



Integrating Ecological, Carbon and Water Footprint:

Defining the “Footprint Family” and its Application in
Tracking Human Pressure on the Planet



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TECHNICAL DOCUMENT

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Executive Summary

Building on the premise that no single indicator per se is able to comprehensively monitor (progress towards) sustainability, and that indicators need to be used and interpreted jointly, this report, which is part of Work Package 8 (WP8) of the One Planet Economy Network: Europe (OPEN:EU) project, aims to define a “Footprint Family” of indicators and inform on its potential use in tracking human pressure on the planet.

A clear description of the research question, rationale, accounting methodology as well as strengths and weaknesses of Ecological, Carbon, and Water Footprint is first provided. Linkages, overlaps, and differences among the three indicators are then highlighted to show how the indicators interact and complement each other. The report concludes by defining the “Footprint Family” and outlining possible areas of use for policy makers in the EU-27 interested in transforming Europe into a One Planet Economy by 2050.

In evaluating the three indicators, this report builds on the common accounting methods reported in the scientific literature and used by Global Footprint Network, Norwegian Institute of Science and Technology/Stockholm Environment Institute and University of Twente, respectively. This is done to produce a single background document on the three indicators, which can then be used for future reference during the course of the OPEN:EU project.

The Footprint Family of indicators is here defined as a set of resource accounting tools characterized by a consumption-based perspective able to track human *pressure* on the surrounding environment, where pressure is defined as appropriation of biological natural resources and CO₂ uptake, emission of GHGs, and consumption and pollution of global freshwater resources. Three key ecosystem compartments are monitored in the Footprint Family, namely the *biosphere*, *atmosphere*, and *hydrosphere* through the Ecological, Carbon, and Water Footprint, respectively.

The Footprint Family of indicators can provide a key element of a multidisciplinary sustainability assessment as its use allows the constituting indicators to complement each other. However, it is acknowledged that a full sustainability assessment would require additional indicators covering environmental issues still not covered by the Footprint Family (e.g., toxicity, soil quality and land degradation, nuclear wastes, etc.) as well as economic and social indicators.

The Footprint Family of indicators introduced in this study is intended to assist policy makers as well as academics, NGOs, and other practitioners in understanding the pressures human activities place on the planet. As discussed in the report, the Footprint Family has a wide range of applicability as it can be applied at scales ranging from a single product, a process, a sector, up to individual, cities, countries, and the world.

This report for Work Package 8 will serve researchers of all Work Packages (WP) to more accurately represent the linkages and differences among the indicators, as well as final users of the outcomes of OPEN:EU project to understand when to use each single indicator, and how to jointly use the Footprint Family to set targets and understand trade offs.

It is believed that such background document will also be of high interest to the many researchers and users of the Footprint indicators as it helps clarify most of the

misconceptions and misunderstanding around these three indicators, which are similar in name but different in scope and accounting procedure.

Finally, it must be mentioned that in order to fully align the three Footprint indicators into a consistent streamlined ecological-economic modelling framework, an alternative calculation methodology has been developed and explored for use in the OPEN:EU project. This alternative method differs from the “common” accounting methodologies described in this report and its full description can be found in the technical report “Footprint Family Technical Report: Integration into MRIO Model” for the Work Package 2 (WP2) of the OPEN:EU project (Weinzettel et al., 2011).

1. Introduction

In the last four decades countries around the world have significantly changed, most have experienced economic growth, poverty reduction, and improved welfare (UNDP, 2006, 2007; UNEP, 2007). Global economic and social changes, however, have been reached at the expense of the planet's ecosystem preconditions and its ability to sustain life (Goudie, 1981; Haberl, 2006; Nelson et al., 2006; Fisher-Kowalski and Haberl, 2007; Rockström et al., 2009).

Global renewable resource consumption and waste emissions have grown to a point where humanity now consumes resources at a faster pace than the Earth can regenerate or sequester, and there are many locations around the world where human water use is no longer sustainable (Meadows et al., 1972; Catton, 1982; Ehrlich, 1982; Vitousek et al., 1986; Wackernagel et al., 2002; Haberl et al., 2007; WWF, 2010; Hoekstra et al., 2009). Human pressure on the planet is at the root of many of the most pressing environmental problems we face today: water scarcity, energy shortages, climate change, declining biodiversity, shrinking forests, land and soil erosion and pollution, desertification, decreased groundwater tables, low or non-existent river flows, water depletion and pollution, fisheries collapse, and many of the factors contributing to food shortage. In addition, greenhouse gas (GHG) emissions are accumulating in the atmosphere, causing climatic changes and potential negative feedback on the health of ecosystems (Haberl, 2006; Holdren, 2008; UNEP, 2007; Butchart et al., 2010).

Worldwide atmospheric concentrations of carbon dioxide (CO₂), Methane (CH₄), and nitrous oxide (N₂O), for example, have noticeably increased in recent decades, and they now considerably exceed the natural range over the last 650,000 years. With high confidence, scientists have concluded that these global average concentrations are due to human activities (IPCC, 2007). Many forests, particularly in tropical zones, are cut faster than they can regrow: 130,000 km² of forest have been destroyed each year for the last 15 years. 15% of ocean stocks were depleted over the same period and fish are caught faster than they can restock (UNEP, 2007). World average per capita food and services (e.g., electricity distribution, per capita literacy) consumption has grown during the last four decades (Turner, 2008). Global extraction of natural resources (e.g., biomass, fossil fuels, metal ores, and other minerals) has increased by approximately 50% in the last 25 years (Behrens et al., 2007; Giljum et al., 2009a; Krausmann et al., 2009) in part as a result of a world population quadrupling over the last one hundred years. Freshwater availability in countries in arid and semi-arid regions of the world, especially Central and West Asia and North Africa are already close to or below 1000 m³/capita/year, which is the threshold of water scarcity (Falkenmark et al., 1989).

In summary, demand for ecological assets is growing unabated as global population grows, standards of living improve and the size of the global economy increases. These trends will likely continue in the future if measures are not taken to reduce this demand. For example, in a business-as-usual scenario, global extraction of natural resources could further grow by more than 50% by 2030 compared to today's situation (Lutz and Giljum, 2009), and humanity's demand on ecological assets (in Ecological Footprint terms) could equal two Earths worth of resources by approximately 2030 (Ewing et al., 2010a). Up to two-thirds of the world population will experience water scarcity over the next few decades (Alcamo et al., 2000; Vorosmarty et al., 2000) and slightly more than one billion

people living in arid regions will face absolute water scarcity (less than 500 m³/capita/year) by 2025 (Rosegrant et al., 2002).

