# Significance of environmental footprints for evaluating sustainability and security of development

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**Summary**

This contribution presents the selected categories of environmental footprints related to the planetary boundaries and threats to human security. The analysis covers the Footprint Family of indicators that usually consists of Ecological, Carbon or more precisely Greenhouse Gas and Water Footprints and also sometimes the Energy Footprint. The other assessed footprints that are important for ecosystem health in regards to water, health, food, and land and species security are: Nitrogen, Phosphorus, Biodiversity and Land Footprints, which have already transgressed the planetary boundaries and are therefore outside the safe operating space. The importance of the various footprints is discussed and the simultaneous analysis of footprints is emphasised as a major direction of research and practice. The comprehensive set of environmental impacts, e.g. set of presented footprints in this contribution, should be considered and should incorporate the burdening and unburdening concept from the life cycle perspective. Some applications of the presented environmental footprints are offered, and conclusions and remarks provided for future observation.

**Aims**

This review addresses recent developments in environmental impact assessment; particularly in environmental footprints assessment. The burdening and unburdening concept from the life-cycle perspective is briefly presented as the first step. Environmental footprints that could be categorised as important ones are assessed in the second step. Selected environmental footprints consist of the 'Footprint Family' of indicators (Fang et al., 2013) and of footprints outside the safe operating space – footprints that could lead to major disruption of the Earth's natural system (Rockström et al., 2009, and updated by Steffen et al., 2015) by exceeding the Earth's biocapacity.

**Burdening and Unburdening Effects from the Life Cycle Perspective**

In order to move towards more sustainable processes, products or activities it is essential that the entire life cycle (Allen, 2008) and total effects are considered. Usually only burdening effects on the environment are measured (Hundal, 2000). However, a broader view should also incorporate any possible unburdening effects of an activity (Čuček et al., 2012a). Burdening and unburdening effects together form total effects (Kravanja and Čuček, 2013).

Environmental footprints should be defined from the life cycle perspective, accounting for a system's full life cycle (Fiksel et al., 2014). A system's life cycle consists of the extraction and processing of

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resources, manufacturing, usage, and maintenance, and recycling or disposal, by including all transportation and distribution steps (Bojarski et al., 2009). In order to avoid problem-shifting or limited sustainability evaluation, it is important to select boundaries as widely as possible. The preferred options are 'cradle-to-grave' and especially 'cradle-to-cradle'. The 'cradle-to-grave' option represents the flow of materials from resource extraction ('cradle') to disposal ('grave') and 'cradle-to-cradle' system represents cyclical design from resource extraction ('cradle') to recycling and/or reuse ('cradle'). The 'cradle-to-cradle' systems opt for 100 % utilisation of waste and thus waste-free systems. The 'cradle-to cradle' and 'cradle to grave' material flows are shown in Figure 1.

