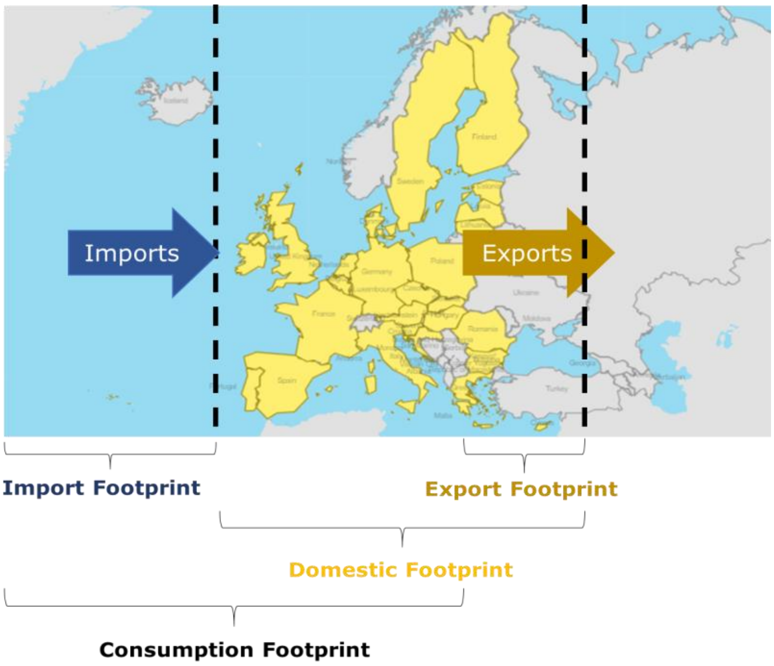
The Consumption Footprint takes into account both the burdens associated with domestic activities (within the domestic boundaries of EU) and those due to trade. In order to do so, **three different accounting components are quantified: domestic, import, and export**. The sum of environmental impacts 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 26).

The following equation is applied:

Consumption Footprint = Import Footprint (impacts due to imports) **+ Domestic Footprint** (impacts due to activities occurring within the EU boundaries) **– Export Footprint** (impacts due to exports)

The three components building the Consumption Footprint are estimated through different accounting perspectives. 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**).

Figure 26. The Consumption Footprint, calculated by use of Domestic and Trade Footprints[4]: scheme of concept



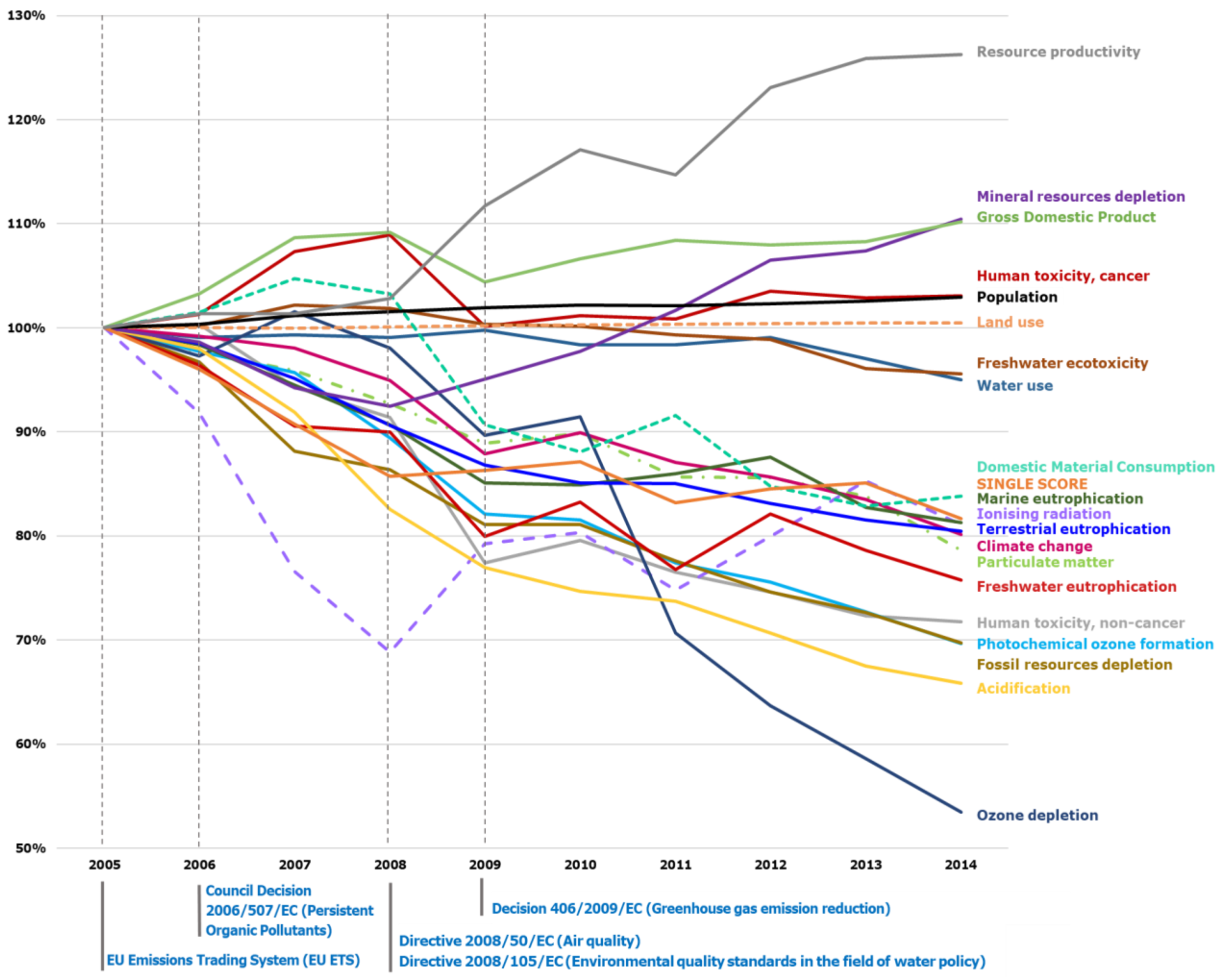
[4] Image taken from https://europa.eu/european-union/about-eu/countries_en (26/11/2018)

5.1 Domestic Footprint: what are the impacts generated in the EU territory?

The **Domestic Footprint** is a **set of 16 LCA-based indicators (also available as single score)** whos purpose is to quantify the **environmental impacts due to resource extraction, and emissions in the EU territory** in order to monitor the efforts of EU Member States to decouple economic growth from environmental impacts.

Between 2005 and 2014, the EU Domestic Footprint decreased in most impacts to the environment and resources, while GDP increased (+8%). An **absolute decoupling** is observed regarding this period for EU and many impacts (Figure 27). The decoupling is more evident for the ozone depletion (-47%), resource use-fossils, human toxicity-non cancer, photochemical ozone formation, and acidification (all around -30%). Overall, considering the single score, the **Domestic Footprint decreased by 18% from 2005 to 2014**.