Moreover, the distribution of human-induced pressures is uneven in both its nature (Haberl, 2006; Behrens et al., 2007; Krausmann et al., 2009; Galli et al., *in press*) and its geographic location (Ramankutty et al., 1999, 2002; Foley et al., 2005; Hoekstra and Chapagain, 2007; Haberl et al., 2007; Halpern et al., 2008; Kitzes et al., 2008; Moran et al., 2008; Erb et al., 2009; Giljum et al., 2009a; Hertwich and Peters, 2009). On a per capita basis, people in high income countries consume much more natural resources than those in lower income countries. In addition, the transition from biomass-driven (agricultural) to fossil-fuel-driven (industrial) societies experienced by many high income countries has determined a shift in the nature of the resources currently demanded and the ecosystem compartments that are now under the highest human-induced pressure.

Acknowledging the increasing human impact on the natural world, more empirical measurements have been sought to understand the driving forces behind these impacts and find ways to reduce them while maintaining economic and societal well-being.

1.1 Resource trends in Europe

As the world's largest economy, Europe – as well as other industrialized countries with high levels of per capita resource consumption – must embark upon an immediate and major transformation to sustainability to avert climate change, resource scarcity, and prevent ecosystem collapse. The European Union uses 20% of what the world's ecosystems provide in terms of fibers, food, energy, and waste absorption (WWF, 2005). Home to 11% of the world population (in 2007), Europe's demand on the biological capacities of the planet has risen by more than 70% since 1961 (WWF, 2010; Ewing et al., 2010a) despite a population increase of only 13% (FAO, 2009d).

Inhabitants of Europe have per capita resource consumption levels around 3 to 5 times higher than those of developing countries (Giljum et al., 2009a; WWF, 2010; Galli et al., *in press*). While extraction of natural resources has stabilized in Europe over the past 20 years, imports of raw materials and products have significantly increased (Dittrich, 2009; Weisz et al., 2006).

Although trade has provided many economic and social benefits to the exporting countries, when payment for resource extraction is distributed among the population (but in some cases very few benefit), residents of the global South continue to bear the negative impacts of Europe's profligate consumption. The negative impacts, on one hand, stem from extraction and processing of raw materials (such as metal ores, timber, agricultural products, etc.) as the material basis for products consumed in Europe. On the other hand, the global South bears an over proportional burden from waste and emissions originating from European consumption. For example, each EU-27 citizen emitted on average 10.2 t of GHG emissions (in CO₂-equivalents) in 2009 (EEA, 2009). This number has been falling in the past years due to efforts to decrease domestic emissions, however, GHG emissions embodied in European imports from other world regions have risen rapidly in the past 15 years (Bruckner et al. 2010; Peters and Hertwich, 2008c; Wiedmann et al., 2008). Europe is also expanding built-up and urban areas for housing, industrial, and commercial sites and transport networks. From 1990 to

2000, more than 4.000 km² of agricultural and pasture land were transformed into built-up land, increasing anthropogenic pressures on biodiversity (EEA, 2006).

Fresh water is also increasingly becoming a global resource, driven by growing international trade in goods and services. In this context, Europe, particularly Western Europe, is one of the largest virtual water importers in the world with an import of 152 Gm³/yr (Chapagain and Hoekstra, 2004); the people of Europe have higher Water Footprints per capita than the world average (especially in south European countries such as Greece, Italy and Spain, 2300-2400 m³/yr per capita). Additionally, European countries are more dependent on foreign water resources for their consumption activities. In some European countries external Water Footprints contribute to 50-80% of the total Water Footprint (e.g. Italy, Germany, the UK, and the Netherlands) (Chapagain and Hoekstra, 2004).

A shift to a more sustainable future, therefore, requires a qualitative and quantitative understanding of the drivers in play, as well as a significant mobilization and behavioral change of actors and institutions from all sides of the public, private, and consumer spheres. It is clear that a sustainable future for Europe can be achieved only by building an economy that respects environmental limits (including biodiversity) while also improving social and financial health.

1.2 Background to the OPEN:EU project

Acknowledging the need to understand and account for the main drivers behind Europe's use of natural resources and related environmental impacts, the European Commission (EC) launched several strategies calling for such assessments.

The Sustainable Development Strategy (SDS), which was adopted by the European Commission at the Gothenburg European Council in 2001 and renewed in 2006, outlines a long-term vision for sustainable development in Europe. The key objectives for the area of "environmental protection" in the revised EU SDS (p. 3) are to "safeguard the Earth's capacity to support life in all its diversity, respect the limits of the planet's natural resources and ensure a high level of protection and improvement of the quality of the environment, prevent and reduce environmental pollution, and promote sustainable consumption and production to break the link between economic growth and environmental degradation".

The Thematic Strategy on the Sustainable Use of Natural Resources (referred to shorthand as "Resource Strategy"), launched in 2005, is one of seven Thematic Strategies implementing the goals of the Sixth Environmental Action Programme (6th EAP). The overall goal of the Resource Strategy is targeted towards decoupling i.e. "to reduce the negative environmental impacts generated by the use of natural resources in a growing economy" (p. 5). It aims to achieve this through so-called double decoupling: the decoupling of resource use from economic growth and environmental impacts from resource use (see Figure 1). The Resource Strategy requires resource-specific indicators to evaluate the environmental impact of resource use. As part of the implementation of the Resource Strategy, a basket of indicators is being developed, which aims to illustrate the different types of impacts (Best et al., 2008). In addition the Joint Research Centre is

developing life-cycle inventory and trade flow based indicators to monitor the double decoupling called for by the strategy.

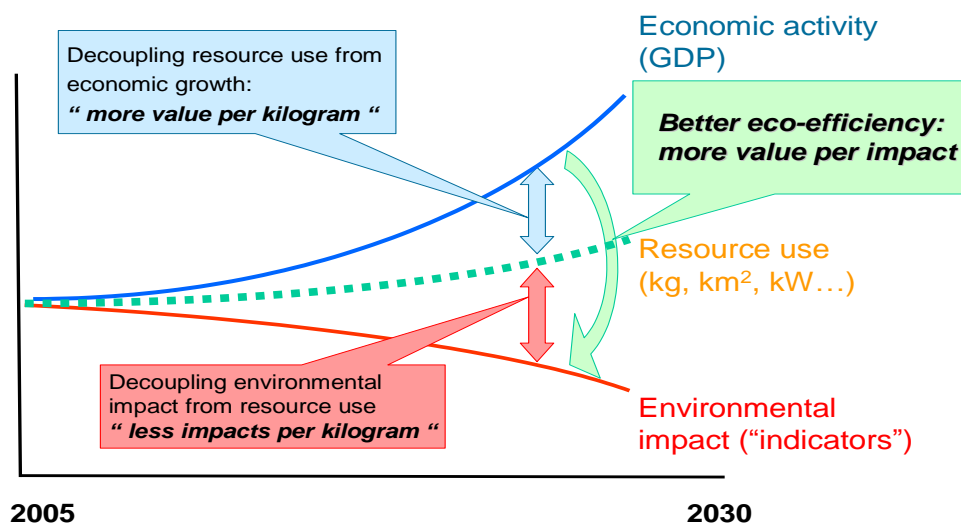


Figure 1: The double decoupling objective from the Thematic Strategy on the Use of Natural Resources