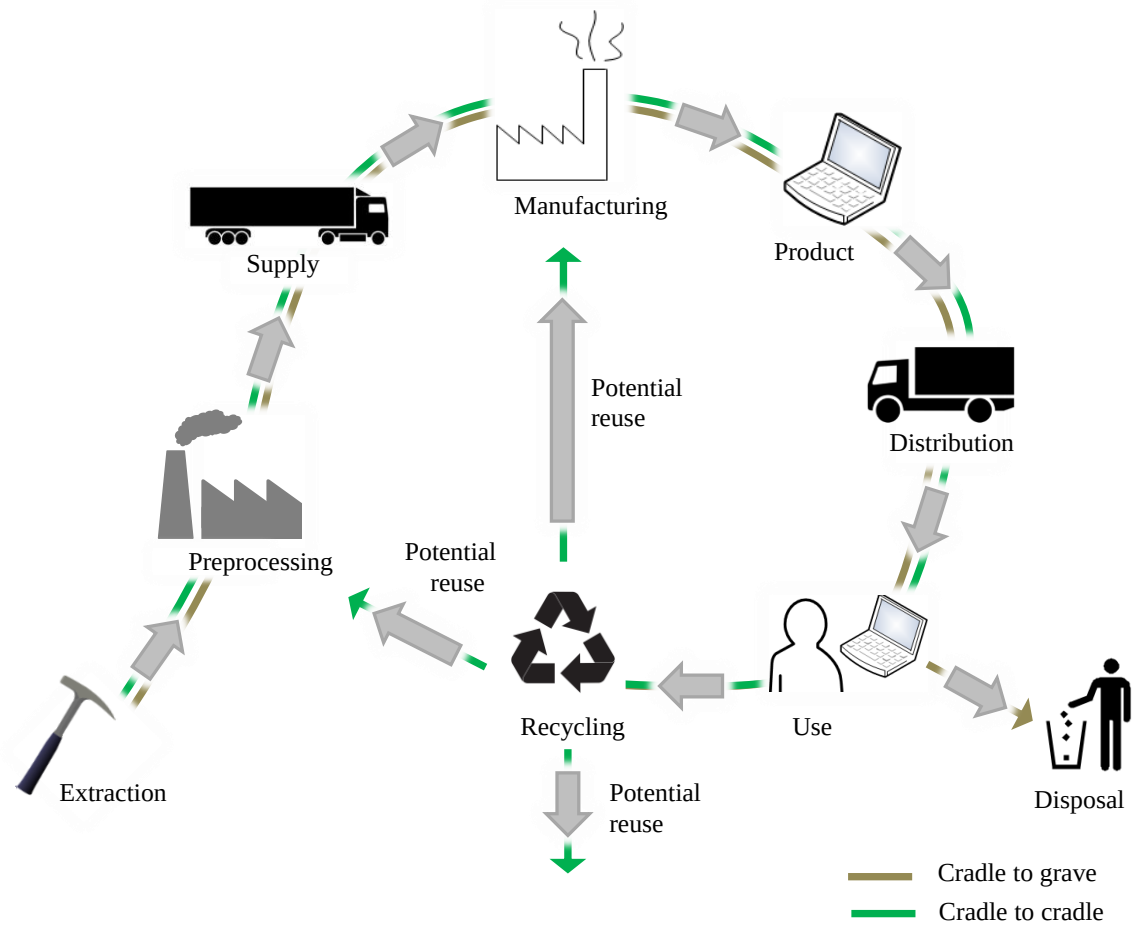


Figure 1. Material flows from resource extraction ('cradle') to disposal ('grave') and/or recycling and reuse ('cradle') (modified from Čuček et al., 2015)

**Selected Categories of Environmental Footprints**

The most commonly used categories of footprints developed to date are Carbon (CF), Ecological (EF) and Water (WF) Footprints forming the so-called 'Footprint Family' (Galli et al., 2011). Recently the Energy Footprint was also included as a selected indicator (member) of the 'Footprint Family' (Fang et al., 2014), see Figure 2.

Besides members of the 'Footprint Family', other important footprints are Nitrogen (NF), Phosphorus (PF), Biodiversity (BF), and Land Footprints (LF), which can be seen from Figure 3 – the planetary boundaries (Steffen et al., 2015). Planetary boundaries are associated with the planet's biophysical subsystems or processes (Rockström et al., 2009) and define the safe operating areas for humanity with respect to the Earth's system (Moldan et al., 2012). They represent boundary conditions within

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the Earth's system that could, if crossed, result in a major disruption in (parts of) the system and a transition to a different state (Biermann, 2012).