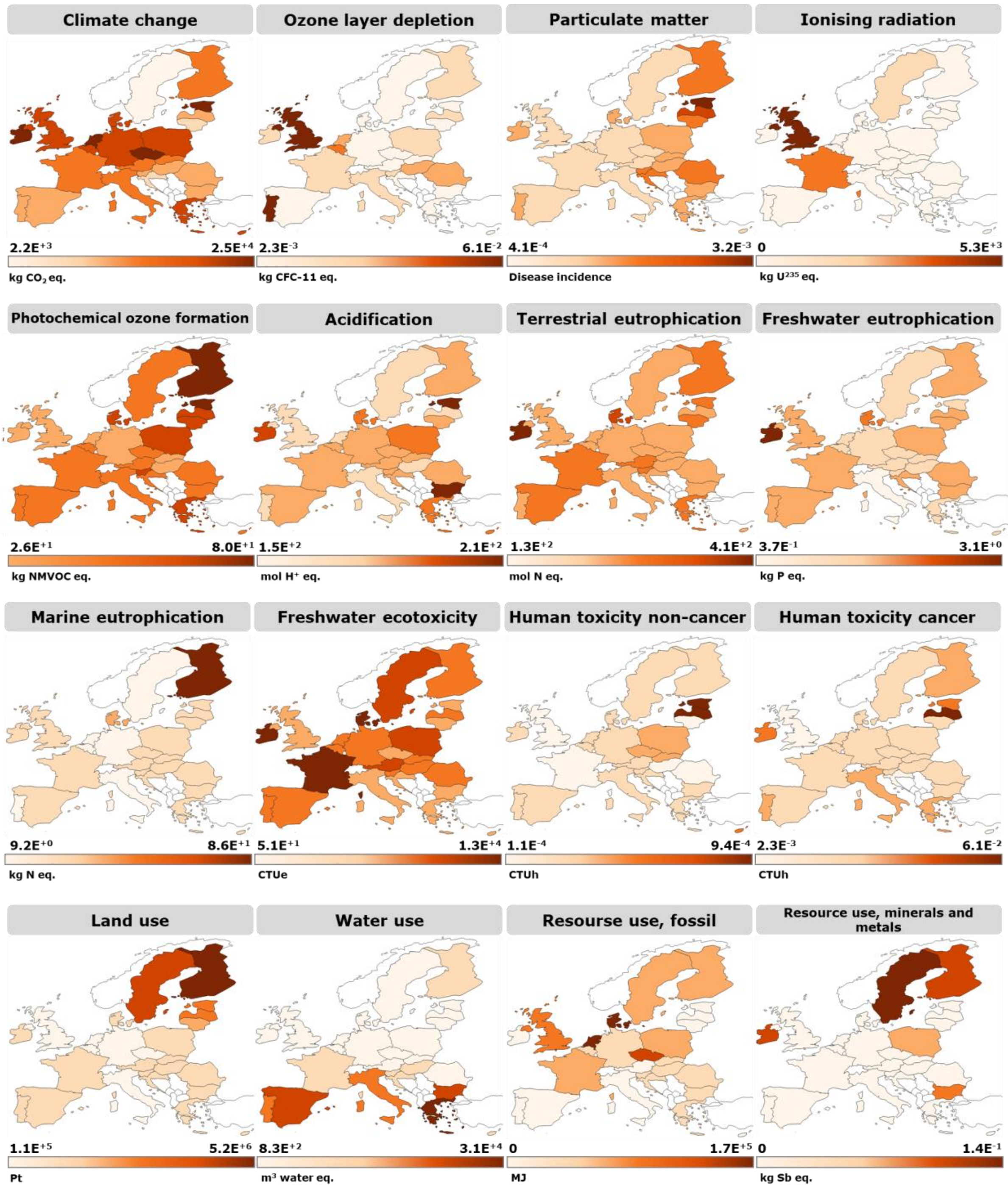
Figure 27. Domestic Footprint variation between 2005 and 2014 (both as single score and as separated impact indicators), compared with GDP and DMC



Note: Results for 2005 are reported as 100%, and results for the other years are rescaled accordingly. The following substances are taken into account in each cited policy: (i) EU Emissions Trading System: CO_2, PFCs, N_2O; (ii) Council Decision 2006/507/EC: aldrin, chlordane, dieldrin, endrin, hexabromobiphenyl, hexachlorobenzene, hexachlorocyclohexane, lindane, mirex, polychlorobiphenyls, endosulfan, and toxaphene; (iii) Directive 2008/50/EC: SO_2, NO_2, NO_x, CO, Benzene, $PM_{2.5}$, PM_{10}, Lead, O_3, NO, NO_3; (iv) Directive 2008/105/EC: Priority substances list (including e.g. Heavy Metals, Polybrominated diphenyl ethers (PBDEs), Polycyclic aromatic hydrocarbon (PAHs), active substances in pesticides); (v) Decision 406/2009/EC: Greenhouse gases (GHGs).

Member States contribute to the EU Domestic Footprint to different degrees. Figure 28 shows the Domestic Footprint per average citizen in each EU Member State, considering each impact to the environment and resources. **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). Regarding the spatial distribution, southern countries tend to show a lower impact intensity per citizen, apart from the impact on water use.

Figure 28. Domestic Footprint per citizen of the 28 EU Member States, considering 16 impacts on the environment and resources use (2010)



5.2 Trade Footprint: what are the environmental impacts generated by EU trade?

The **Trade Footprint** is a set of **LCA-based indicators (also available as single score)** whose purpose is to quantify the **environmental impacts of** emissions of pollutants and extraction of resources **along the supply-chain of trade** (namely, imports and exports). It accounts for environmental impacts associated to product's stages of the supply chains happening outside EU borders. It is calculated according to two modelling approaches: bottom-up and top-down.

Example: environmental impacts of car imports

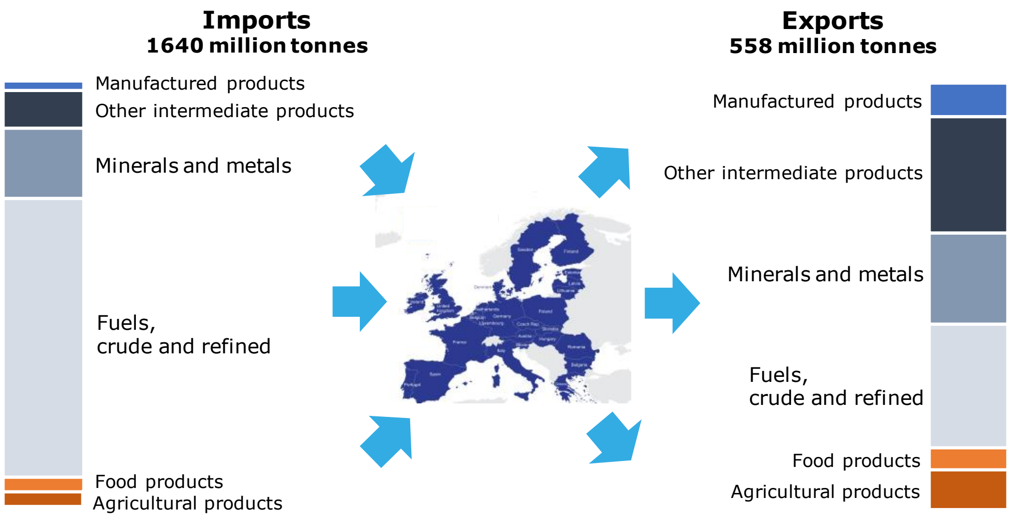
The production of a car imported in one of the Member States requires several production steps, which imply the use of resources such as fossil fuels, metals and minerals as well as the emission of a number of pollutants, leading to environmental impacts. Such impacts are allocated to the car according to LCA method and represent the environmental burden associated with the production of a car.