The “Action Plan on Sustainable Consumption and Production and Sustainable Industrial Policy”, which was launched in 2008, aims at setting up “a dynamic policy framework to improve the energy and environmental performance of products and support their uptake by consumers. The Action Plan has a focus on energy issues and products, and envisages the revision and expansion of several directives, regulations and communications to ensure the implementation of the goals; for example, the Ecodesign Directive for energy-using products, the Energy Labelling Directive, the Energy Star Regulation, the Ecolabel Regulation and the Communication on Green Public Procurement.

Also, the EU trade strategy “Global Europe” from 2006 and the “Raw Materials Initiative” of 2008 are of high relevance for issues of European resource use and emphasise the need to maintain European access to resources in other world regions.

However, most resource policy documents remain on a general level of declarations of intent, without detailing those concrete policy measures that should be implemented to achieve the formulated objectives. A strategy to systematically adjust EU policies to promote resource productivity in the EU is far from being realised. No quantitative targets have been formulated for increased resource productivity or for a reduction of environmental impact of resource use in any of the main EU policies.

In summary, one can argue that despite widespread support in different EU policy fields for the general ideas of increasing resource efficiency and reducing negative environmental impacts, little concrete action has been taken.

The One Planet Economy Network: Europe (OPEN:EU) project originates from a wish to answer the renewed EU Sustainable Development Strategy (SDS) call for the development of indicators which are capable of capturing the full complexity of Sustainable Development. The OPEN:EU project aims to contribute indicators which can monitor some elements of sustainable development and thus support the implementation of some of the objectives of the EU SDS and other policy strategies mentioned above.

To meet its goals, the OPEN:EU project has developed an academically robust “Footprint Family” of indicators, group the indicators under a single streamlined ecological-economic modelling framework (see Weinzettel et al., 2011), will present them alongside economic and demographic indicators, and place these in a scenario modelling tool (see WP3 of the OPEN:EU project) for evidence-based policy (see Knoblauch and Neubauer 2010). This will help create a new forum for the visions, knowledge and interests of different stakeholders to help transform the EU to a One Planet Economy¹ by 2050. It should be noted that the indicators developed under the OPEN:EU project will only cover part of the scope of sustainable development and would need to be considered as part of a wider range of indicators capturing the whole complexity of sustainability.

¹ A One Planet Economy is an economy that respects all environmental limits and is socially and financially sustainable, enabling people and nature to thrive.

2. The Need for a Set of Indicators

Human societies and economies depend on the biosphere's natural capital for many underpinning functions including regulation of local and regional climates, soil stabilization, water purification, as well as for the provision of primary resources and a large spectrum of life-supporting ecological services (Levin and Pacala, 2003; Best et al., 2008). Managing the biosphere's ecological assets must thus become a central issue for those decision makers interested in securing human well-being while respecting the physical and thermodynamic constraints typical of our planet (Morowitz, 1979; Odum, 1988; Ruth, 1993). Increasingly, decision makers and the public are realizing that humanity is 'unbalancing' nature's budget because of the overconsumption of both renewable and non-renewable resources (Kitzes et al., 2008; WWF, 2010; Haberl et al., 2007; Ewing et al., 2010a; Krausmann et al., 2009; Giljum et al., 2011).

The urgency and relevance of these issues emphasize the need to act, however, actions must be based on scientifically-sound accounting; knowing how far we are from living within the limits of our planet enables us to plan for a sustainable society. Tools are needed that can help decision makers further investigate human impact on the environment due to production and consumption activities.

In an 'empty world', as it was until the middle of the past century, i.e. rich in environmental assets but poor in people and man-made capital (Daly, 1990), decisions and planning processes have been driven by indicators able to track the then-current limiting factors. However, the situation has changed and new tools are needed to track today's limiting factors to further social and economic development: ecological assets and environmental services. Good governance now depends on natural resource accounting tools in addition to traditional indicators such as GDP and financial accounts.

Without a way of measuring the status (and human rate of use) of our ecological assets, it is easy for policy makers to ignore the impossibility of infinite growth, and remain entangled in ideological debates over the "affordability of sustainability." Clear metrics are needed to change these ideological debates into discussions based on empirical facts. This will lead to an understanding of what the real risks are, and facilitate building consensus over the actions needed to address them (Ewing et al., 2010a; Kitzes et al., 2009a).

To this point, a set of indicators could best serve the need to account for the environmental consequences of human activities and where possible to what extent these approach or exceed ecological limits. The way human activities are linked to each other and affect different compartments of the planet has to be first understood (Vörösmarty et al., 2000; Weisz and Lucht, 2009). Climate change, for example, is currently seen as the most impending environmental impact associated with human activity. Unfortunately, in the search for sustainability, decision makers have approached sustainable development through the climate change lens (Robinson et al., 2006), with a smaller focus upon other impacts on the planet caused by humanity. Looking at carbon in isolation – rather than a symptom of humanity's overall metabolism of resources – has taken some of the focus from some other environmental impacts. The world's appetite for water, food, timber, marine, and many other resources is also of key relevance with respect to limits of natural resources and environmental services (Fischer-Kowalski and Haberl, 2007; WWF, 2010; Ewing et al., 2010a; Giljum et al., 2009b; Krausmann et al., 2009).

Solving the sustainability challenge requires a new holistic approach that considers human impact on the atmosphere as one of the various impacts. An integrated ecosystem approach is required in order to tackle multiple issues concurrently, and helps avoid additional costs and inadvertently undoing progress in one sector by not accounting for direct and indirect implications of actions in another sector (Robinson et al., 2006; Turner, 2008). By using the Ecological, Carbon, and Water Footprints, the OPEN:EU project moves in the direction of an integrated ecosystem approach: “integrated” in the sense that it gathers, for the first time, the Ecological, Carbon, and Water Footprints under a single conceptual framework (see section 6.1 The Footprint Family: definition and scope) and accounting methodology (see Weinzettel et al., 2011); “ecosystem” approach in that it tries to qualitatively and quantitatively measure human-induced pressures on the planet and its key ecosystem compartments (see section 6.1 The Footprint Family: definition and scope).