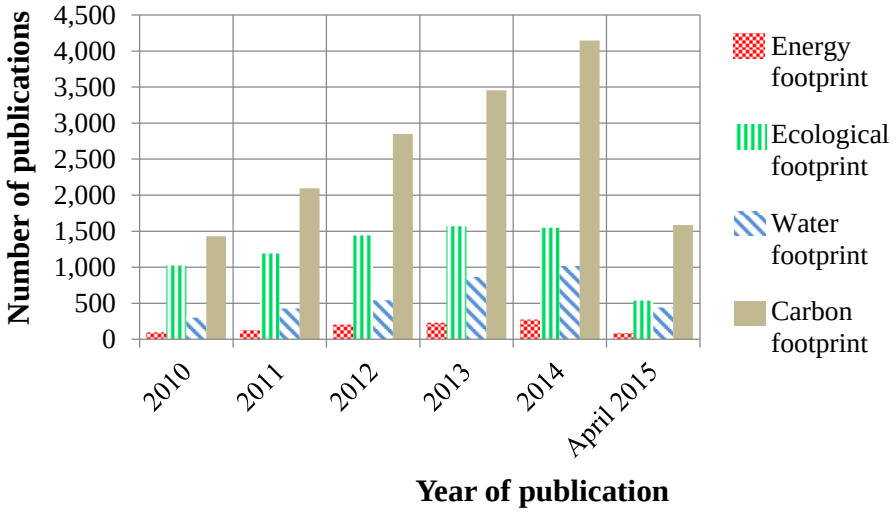


Figure 2. Number of publications addressing Footprint family of indicators in Science Direct and Scopus during 2010 – April 2015

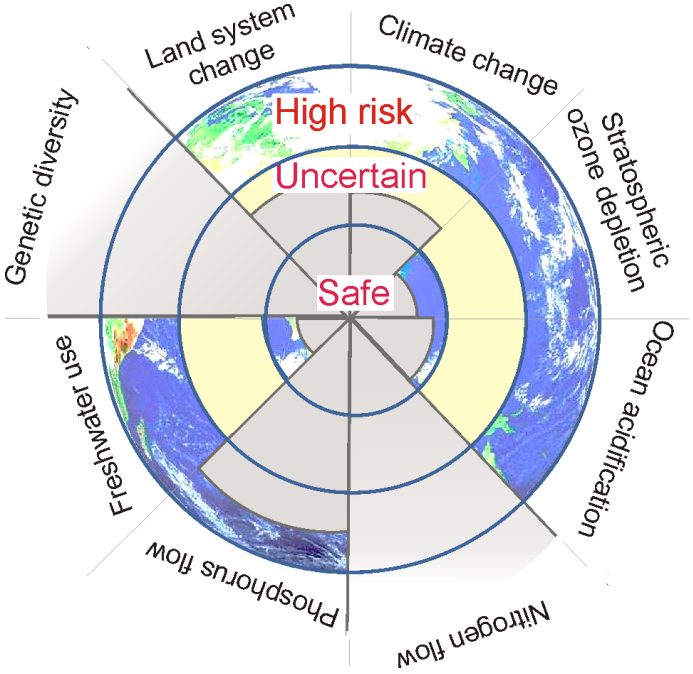


Figure 3. Planetary boundaries (updated from Steffen et al., 2015 and modified from Čuček et al., 2015)

Table 1 shows the selected environmental footprints in terms of their definitions, reduction/increase over recent years, and the main mitigation options. It can be seen that all of them are still increasing, except for land footprint, which has been stabilising.

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Table 1 Definitions, possibilities and practical efforts to improve the presented environmental footprints and changes in footprints over the years

| Footprint | Definition | Trends in footprint in recent years | Main mitigation options |
|---|---|---|---|
| Greenhouse gas footprint | It usually stands for the amount of $CO_2$ and other GHGs, emitted over the full life-cycle of a process or product. It is expressed in mass of $CO_2$-eq. | Increasing<br>- $CO_2$: 2000: 369.5 ppm<br>2014: 398.6 ppm<br>- $CH_4$: 2000: 1,775 ppb<br>2014: 1,820 ppm<br>- $N_2O$: 2000: 315 ppb<br>2014: 336.5 ppb<br>(ESRL, 2015)<br>Between 1900 and 2008 CF increased 16 times (Hoekstra and Wiedmann, 2014) | - Reduced energy consumption<br>- Increased energy efficiency<br>- Low-carbon energy sources<br>- Reforestation and avoided deforestation<br>- Carbon capture and storage (CCS) |
| Water footprint | Indicator of direct and indirect water use by a consumer or producer (Hoekstra et al., 2011). It is divided into blue (freshwater), green (rainwater), and grey WFs (indicator of pollution). It is expressed in volumetric units. | Increasing<br>Global water consumption;<br>- 1900: about 600 $km^3/y$<br>- 1950: about 2,500 $km^3/y$<br>- 2000: about 3,900 $km^3/y$<br>- 2010: about 4,200 $km^3/y$<br>(Girard, 2014) | - Responsible and efficient water use at all levels<br>- Better water conservation and management<br>- Minimising grey WF<br>- Substitute the products with smaller WF |
| Ecological footprint | Indicator that measures the anthropogenic impact on Earth. It is related to Earth global biocapacity and overshooting. EF is expressed in global hectares – hectares of biologically productive land or sea with world average bioproductivity in a given year (Galli et al., 2014) | Increasing<br>- 1961: 0.77 planet Earths<br>- 2000: 1.33 planet Earths<br>- 2010: 1.5 planet Earths<br>(Mclellan et al., 2014) | - Reduced CF, WF and EF<br>- Renewable energy utilisation<br>- Responsible and efficient use or products<br>- Reducing, reusing and recycling of products<br>- Reducing waste |
| Energy footprint | It is currently superficially defined. It is suggested that it stands for the specific energy usage per functional unit considering fossil-based and renewable-based energy (Sobhani et al., 2012). | Increasing<br>- 1965: 3,765.1 Mtoe/y<br>- 2000: 9,342.1 Mtoe/y<br>- 2013: 12,730.4 Mtoe/y<br>(BP, 2014) | - Technological developments<br>- Reduced energy consumption<br>- Improved energy efficiency as one of the largest and least-cost opportunity<br>- Using more sustainable transport |