The sum of all the environmental burdens associated to the entire volume of imported, or exported, goods and services leads to the total environmental impact associated with imports, or exports, of an economy.

When considering the total mass of goods imported, the EU **mainly imports fossil fuels** (from crude to refined) and to a lower extent minerals and metals (from ores to transformed), i.e. **goods with limited supply-chains** (Figure 13). Fossil fuels and minerals and metals also represent a significant share of the total **exports** from EU, but in that case **"other intermediate products"** (such as e.g. rubber and plastic products) and **manufactured products** represent a larger share of the total mass.

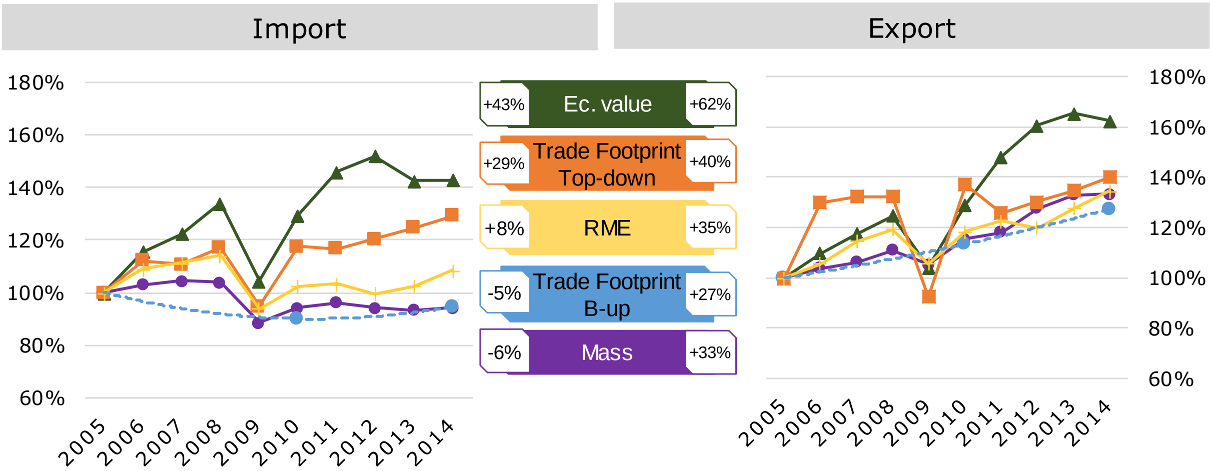
According to both calculation approaches (bottom-up and top-down), EU is a **"net importer of environmental impacts"**, with some exceptions for the bottom-up approach regarding human toxicity, non-cancer, freshwater eutrophication, and land use.

Figure 29. Relative share of mass of goods imported and exported by EU, by product groups, according to the bottom-up approach (2010)



In the meantime, an **important increase of the impacts of exports** is observed **between 2005 and 2014** (Figure 30), with a beneficial effect on the reduction of the apparent consumption (while the overall impacts generated increase; "export effect").

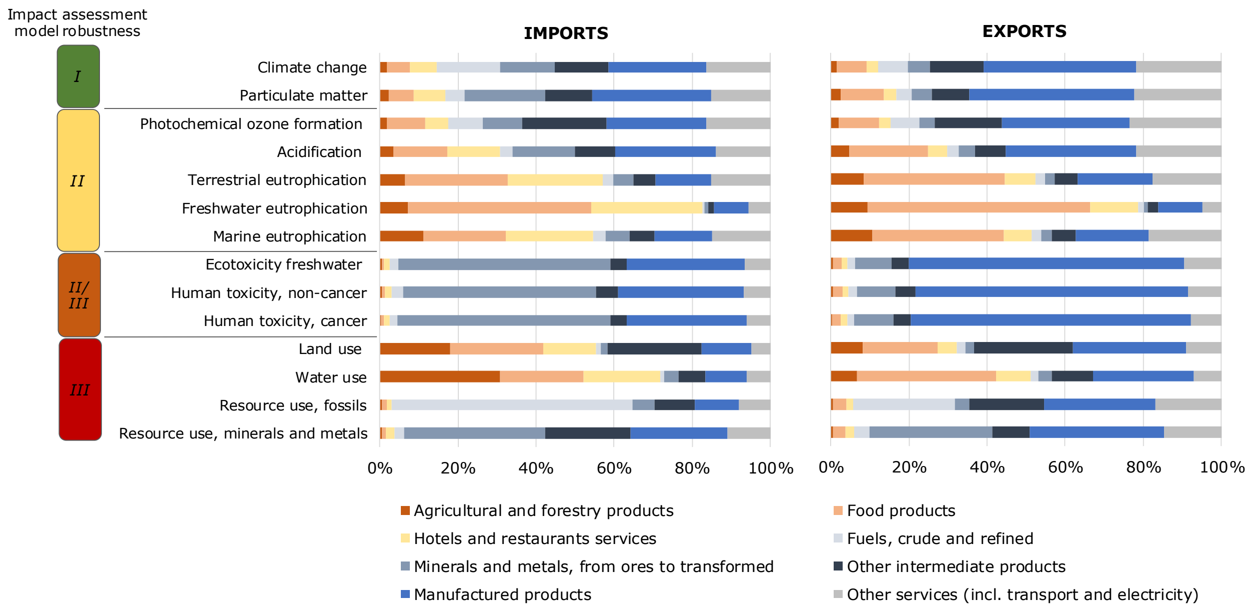
Figure 30. Temporal trends (2005-2014) of Trade Footprints (top-down and bottom-up), Raw Material Equivalents (RME) and Gross Domestic Product (GDP)



Note: Ec. Value = economic value, RME= raw material equivalent

Products with limited supply chains are the **main contributors** to the impacts induced by imports (Figure 31): i) **agricultural and food products** (in particular meat products) and food-related services regarding acidification, terrestrial eutrophication, freshwater eutrophication, marine eutrophication, land use and water use, ii) **metals** (in particular basic iron and steel) and **other intermediate products** (in particular rubber and plastic products) regarding human toxicity-cancer and non-cancer, freshwater ecotoxicity, particulate matter and photochemical ozone formation, iii) **materials** (metals, ores and concentrates, and fossil fuels) regarding both minerals and metals and fossils resource use, and iv) **materials** (in particular basic iron and steel and fossil fuels) and **other intermediate products** regarding climate change. A larger contribution of **manufactured products** is observed regarding the **impacts of exports** from EU, when compared both to the contribution of other products and services exported and to the share of manufactured products in the impacts of imports.