By introducing the Footprint Family concept, the project aims to provide policy makers and practitioners with a set of tools that can embrace a wider range of topics as opposed to those addressed by the single indicators. However, achieving sustainability depends on a number of critical issues that cannot be addressed by the sole Footprint Family. We fully recognize the need for several key indicators and acknowledge that Ecological, Carbon, and Water Footprint, even when used together as a “Footprint Family” of indicators, cannot provide a full sustainability assessment.

3. Opting for a Consumer Approach

If we lived in a world where countries produced and consumed all goods and services within the boundaries of their country, the distinction between consumption-based and production-based accounting would be unnecessary when dealing with nation-level use of resources. But we live in a highly globalized world, where economies of scale and comparative advantage in certain areas exist, rendering trade and commerce highly valuable and “responsibility” over impacts much more complex. Given the existing global environmental policy framework (e.g. Kyoto protocol), which largely holds producers rather than final consumers responsible for human impact, industrialized countries are pushed towards imposing increasingly strict regulation on environmentally pressure-intensive industries, with the long term effect of outsourcing this production to transition economies, where it may be carried out less eco-efficiently. The result when seen from a global perspective is likely to be an overall increase in environmental pressures (Watson and Moll, 2008; Galli et al., *submitted*).

After years of discussion regarding the principles of producer and consumer responsibility (Eder and Narodoslawsky, 1999; Munksgaard and Pedersen, 2001; Bastianoni et al., 2004; Peters, 2008), consumption-based accounting (CBA) is becoming increasingly relevant and, as recently highlighted by Wiedmann (2009), it can provide several opportunities for policy and decision making processes:

- a) Complement the territorial-based approach by including all driving forces for demands on ecological assets associated with consumption activities;
- b) Provide complementary information for international environmental policy frameworks, particularly in relation to participation of developing countries by alleviating competitiveness concerns;
- c) Provide a better understanding of the common but differentiated responsibility between countries thus facilitating international cooperation and partnerships among (developing and developed) countries;
- d) Quantify the economic and environmental trade linkages between countries;
- e) Help policy makers monitor decoupling as it gives insight on the impact of a country;
- f) Increase consumers’ awareness on the environmental consequences of their life-style and consumption behaviour; and
- g) Help design strategies on sustainable consumption and production, as well as climate change mitigation and adaptation policies at the national, regional and local levels.

The Ecological, Carbon, and Water Footprints emphasize the analysis of human demand from a consumer rather than a producer perspective. These indicators are not based on who produces a good or service but on the end-users that consume them. Due to their consumption-based approaches, these indicators present a quantifiable and rational basis on which to begin discussions and develop answers on the limits to resource consumption, the international distribution of the world’s natural resources, and how to address the sustainability of the use of our ecological assets across the globe (Senbel et al., 2003). The possibility to provide governments and decision makers with concrete measures of ecosystem limits is an important step in developing sound environmental policies (Jollands et al., 2003).

However, if consumption-based accounting is to be accepted and used by decision makers, the tools to be used and their underlying calculation methodologies need to be

reliable and robust (Wiedmann, 2009). The remainder of this paper describes the agreed and commonly accepted definitions of the three Footprint indicators used in the OPEN: EU project. This will then serve as starting point for the definition of the “Footprint Family” of indicators (see section 6.1 The Footprint Family: definition and scope) and the possible areas of its use by policy makers in the EU interested in transforming Europe into a One Planet Economy by 2050.

4. Methods

Three accounting tools have been selected to be included in the “Footprint Family” of indicators in use in the OPEN:EU project: Ecological, Carbon, and Water Footprint. Beyond the similarity in the name, these three methods have been selected because of their aims and underlying research questions. Their different, yet complementary, points of view allow for a more comprehensive assessment of the demand humans place on the planet and its set of ecosystem compartments.

In this report, we describe the accounting methods of the three Footprint indicators as they are commonly reported in the scientific literature and traditionally used. This serves the purpose of creating a single background document on the three indicators, where specific criteria such as research question, main message, scientific robustness (in terms of accounting methodology, data and sources, and unit of measure), strengths and weaknesses, policy usefulness as well as complementary and overlapping properties of the indicators are discussed. This report can thus be used as a reference point by researchers of all other work packages, as well as readers interested in the indicators and the OPEN:EU project itself.

The Ecological, Carbon, and Water Footprints are here grouped for the first time under a single conceptual framework (see section 6.1 The Footprint Family: definition and scope) named “Footprint Family”. Among the goals of the OPEN:EU project is to both define this conceptual framework and align the indicators’ accounting methods. Therefore, an alternative calculation methodology has been developed by the OPEN:EU project to fully align the three Footprint methodologies into a consistent streamlined ecological-economic modelling framework. While the definition of the Footprint Family and its rationale is described in this report, a full description of the integrated Footprint-MRIO (Multi-Regional Input-Output) model in use in the OPEN:EU project is provided by the report titled “Footprint Family Technical Report: Integration into MRIO Model” (Weinzettel et al., 2011). Such integrated model will then serve as the basis for the development of the EUREAPA tool, which will allow users to estimate the direct and indirect environmental pressures caused by the consumption of goods and services in the EU. Further details on the EUREAPA tool and its outcomes (Footprint scenarios) can be found in the “EUREAPA technical report” and the “Scenarios Report”, respectively.

4.1 Ecological Footprint

4.1.1 DEFINITION AND RESEARCH QUESTION

The Ecological Footprint (EF) is a resource and emission² accounting tool introduced in the early '90s by Mathis Wackernagel and William Rees to track human demand on the biosphere’s regenerative capacity (Wackernagel et al., 1999a, 2002). It documents both direct and indirect human demands for resource production and waste assimilation and compares them with the planet’s ecological assets (biocapacity) (Wackernagel et al., 1999b; Monfreda et al., 2004).

² It should be noted that CO₂ is the only greenhouse gas accounted for in the Ecological Footprint method.

The Ecological Footprint can be applied at scales ranging from single products, to cities and regions (Wackernagel et al. 2006), to countries and the world as a whole (Wackernagel et al. 2002; Ewing et al. 2010a). Country-level Ecological Footprint assessments (namely National Footprint Accounts) are regarded as the most complete. The Ecological Footprint tracks resource and emissions flows and provides a picture of a country's dependence on ecological assets, in the same way GDP tracks value added for an economy and provides a picture of the productivity of a country.