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Table 1. Definitions, possibilities and practical efforts to improve the presented environmental footprints and changes in footprints over the years – continued

| Footprint | Definition | Trends in footprint in recent years | Main mitigation options |
|---|---|---|---|
| Nitrogen footprint | Total amount of reactive nitrogen released to the environment as a result of an entity's resource consumption, expressed in mass units of reactive nitrogen (Leach et al., 2012). | Increasing<br>- 1860: 15 $10^6$ t /y<br>- 1995: 156 $10^6$ t /y<br>- 2005: 187 $10^6$ t /y<br>(Galloway et al., 2008)<br>- 2010: 210 $10^6$ t /y<br>(Stevens et al., 2014) | - Changing diets by consuming less meat<br>- Reducing food-waste<br>- Reducing energy consumption<br>- Precision farming<br>- Legume cultivation<br>- Wastewater treatment by recycling of nitrogen |
| Phosphorus footprint | PF represents disruption of phosphorus cycle. It is expressed in mass units of phosphorus. | Increasing<br>- 1900: 3.15 $10^6$ t /y<br>- 1950: 23.4 $10^6$ t/y<br>- 2000: 132 $10^6$ t/y<br>- 2012: 217 $10^6$ t/y<br>(Kelly and Matos, 2014) | - Consuming less meat and dairy products<br>- Reducing food-waste<br>- Efficient fertilisation, using agricultural residues and animal waste as fertilizer<br>- Halt excreted phosphorus<br>- Wastewater treatment by recycling of phosphorus<br>- Avoid competing demands for phosphorus |
| Biodiversity footprint | BF is defined as *"the summation of all the pressures that have potential consequences for biodiversity"* (de Bie and van Dessel, 2011) | Increasing<br>Extinction numbers:<br>- 1800: less than 1,000 /y<br>-1950: around 7,000 /y<br>- 2000: around 27,500 /y<br>-2010: around 40,000 /y<br>(Lehsten, 2014) | - Protecting areas to conserve the native habitats, particular species and biodiversity<br>- Restoration of ecosystems and their services<br>- Combating invasive alien species<br>- Sustainable use of fisheries resources<br>- More resource-efficient economy<br>- CF, NF, WF and PF mitigation (see above) |
| Land footprint | LF, is related to land requirement and is defined as the summation of all the areas directly and indirectly required to satisfy the consumption (Giljum et al., 2013a). | Stabilising<br>Total arable land:<br>- 1962: about 12.83 $10^6$ $km^2$/y<br>- 1990: about 14 $10^6$ $km^2$/y<br>- 2007: about 14.13 $10^6$ $km^2$/y<br>(Land Commodities, 2014) | - Careful land-use planning<br>- Reduce consumption of meat and other animal products<br>- Opt for renewable energy which has low LF, and therefore avoid the use of biofuels |

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