Figure 31. The Trade Footprint (top-down) of EU: contribution analysis (2011)

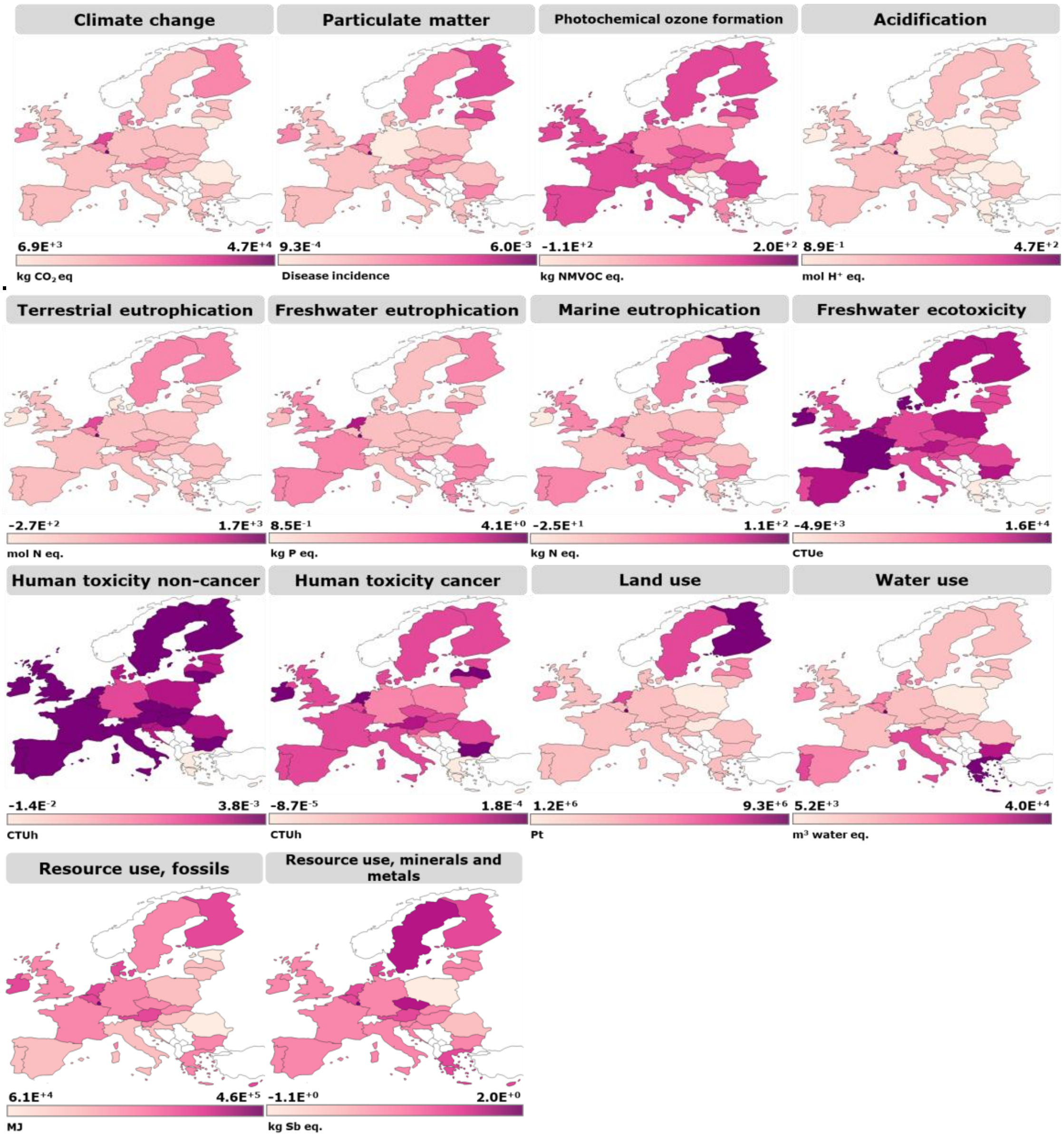


Model robustness of the impact assessment model used to assess each indicator is taken from EC (2017). In the top-down approach, 14 environmental impacts are considered, because of data constraints on emissions with an impact on ionising radiation and ozone depletion in the input-output database.

5.3 Consumption Footprint: what are the impacts and related drivers in EU countries?

The Consumption Footprint quantifies the environmental impacts associated with EU apparent consumption. It takes into account both the burdens associated with domestic activities (within the domestic boundaries of EU) and those due to trade. Member States contribute to different degrees to the EU Consumption Footprint. The Consumption Footprint (top-down) per average citizen in each EU Member State, by each impact to the environment, is shown in Figure 32. As for the Domestic Footprint (Figure 28), **Member States with a high GDP per citizen frequently present high impact per citizen** (e.g. Luxemburg, the Netherlands, Denmark, Finland, Sweden, and Belgium). As well in terms of spatial distribution, southern countries tend to show a lower impact intensity per citizen, apart from water use. For some indicators, the negative values observed are outliers, as the result of the relative high relevance of import and export over the domestic values and or due to uncertainty in the underpinning calculations (e.g. Greece for Human toxicity cancer and non-cancer, and freshwater ecotoxicity).

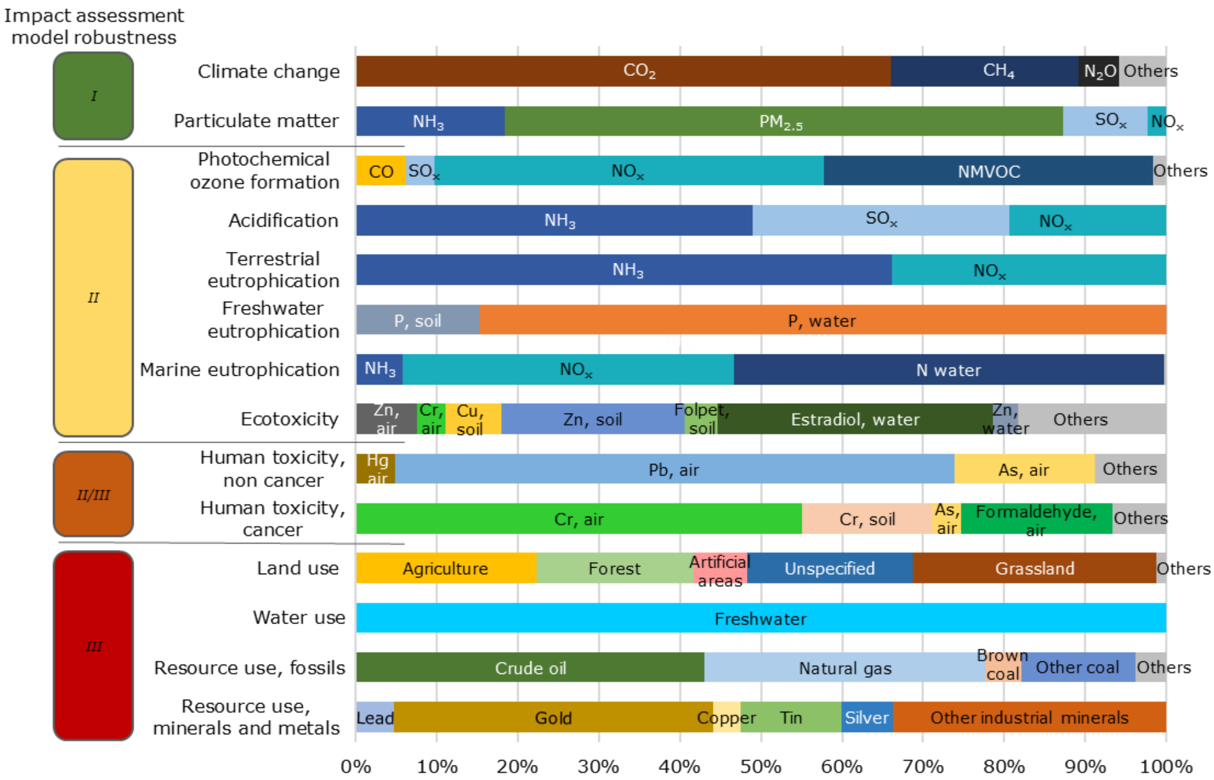
Figure 32. Consumption Footprint top-down per citizen of the 28 EU Member States (2010)



In the top-down approach, 14 environmental impacts are considered, because of data constraints on emissions with an impact on ionising radiation and ozone depletion in the input-output database.