By tracking a wide range of human activities, the Ecological Footprint provides an aggregated indicator for some anthropogenic pressures that are more typically evaluated independently (carbon dioxide emissions, fisheries collapse, land-use change, deforestation, agricultural intensification, etc.) and can thus be used to understand, in an integrated manner, the environmental consequences of the pressures humans place on the biosphere and its composing ecosystems.

Six key ecosystem services widely demanded by the human economy are tracked and associated with a type of bioproductive land: plant-based food and fiber products (cropland); animal-based food and other animal products (cropland and grazing land - agricultural land); fish-based food products (fishing grounds); timber and other forest products (forest); absorption of fossil carbon dioxide emissions (carbon uptake land); and the provision of physical space for shelter and other infrastructure (built-up area). It should be noted that the demand for the biosphere's capacity to uptake CO₂ is usually also referred to as "carbon Footprint", though this should not be confused with the "Carbon Footprint", a methodology in its own, used in the climate change debate and in this project (see section 4.2 Carbon Footprint) to account for the emission of a wider set of GHGs.

The Ecological Footprint analysis takes into account both the sustainability principles identified by Herman Daly (1990); it identifies the extent to which human activities exceed a) the availability of bioproductive land to produce resources and b) the availability of forests to uptake carbon dioxide emissions. The aim is to promote recognition of these ecological limits, therefore safeguarding the ecosystems' preconditions (healthy forests, clean waters, clean air, fertile soils, biodiversity, etc) and life-supporting services that enable the biosphere to provide for us all in the long term.

It should be noted that the Ecological Footprint measures one main aspect of sustainability only: the human appropriation of the Earth's biological capacity. It attempts to answer this particular scientific research question, not all aspects of sustainability, or all environmental concerns. It analyzes the human predicament from this distinct angle, motivated by the assumption that Earth's regenerative capacity might be the limiting factor for the human economy if human demand continues to overuse beyond what the biosphere can renew.

A complete description of the Ecological Footprint methodology is reported in section 7.1 Ecological Footprint. Source data used in Ecological Footprint analyses are reported in section 8.1 Ecological Footprint.

4.1.2 UNITS OF MEASURE

Both the Ecological Footprint and the biocapacity are resource flow measures. However, rather than being expressed in tonnes per year, each flow is expressed in units of area (i.e. the stock) annually necessary to provide (or regenerate) the respective resource flows.

There is an advantage in expressing demand for flows in terms of bioproductive land appropriation, in that the use of an area better reflects the fact that many basic ecosystem services and ecological resources are provided by surfaces where photosynthesis takes place (bioproductive areas). These surfaces are limited by physical and planetary constraints and the use of an area helps to better communicate the existence of physical limits to the growth of human economies (GFN, 2010).

However, average bioproductivity differs between various land use types, as well as between countries for any given land use type. For comparability across countries and land use types, Ecological Footprint and biocapacity are usually expressed in units of world average bioproductive area, namely global hectares – gha.

Each global hectare represents the same fraction of the Earth's total bioproductivity, and is defined as one hectare of land or water normalized to have the world average productivity of all biologically productive land and water in a given year (Wackernagel et al., 1999a,b, 2002; Monfreda et al., 2004; Wiedmann and Lenzen, 2007; Kitzes et al., 2007; Galli et al., 2007).

The ecological production of global hectares is calculated by dividing the total amount of biological materials useful to humans produced in the Earth by the total biologically productive area available (~12 billion hectares). This provides an average productivity per hectare, which is set equal to (the productive flow of) one global hectare. In theory each global hectare can therefore be considered as an average hectare of all land types combined.

Global hectares provide a useful unit of measurement for the ecological demand associated with the flow of a product, as they measure how much of global ecological productivity is required to produce a given flow. They provide more information than (1) weight - which does not capture the extent of land and sea area used or (2) physical area - which does not capture how much ecological production is associated with that land (Galli et al., 2007; Ewing et al., 2010b).

Yield factors and equivalence factors are the two 'scaling factors' needed to express ecological demand in terms of global hectares (Monfreda et al., 2004; Galli et al., 2007), thus allowing for comparisons between various countries' Ecological Footprint and/or biocapacity values.

Yield factors are evaluated annually as the ratio between the yield for the production of each given product in the producing country, and the yield for the production of that same product in the world as a whole, with the world yield factor equal to 1 (by definition). These factors capture the difference between local and global (world average) productivity within a given land use category.

Equivalence factors translate the area supplied or demanded of a specific land use type (e.g. world average cropland, grazing land, forest land, fishing grounds, carbon uptake

land, and built-up land) into global hectares. They are evaluated each year for each specific land use type (such as cropland) and are calculated as the ratio between the maximum potential world average ecological productivity (where ecological productivity is defined as potential crop yield in kg of the highest yielding crop) for that land use type and the average productivity of *all* land use types on Earth. Equivalence factors are calculated using the suitability index from the Global Agro-Ecological Zones model – which estimates potential crop productivity – along with land cover data from FAOSTAT (FAO and IIASA Global Agro-Ecological Zones 2000 FAO ResourceSTAT Statistical Database 2007). The calculation of the equivalence factors assumes the most productive land is put to its most productive use: the most suitable land available is cropland, the next most suitable land is forest land, and the least suitable land is grazing land.

This method for measuring natural capital reflects the fact that humanity is constrained by the Earth's limits; the surface of the Earth is finite, and therefore the available ecologically productive area and the annual amount of resources produced and wastes absorbed must be finite as well (Monfreda et al., 2004; Wackernagel et al., 2005; Wackernagel and Galli, 2007). It is important to note that for national or regional case studies, both Ecological Footprint and available biocapacity are often expressed per capita, i.e. Ecological Footprint as per capita of the country or region and biocapacity as global biocapacity per global citizen or national biocapacity per national citizen

4.1.3 POLICY USEFULNESS AND MESSAGES FROM ECOLOGICAL FOOTPRINT ACCOUNTING

In order to assess the policy relevance of an indicator, we first have to define what being policy relevant means, what are the steps involved in developing and implementing policies, and what is that decision makers need to know (compared with what indicator can offer) in each step of the policy formulation process. In brief, the process of developing policies could be divided into the stages below. Each stage of the cycle is fundamental and indicators are needed that can help decision makers derive decisions at different stages:

- Early warning: the big picture is initially given to decision makers; this can help generate political will (self-interest) and guide policy action; this is also the stage where new issues could be identified and new “ways of thinking” emerge;
- Headline and Issue framing: at this stage, causes of the problems and potential solution are identified via data, indicators, matrices and tools;
- Policy development: building on info drawn from previous stages, actions are taken and policies drafted and proposed;
- Implementation: political tools are used to ensure drafted policies are implemented; and
- Monitoring: tools are used to quantitatively monitor the effectiveness of policies.

Ecological Footprint and biocapacity results by land use type can be used in the “early warning” stage to inform how much human demand exceeds the renewal capacity of nature. They can also be used in the “headline” and “issue framing” stages to identify the

ecosystems under the highest human-induced stress thus supporting, for instance, biodiversity conservation assessments (Butchart et al., 2010; Galli, 2010).

In the last decades, the Ecological Footprint has become an influential measure of global demand for biological capital. However, while its communication value is recognized (e.g., Costanza, 2000; Deutsch et al., 2000; Stiglitz et al., 2009), the policy value of the Ecological Footprint has to date been limited (Barrett et al., 2005; Best et al., 2008; Kitzes et al., 2009a).

Although we acknowledge that it might be hard to develop issue-specific policies with it, the Ecological Footprint is able to help policy makers understand and communicate the wider effect of human pressures on the environment. As such, its policy usefulness resides in the capacity to track cross-cutting issues, enable change, and favor new “limits aware” thinking in the policy process which can be achieved through the five stages above.

The Ecological Footprint can help decision makers track the demand countries place on the ecological assets because of the overall structure and functioning of their economies and can address the following main areas when linked with other indicators (Best et al., 2008):

1. Double decoupling
2. Sustainable production/consumption
3. Energy and climate

For instance, the double decoupling concept aims at both increasing resource productivity and reducing negative pressures on the environment, while maintaining economic growth. The Ecological Footprint may not be able to directly show the decoupling from resource use and the impacts upon, for example, biodiversity. However, a comparison of the Ecological Footprint of production (production in this context excludes embodied footprint in imports,) (see section 7.1 Ecological Footprint) and GDP trends allows users to link changes in Footprint intensiveness with changes in GDP. A further refinement of the analysis, to compare GDP, material use, and Footprint intensity trends, enable to show the links between economic growth, material use, and pressure on the ecological assets. Being able to clearly outline these relationships in turn allows decision makers to take actions in order to reverse such trends.

To tackle the three above mentioned areas, Ecological Footprint results can be presented through both:

1. Detailed sets of indicators allowing for in-depth reporting of each variable:
 - Footprint by land category;
 - Footprint by households, governments and for investments;
 - Footprint by industrial sectors; and
 - Footprint of individual consumption activities³
2. Final aggregate indicators facilitating communication and reporting to policy makers:
 - National total Ecological Footprints (in relation to national or global biocapacity); and
 - World average Ecological Footprint (in relation to global biocapacity)

³ Here the COICOP classification is used.

It should however be noted that detailed Ecological Footprint results by “final demand categories” (households, governments, and capital investments) and “industrial sectors” can only be obtained by linking classical Ecological Footprint assessments (as reported in the National Footprint Accounts) with national level or multi-regional input-output (MRIO) models⁴. Therefore, an integrated Footprint-MRIO model has been developed for the EU-27 nations and its main trading partners during the OPEN:EU project (see Hertwich and Peters, 2010; Weinzettel et al., 2011)⁵.

The use of the Ecological Footprint within an input-output model can provide the kind of information on the economy-environment interactions that are needed at various stages of the ‘policy cycle’ from framing the most relevant environmental issues, to the development and implementation of environmental policies and the subsequent monitoring of their effectiveness.

Footprint results by final demand provide important insights into policy priorities and communications. It shows the role that each of the three players (households, governments, and businesses) can play to reduce the Ecological Footprint and could thus be used to address awareness campaigns.

Footprint results by industrial sectors and/or consumption categories can be used to further identify the main Ecological Footprint “hot spots”, thus providing important insights for policymakers. This can help develop and implement strategic actions and policies, e.g. in the framework of the EU Resource Strategy or the EU Sustainable Consumption and Production Action Plan to reduce human impact on the planet because of production and subsequent consumption activities. These sets of results provide important insights into:

- Economic sectors to prioritize from a policy-making perspective to help reduce human pressure;
- Targeting public communication campaigns (e.g. educating people on sustainable food consumption or energy; and
- Priority policy areas that can help reduce the human demand for natural resources and ecological services (e.g. household energy consumption or transport policy).

For all of the above mentioned sets of results, time series results can then be used in the “monitoring” stage to track the effectiveness of established resource use policies. Particular focus can be put towards monitoring, through time, the eventual increase in resource efficiency and decrease in negative impacts on the environment (double decoupling).

The understanding of the environmental consequences of different consumption patterns as well as consumers' life-style is of fundamental importance for both planning national policies on sustainable consumption and rising awareness on personal behaviors. While

⁴ A multi-region input-output (MRIO) model combines multiple national-level IO tables through the use of international trade data and shows the interdependencies between domestic and foreign sectors with different production technology, resource use and pollution intensities. Environmentally extended MRIO models are able to assign impacts along the track of international supply chains across several trading partners and are seen as a methodological sound approach for the enumeration of environmental impacts from consumption (Wiedmann et al. 2009; see also WP2 Weinzettel et al., 2011).

⁵ Learning from this model will be used by Global Footprint Network to generate an MRIO-based beta version of the 2011 National Footprint Accounts, which will be produced alongside the classical calculation. Such beta version will be tested and compared against classical Ecological Footprint values, expanded and used as starting point to arrive at a full implementation of a Footprint-MRIO model in the 2012 Edition of the National Footprint Accounts.

new and alternative policies need to be set and implemented, new ways to communicate and create awareness also need to be developed to favor a real shift towards sustainable societies. As such, being able to influence and shift consumers' behavior is among the tasks policy makers are responsible for; hence, the high communication value of the Ecological Footprint has to be considered as a characteristic of political usefulness.

4.1.4 STRENGTHS AND WEAKNESSES

Several reviews of the Ecological Footprint indicator have been independently performed in the last years by third party organizations (ECOTEC, 2001; George and Dias, 2005; Schaefer, 2006; von Stokar et al., 2006a, b; Giljum et al., 2007; Risk & Policy Analysts Ltd, 2007; Best et al., 2008; Pon et al., 2008; CES, 2009; Stiglitz et al., 2009; David et al., 2010; Hild et al., 2010). Since 2005, Global Footprint Network has also started engaging in official research collaborations⁶ with governments around the world, including, among others, Switzerland, Japan, United Arab Emirates, Luxembourg, Ecuador, and Colombia. Finally, several scientific papers have been focusing on the merits and drawbacks of the Ecological Footprint methodology since its introduction in the early '90s (Bicknell et al., 1998; Levett, 1998; van den Bergh and Verbruggen 1999; Lenzen and Murray, 2001; Lenzen et al., 2007a; Mayer, 2008; Fiala, 2008; Kitzes et al., 2009a, b; Venetoulis and Talberth, 2008; Niccolucci et al., 2009; Wiedmann and Barrett, 2010; Giljum et al., 2011; Bastianoni et al., *forthcoming*).