Regarding the main pollutants and resources driving the impact of consumption, **a relatively limited set of pressures** contribute to **a major share of the impacts** as reported in Figure 33.

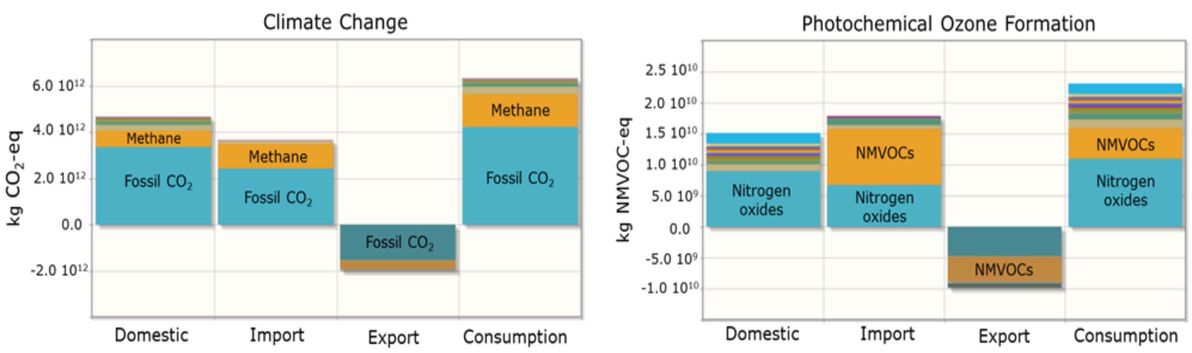
Figure 33. Percentage contributions of pollutants and resources to the Consumption Footprint top-down (2011)



In the top-down approach, 14 environmental impacts are considered, because of data constraints on emissions with an impact on ionising radiation and ozone depletion in the input-output database.

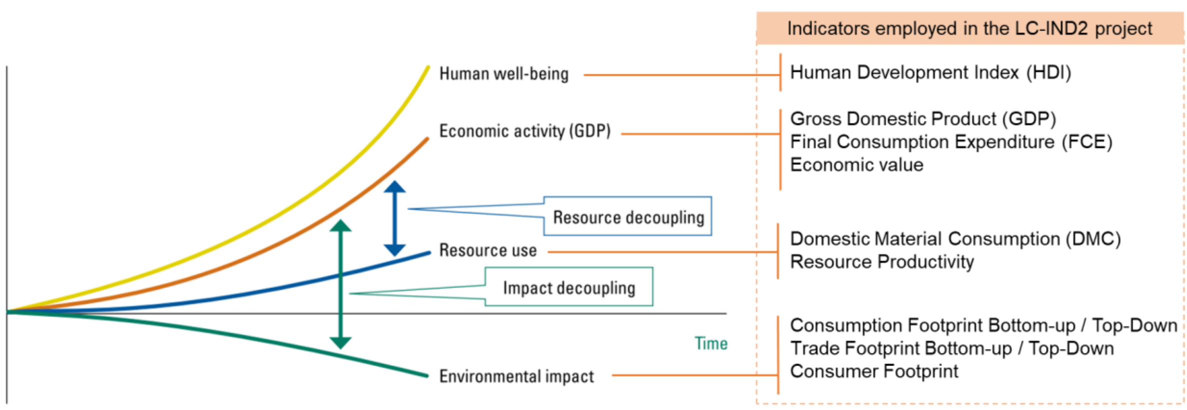
For the majority of impacts (climate change, acidification, eutrophication freshwater, terrestrial and marine, fossil resource use, land use, photochemical ozone formation, particulate matter and water use), the set of most contributing elementary flows is the same considering both the domestic component and the trade one. Figure 34 illustrates an example of the main substances contributing to photochemical ozone depletion and climate change, highlighting the breakdown of substances in the domestic, import, export and apparent consumption. From the figure it is clear that increasing both import and export the apparent consumption (domestic +import –export) might result lower but the global impacts generated by the trade are increasing.

Figure 34. Consumption Footprint top-down of EU (2011): key pollutants driving the impacts on climate change and photochemical ozone formation



5.4 Decoupling assessment: why is a consumption-based approach key?

Decoupling: using less resources per unit of economic output and reducing the environmental impacts (UNEP, 2011).



Absolute decoupling: the environmental impacts decrease while the economic activity keeps growing.

Relative decoupling: the increase of the environmental impacts is lower than the growth of the economic activity.

The assessment of environmental impacts can be performed for a certain year to show the status quo, as well as for a period of time to evaluate the evolution of the impacts. To assess the decoupling of the environmental impacts of consumption from the economic output, the trends along the temporal period 2004-2011 were evaluated for the EU and Member States (Figure 35). **EU showed absolute decoupling along this period**.

EU countries showed different and contrasting profiles regarding the environmental impact decoupling along the assessed period (Figure 35). **More than half of the EU Member States show an absolute decoupling trend**, being Poland the country with the highest environmental impact reduction (~-80%). Contrarily, Luxembourg showed the largest environmental impact increase (~+78%), among the non-decoupling countries. While some countries show a relative decoupling, Italy and Greece are stagnant countries where the GDP variation is limited (Sanyé-Mengual et al., 2019).

Territorial vs. Consumption-based approach

- **Considering a consumption-based perspective rather than a territorial or a production-based one is key in the evaluation of the decoupling of the environmental impacts of consumption from the economic output.** Figure 35 compares the environmental decoupling behavior of the EU countries for the weighted score of the Domestic Footprint and the Consumption Footprint top-down, both for 14 indicators and global normalisation.
- From a production-based approach (Domestic Footprint), most of the countries showed an absolute decoupling. This trend indicates that the territorial environmental policies implemented in the EU framework are pushing towards a decrease of the environmental impacts (Figure 27). However, the inclusion of the trade in the environmental modelling in the Consumption Footprint top-down shows a more equilibrated distribution between non-decouplers, relative decouplers, and absolute decouplers.
- Therefore, the environmental impacts embodied both in imports and exports have a significant role in the environmental burdens of consumption and, thus, a territorial perspective would lead to a biased conclusion as the environmental impacts are decoupling from the economic growth more intensely in the territory than abroad.