In the last 5 years, Global Footprint Network has worked to overcome some of the drawbacks highlighted by the above mentioned sources (Kitzes et al., 2009a; Ewing et al 2010a, b). However several drawbacks still remain to be addressed and are listed in this section alongside with the indicator's strengths.

The strengths and benefits of the Ecological Footprint methodology are:

- Unique in its ability to relate human use of natural, renewable resources and carbon dioxide emissions to the planet's carrying capacity via the comparison of Ecological Footprint and biocapacity results;
- Provides an aggregated assessment of anthropogenic pressures which are more typically evaluated independently;
- Helps the understanding of the complex relationships between the many environmental problems exposing humanity to a "peak-everything" situation;
- Supports the need to incorporate "externalities" into planning and decision making in every sector;
- The Ecological Footprint is an intuitively appealing indicator (easy to communicate and understand with a strong conservation message);
- Helps making consumers aware of some of the broad set of environmental consequences (e.g., resource depletion and CO₂ emissions) of their life-style and consumption choices ("carbon plus" view);
- Can be applied at multiple scales, from single products up to countries' populations and to humanity as a whole;
- Can be used to make temporal comparisons (for the 1961-2007 period) and compare countries (more than 150 countries and the world tracked by the National Footprint Accounts);
- Can be applied at a sub-national, regional and global level;

⁶ See http://www.footprintnetwork.org/en/index.php/GFN/page/ten_in_ten_campaign/ for further details on Global Footprint Network's work with National Governments.

- Enables benchmarking human demand (for regenerative capacity) with the biosphere's supply to help inform clear policy targets;
- Considers trade flows (incl. embodied energy) and thus enables analysis regarding the outsourcing of environmental pressures to other countries and world regions;
- Based on a clear and significant research question (see 4.1.1 Definition and research question);
- Data needed and methodology applied in the calculation process are transparently communicated through the *Ecological Footprint Standards 2009* (Global Footprint Network, 2009), and the *Guidebook to the National Accounts 2008* (Kitzes et al. 2008)⁷;
- The methodology is continuously improved with the guidance and oversight of the National Accounts Review Committee; and
- *Ecological Footprint Standards 2009* (Global Footprint Network, 2009) provide an internationally agreed process for conducting an Ecological Footprint analysis; created and maintained by the Ecological Footprint Standards Committee.

Weaknesses and limitations of the Ecological Footprint include:

- Monitors only one aspect of sustainability: the extent to which humanity is consuming available biocapacity;
- Systematic errors in assessing the overall demand on nature.
 - The Ecological Footprint cannot cover impacts for which no regenerative capacity exists (e.g. pollution in terms of waste generation, toxicity, eutrophication, etc.); and
 - Some demands, such as freshwater consumption, and soil erosion are excluded from the calculations leading to underestimates of ecological deficit.
- The Ecological Footprint covers non-renewable resources only in an indirect way, i.e. through the appropriation of land (e.g. for mining) and in terms of CO₂ emissions generated in extraction and processing.
- Unable to show unsustainable practices and their consequences. The Ecological Footprint methodology could thus be interpreted as encouraging more intensive farming as increased agricultural intensities result on an higher biocapacity⁸;
- The Ecological Footprint shows pressures that could lead to degradation of natural capital (e.g. reduced quality of land or reduced biodiversity), but does not predict this degradation;
- Carbon dioxide is the only greenhouse gas accounted for and its associated Footprint relies on the assumption that all emissions are absorbed only by forests, neglecting carbon uptake by other biomes;
- Issues exist on the ecological tradeoffs due to land conversion because of the lack of geographic specificity;
- Even if it has a wide range of applicability, the Ecological Footprint is most effective, meaningful and robust at aggregate levels (national and above);
- In its traditional formulation, it does not provide spatially explicit information, at a national level, on human demand on nature (this will be overcome during the OPEN:EU project through the integration of the Ecological Footprint in a multi-regional input-output framework);
- Time lag (usually 3 years) exists between National Footprint Accounts publication year and data year;
- Currently, few uncertainty and sensitivity studies are available (e.g., Simmons et al., 2007);
- Data quality problems and data errors in statistical sources⁹:

⁷ See also Weinzettel et al., 2011 for a detailed list of source data.

⁸ It should be noticed that increased production intensity is taken care of in the Ecological Footprint calculation (as energy and resource inputs are needed to boost productivity); however, it may carry other environmental burdens that are not currently covered by the Footprint, such as increased eco-toxicity (through use of pesticides) and soil erosion.

- Source data sets are currently taken at face value, and errors (coverage is often incomplete and some reported values are questionable) in these data sets affect final Ecological Footprint results;
- Distortions may arise from poorly funded statistical offices, and subsistence, black market, and non-market (or informal) activities; and
- Some demands on nature are significant but are not, or are not adequately, documented in UN statistics;
- Some underlying assumptions are controversial (van den Bergh and Verbruggen, 1999), though documented (Wackernagel et al., 2002; Ewing et al., 2010a):
 - By scaling each area in proportion to its bioproductivity, different types of areas can be converted into the common unit of average bioproductivity, the global hectare; and
 - Each hectare is only counted once, even though it might provide multiple services;

4.2 Carbon Footprint

4.2.1 DEFINITION AND RESEARCH QUESTION

Introduced in the scientific and public arena almost ten years ago, the Carbon Footprint is a measure of the total amount of GHG emissions that are directly and indirectly caused by an activity or are accumulated over the life stages of a product. This includes activities of individuals, populations, governments, companies, organizations, processes, industry sectors, etc. Products include goods and services. In any case, all direct (on-site, internal) and indirect emissions (off-site, external, embodied, upstream, and downstream) need to be taken into account. More specific aspects such as which GHGs are included and how double-counting is addressed can vary.

For the purpose of OPEN:EU the Carbon Footprint relates to consumption of goods and services by households, governments, and other 'final demand' categories such as capital investment. It also relates to the GHG emissions embodied in trade: the Carbon Footprint of a country is the sum of all emissions related to a country's consumption, including imports, but excluding exports. As such, the consumption-based perspective of the Carbon Footprint complements the production-based or territorial-based accounting approach such as those taken by national greenhouse gas inventories for reporting under the Kyoto Protocol.