Figure 35. Environmental impact decoupling of the Consumption Footprint top-down from the Gross Domestic Product (2004-2011, 14 indicators, global normalization)

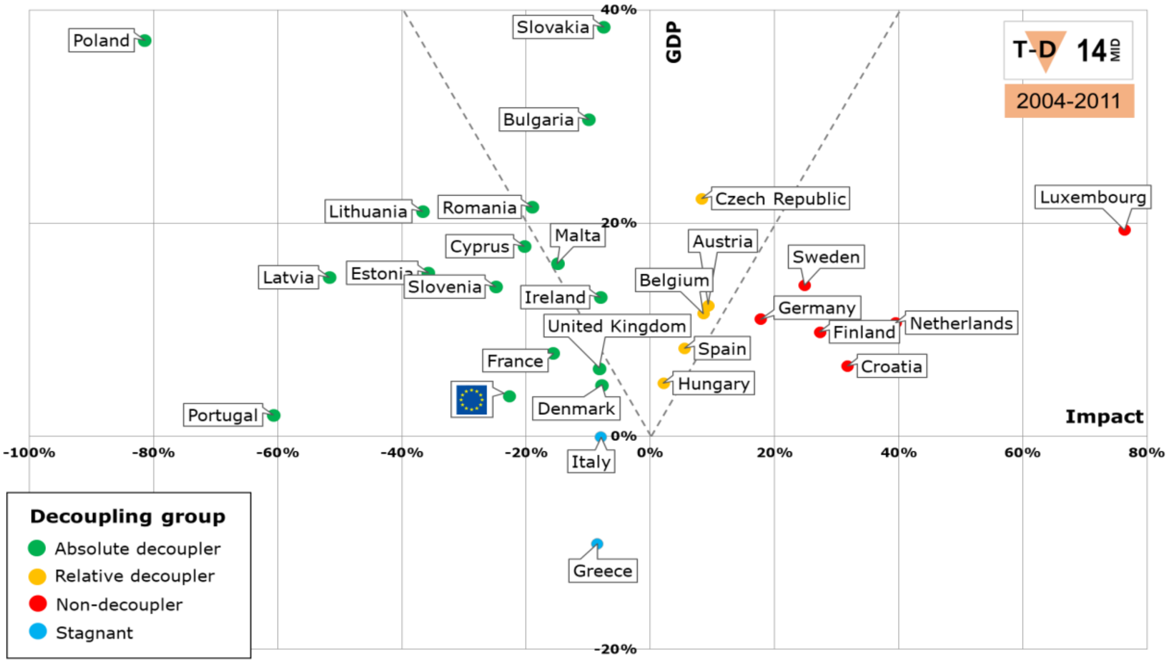
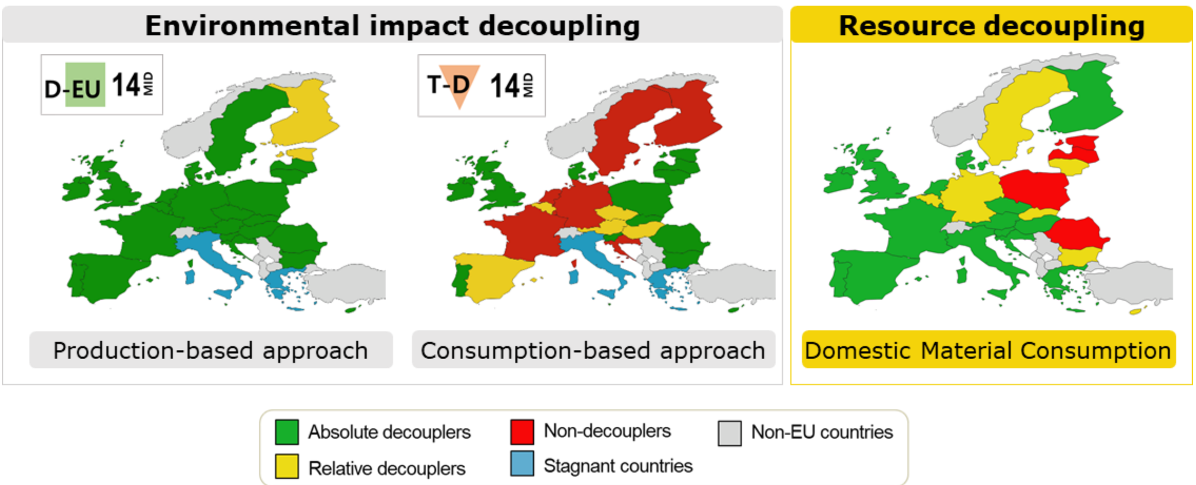


Figure 36. Environmental impact decoupling: Domestic Footprint and Consumption Footprint top-down (2004-2011, 14 indicators, global normalization), and resource decoupling: Domestic material consumption (2004-2011)



Note: Domestic Material Consumption and GDP values are obtained from Eurostat (2018).

Environmental decoupling vs. Resource decoupling

- The resource decoupling can be assessed by comparing the use of resources in terms of Domestic Material Consumption, as a resource productivity indicator employed by Eurostat, with the evolution of the economic output (i.e. Gross Domestic Product).
- Resource decoupling obtained more positive values (more countries as absolute decouplers) than the environmental decoupling. Thus, the assessment of the decoupling in relation to the environmental impact rather than the resources use is key to integrate the environmental behaviour of different environmental pressures beyond the absolute amount of resources depletion (Figure 36).

6 Is consumption of the EU environmentally sustainable and within Planetary Boundaries?

The environmental impact of EU consumption could be further linked to specific **SDGs** (3, 6, 13, 14, and 15) and related to **Planetary Boundaries**, which represent the quantitative estimation of the **Earth carrying capacity**. This link is in line with the "**Living well within the limits of the planet**" concept of the 7th EAP (European Parliament and Council, 2013), and means the quantification of the environmental performance of the EU consumption with respect to the Earth system capacity as an **absolute term of comparison**. The connection to SDGs and Planetary Boundaries helps determining whether the consumption in the EU is **environmentally sustainable**.

Figure 37. Impacts of EU: relative and absolute assessments

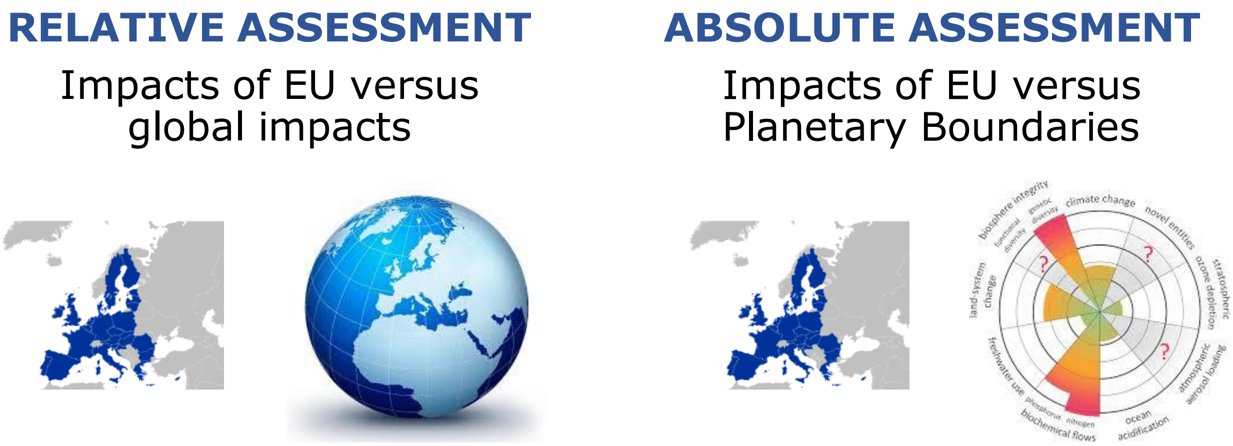


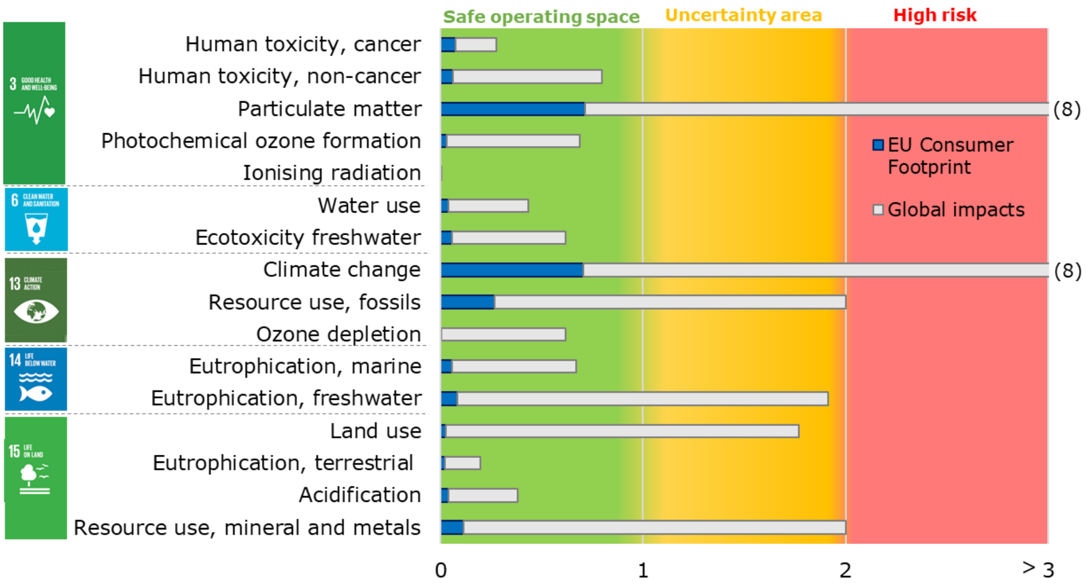
Figure 38. Overview of the link between the (midpoint) impacts adopted in Life Cycle Impact Assessment, the Sustainable Development Goals and the Planetary Boundaries

SUSTAINABLE DEVELOPMENT GOALS	Impact	Biodiversity integrity – Functional / Biodiversity integrity - Genetic	Climate change	Novel entities	Stratos-pheric ozone depletion	Atmos-pheric aerosol loading	Ocean acidifi-cation	Biogeother-mal flows - Nitrogen / Biogeother-mal flows - Phosphorus	Fresh-water use	Land-system change
3	Human toxicity, cancer		●							
3	Human toxicity, non cancer			●						
3	Particulate matter					●				
3	Photochemical ozone formation	●		●						
3	Ionising radiation			●						
6	Water use (impact due to)	●							●	
6	Ecotoxicity, freshwater	●		●						
13	Climate change	●	●				●			
13	Resource use, fossil (impact due to)		●							
13	Ozone depletion				●					
14	Euthrophication, marine	●						●		
14	Eutrophication, freshwater	●						●		
15	Land use (impact due to)	●								●
15	Euthrophication, terrestrial	●							●	
15	Acidification	●							●	
15	Resource use, minerals and metals (impact due to)		●							

Some impacts may fall into more than one SDG. For the sake of simplicity, each impact has been listed once.

The Consumer Footprint is **not overcoming the boundaries**. However, for climate change and particulate matter, the consumption of the average EU citizens uses more than 70% of the safe operating space available for the whole world, thus leaving less than 30% margin to the citizens in the rest of the world.

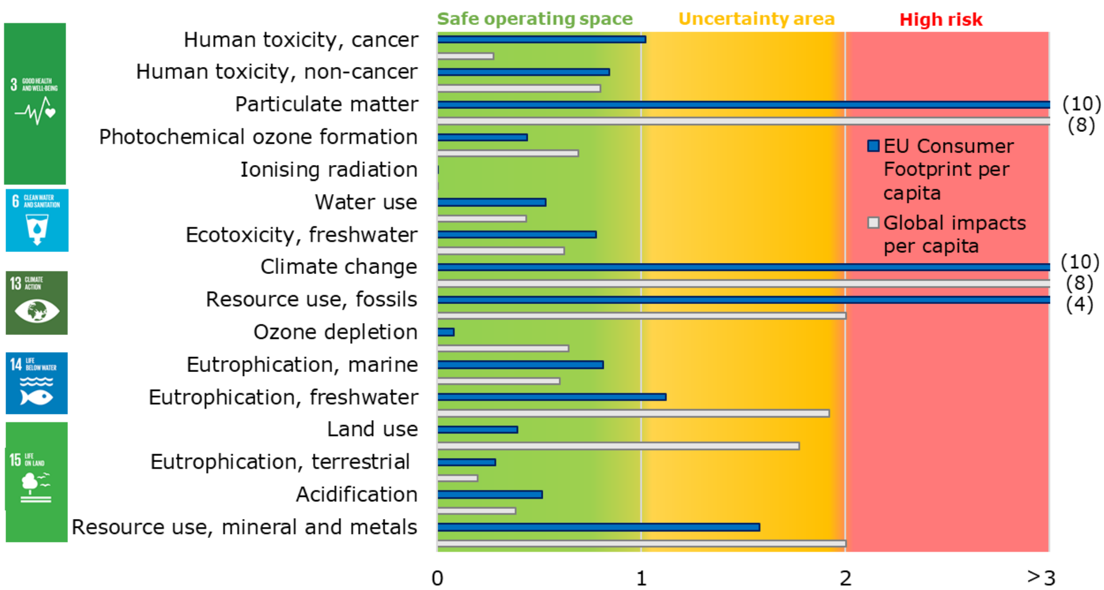
Figure 39. EU Consumer Footprint compared to global (whole world) impact per capita and Planetary Boundaries



Number in brackets refer to the extent to which impacts are overcoming Planetary Boundaries

When considering the **impacts per capita**, the **overcoming of the Planetary Boundaries** is observed with respect to climate change, particulate matter, freshwater eutrophication, human toxicity, cancer, resource use fossils and minerals and metals. For many impact categories the EU per capita results are **higher than the impacts of an average world citizen**. 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 40. EU Consumer Footprint per capita, compared to global (whole world) impact per capita and Planetary Boundaries



Number in brackets refer to the extent to which impacts are overcoming Planetary Boundaries

7 Conclusion

This study has proposed the implementation of different LCA-based approaches to estimate environmental pressures and impacts due to EU Consumption, distinguishing **16 impacts** on the environment and resources (e.g. climate change, freshwater ecotoxicity, land use, water use). **Modelling consumption in the EU to assess SDG 12**, the calculated environmental impacts can be linked with **target 8.4 of SDGs related to decoupling economic growth from environmental degradation** and **5 others SDGs related to environmental aspects (3, 6, 13, 14 and 15)**. The assessment has been performed at different scales: **the EU as whole, 28 individual Member States, sectors and products, and individual citizens**. It is the first study that systematically explores different approaches to model the impact of EU consumption, to evaluate the decoupling of EU economic growth from environmental degradation (including 16 impact categories), comparing their results, including **assessment to the Planetary Boundaries** and aiming towards a **single headline indicator** (a weighted score of the 16 environmental impacts covered) for communicating these results.

LCA can have a crucial role in ensuring a systematic approach to environmental impact assessment to help unveil and assess trade-offs. However, this work is not exhaustive of all environmental concerns: it assessed potential impacts according to the impacts selected in the Environmental Footprint. Future work may focus on **improving the robustness of the assessment of the overcoming of Planetary Boundaries**, as well as **to improve the assessment of impacts related to biodiversity loss** and **to address additional environmental concerns** related to consumption, such as **marine litter**.

Main findings

— 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 the main driver of impacts** generated by household consumption, followed by Housing (especially for space heating) and Mobility (especially the use of private cars). An **increase of Consumer Footprint between 2010 and 2015 is observed for all the areas of consumption**, except Housing.

— The Consumer Footprint in a reference year could be considered a baseline scenario against which different policy options could be tested, from substituting a raw material, to changing a consumer behaviour or a waste management option. Adopting LCA to test the policy options, the trade-offs associated to eco-innovations emerge clearly. More than 50 scenarios on the different areas of consumption have been tested. Overall, results showed that **only integrated actions combining several interventions may ensure significant reduction of the environmental impacts**.

— Between 2005 and 2014, environmental impacts generated within the EU territory have decreased (-18% as weighted score) while GDP has increased, showing an absolute decoupling. Yet when accounting for trade (Consumption Footprint), a more limited decoupling is observed.

— The **EU can be considered a "net importer of environmental impacts"**: environmental impacts of imports are larger than those of exports. This implies that the Consumption Footprint (overall impacts related to consumption of goods and services) is higher than the Domestic Footprint (impacts generated in the EU area).

— Results show that **the consumption of an average EU citizen is generating impacts outside the safe operating space for humanity for several planetary boundaries**, 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 different impacts, results conclude that for most categories the impacts are close to the threshold, when not over it.

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List of abbreviations

BoP	Basket of Products
CFC	Chlorofluorocarbons
DALY	Disability-adjusted life years
DMC	Domestic material consumption
D-EU	Domestic impacts in the EU
EAP	Environment Action Programme
EF	Environmental Footprint
EU	European Union
GDP	Gross Domestic Product
GHG	Greenhouse gas
HH	Human health
LCA	Life Cycle Assessment
MFH	Multi-Family House
OEF	Organisation Environmental Footprint
PDF	Potentially disappeared fraction of species
PEF	Product Environmental Footprint
RME	Raw Material Equivalent
SDGs	Sustainable Development Goals
SFH	Single-Family House
T-D	Top-down

List of definitions

Definiendum	Definition
Absolute decoupling	The environmental impacts decrease while the economic activity keeps growing.
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)
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)
Consumer Footprint	The Consumer Footprint is a set of 16 LCA-based indicators, which may be as well summarised in a "single score" indicator, aimed at quantifying the environmental impacts of an average EU citizen.
Consumption Footprint	The Consumption Footprint is a set of 14 LCA-based indicators aimed at quantifying the environmental impacts of apparent consumption in the EU. Consumption Footprint = Domestic Footprint + Import Footprint – Export Footprint The Consumption Footprint is calculated according to two modelling approaches: bottom-up and top-down.
Domestic Footprint	Overall environmental impact of European Union (EU) and ultimately of each Member State with a production-based approach.
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.
Environmental Footprint (EF) – PEF/OEF	Life cycle based methodology for the assessment of the environmental profile of products (Product Environmental Footprint - PEF) or organisations (Organisation Environmental Footprint - 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).
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).
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 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.
Normalisation	According to ISO 14044, normalisation is an optional interpretation step of a complete LCA study. Normalisation allows the practitioner expressing results after characterization using a common reference impact. 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.
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 increase of the environmental impacts is lower than the growth of the economic activity.
Trade Footprint	The Trade Footprint aims at calculating the impacts due to the emissions of pollutants and extraction of resources along the supply-chain of trade (namely, imports and exports). It accounts for environmental impacts associated to product's stages of the supply chains happening outside EU borders. It is calculated according to two modelling approaches: bottom-up and top-down.
Weighting	According to ISO 14044, weighting is an optional interpretation step of a complete LCA study. 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.

List of figures

Annex 1. Impact categories, underpinning models, and robustness of the impact assessment models

Impact category	Unit	Model adopted as in EF	Model robustness[a]	Global normalisation factors[b]	Planetary Boundaries	Weighting factors[c] (%)
Climate change	kg CO_2 eq.	IPCC, 2013	I	5.55E+13	6.81E+12	21.06
Ozone depletion	kg CFC-11 eq.	World Meteorological Organisation (WMO), 2014	I	3.33E+08	5.39E+08	6.31
Particulate matter	Disease incidence	Fantke et al., 2016	I	4.11E+06	5.16E+05	8.96
Ionising radiation	kBq U-235 eq.	Frischknecht et al., 2000	II	9.54E+11	5.27E+14	5.01
Photochemical ozone formation	kg NMVOC eq.	Van Zelm et al., 2008, as applied in ReCiPe 2008	II	2.80E+11	4.07E+11	4.78
Acidification	mol H^+ eq.	Posch et al., 2008	II	3.83E+11	1.00E+12	6.2
Eutrophication, terrestrial	mol N eq.	Posch et al., 2008	II	1.22E+12	6.13E+12	3.71
Eutrophication, freshwater	kg P eq.	Struijs et al., 2009	II	1.11E+10	5.81E+09	2.8
Eutrophication, marine	kg N eq.	Struijs et al., 2009	II	1.35E+11	2.01E+11	2.96
Freshwater ecotoxicity	CTUe	USEtox (Rosenbaum et al., 2008)	II/III	8.15E+13	1.31E+14	1.92
Human toxicity, non-cancer	CTUh	USEtox (Rosenbaum et al., 2008)	II/III	2.66E+05	4.10E+06	2.13
Human toxicity, cancer	CTUh	USEtox (Rosenbaum et al., 2008)	USEtox (Rosenbaum et al., 2008) (II/III)	3.27E+06	9.62E+05	1.84
Land use	Pt	Bos et al., 2016 (based on)	III	1.54E+16	8.71E+15	7.94
Water use	m^3 water eq.	AWARE 100 (based on) (UNEP 2016; Boulay et al. 2018)	III	7.91E+13	1.82E+14	8.51
Resource use, fossils	MJ	ADP fossils (van Oers et al., 2002)	III	4.48E+14	2.24E+14	8.32
Resource use, minerals and metals	kg Sb eq.	ADP ultimate reserve (van Oers et al., 2002)	III	4.39E+08	2.19E+08	7.55

[a]EC, (2017). PEFCR Guidance document - Guidance for the development of Product Environmental Footprint Category Rules (PEFCRs), version 6.3, December 2017.

[b]Crenna E., Secchi, M., Benini, L., & Sala, S. (2019). Global environmental impacts: data sources and methodological choices for calculating normalisation factors for LCA. The international Journal of Life Cycle Assessment, 1-27.

[c]Sala S., Cerutti, A.K., & Pant, R. (2018). Development of a weighting approach for Environmental Footprint. European Commission, Joint Research Centre, Publication Office of the European Union, Luxembourg. ISBN 978-92-79-68041-0.t al., 2018

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