A complete description of the Carbon Footprint methodology is reported in section

7.2 Carbon Footprint. Source data used in Carbon Footprint analyses are reported in section 8.2 Carbon Footprint.

4.2.2 UNITS OF MEASURE

Despite its name, the Carbon Footprint is not expressed in terms of area. The total amount of greenhouse gases is simply measured in mass units (kg, t, etc.) and no conversion to an area unit (ha, m², km², etc.) takes place. Any conversion into a land area would have to be based on a variety of assumptions that would increase the

⁹ It should however be noted that Ecological Footprint calculations and the data sources employed have improved significantly since 1990, as additional digitized data have been added to the National Footprint Accounts and internal cross-checking and data set correspondence checks have been introduced.

uncertainties and errors associated with a particular Footprint estimate (see section 4.1.4 Strengths and weaknesses above on the limitations of the Ecological Footprint).

If only CO₂ is included, the unit is kg CO₂; if other GHGs are included the unit is kg CO₂-e, expressing the mass of CO₂-equivalents. Those are calculated by multiplying the actual mass of a gas with the global warming potential factor for this particular gas, making the global warming effects of different GHGs comparable and additive (see eq. 10). In most cases, the six greenhouse gases identified by the Kyoto Protocol are included in the analysis: CO₂, CH₄, N₂O, HFC, PFC, and SF₆.

4.2.3 POLICY USEFULNESS AND MESSAGES FROM CARBON FOOTPRINT ACCOUNTING

Recently, consumption-based accounting (CBA), especially for GHGs, is becoming increasingly relevant for policy and decision making. The Carbon Footprint approach, where all emissions occurring along the chains of production and distribution are allocated to the final consumer of products, is seen as providing several opportunities. For instance, by identifying hot spots and unsustainable consumption patterns and trends, consumption-based GHG accounting can help design strategies on sustainable consumption and production, as well as climate change mitigation and adaptation policies at the national, regional, and local levels. This could help in the design of an international harmonized price for greenhouse gas emissions.

Consumption-based Carbon Footprint accounting could encourage and facilitate international cooperation and partnerships between developing and developed countries, for example by prioritizing technology transfers, estimating financial transfers, and streamlining the Clean Development Mechanism (CDM). Moreover, from a communication point of view, CBA can be used to make consumers aware of the GHG emissions from their life-style and consumption choices. Likewise, CBA raises awareness of indirect emissions in governments and businesses.

It has been recognized that the adoption of such a consumption-based perspective – in addition to the traditional approach of territorial emission accounting (Munksgaard et al., 2009) – opens the possibility of extending the range of policy and research applications considerably to cover sectoral, country, and product analysis. One opportunity is to readdress the problem of carbon leakage and to reveal the extent to which a relocation of production and associated shift of embodied emissions has occurred (Peters, 2008b). The wider implications on climate policy that emerge from the possibility of using a consumption-based approach have been well presented (Peters, 2008a; Peters and Hertwich, 2008a; Peters and Hertwich, 2009). Weber and Peters (2009) discuss the challenges for climate policy posed by international trade and specifically examine the effect of introducing carbon tariffs as a means to regulate the flows of embodied carbon (see also Peters, 2008c).

In this context, the question of responsibility for emissions has recently gained renewed interest and various approaches of sharing responsibility between producers and consumers across countries have been discussed (Andrew and Forgie, 2008; Lenzen et al., 2007b; Peters, 2008a; Rodrigues et al., 2006; Rodrigues and Domingos, 2008; Serrano and Dietzenbacher, 2008; Zhou and Kojima, 2009). If countries that import more embodied emissions than they export were to become partially responsible for emissions occurring elsewhere, the exporting countries (mainly China and other

developing countries) might be more willing to play an active role in post-Kyoto climate commitments (Peters and Hertwich, 2008b; Guan et al., 2009). However, importing countries could be hesitant to support the adoption of a consumer approach as the responsibility for GHG emissions would be then shifted to consumers (see Knoblauch and Neubauer 2010).

For communication purposes national Carbon Footprints can be benchmarked against 2050 targets for per capita GHG emissions under contraction and convergence models to achieve the goal of limiting temperature increase limited to 2 deg C above pre-industrial levels (see below).

4.2.4 STRENGTHS AND WEAKNESSES

By definition, the Carbon Footprint is quite a straightforward indicator; it can be regarded more as an inventory than an indicator itself and it thus suffers to a very minor extent of the known problems of composite indicators. As such, only reviews of Carbon Footprint applications rather than of the indicator itself can be currently found in literature (Minx et al., 2009; Peters, 2010; Davis and Caldeira, 2010). However merits and drawbacks, mainly related to the use of MRIO frameworks for its calculation (see section

7.2 Carbon Footprint), exist and have been highlighted below.

The strengths and benefits of national Carbon Footprint accounting are:

- Ability to allocate responsibility for production-related GHG emissions to consuming entities or activities;
- Implicitly bears a message of responsibility to (un)sustainability by linking to modelled thresholds for total GHG emissions to keep under the 2 deg C target¹⁰
- Consistency with standards of economic and environmental accounting;
- Ability to track the impacts of international supply chains, spanning multiple sectors in multiple countries;
- Allows the adoption of different accounting perspectives according to the producer, consumer, or shared responsibility principle;
- Compatible and comparable with existing global economic and trade models; and
- Enables scenario simulations of the combined effects of implementing economic, social and environmental policies.

It should also be mentioned that, by tracking a wider set of GHG (if compared with the Ecological Footprint), the Carbon Footprint allows for a more comprehensive assessment of human contribution to GHG emissions that cause climate change, though additional research would then be needed to assess the link between our activities and climate change. With fewer assumptions than Ecological Footprint approach it leads to (likely) lower uncertainty (i.e., error bars) in estimates of Carbon Footprint for nations, products etc.

Weaknesses and potential disadvantages of national Carbon Footprint accounting are:

¹⁰ It has been suggested that the most serious consequences of global warming might be avoided if global average temperatures rose by no more than 2 °C (3.6 °F) above pre-industrial levels. Recent research suggests that it would be necessary to achieve stabilization below 400 ppm of carbon dioxide in the atmosphere to give a relatively high certainty of not exceeding 2 °C. A concentration of 350 ppm carbon dioxide has been advocated as an appropriate level. As of April 2010, carbon dioxide in the Earth's atmosphere is at a concentration of 391 ppm by volume; thus rendering any additional emissions as 'unsustainable'.

- Calculating the Carbon Footprint alone does not yet answer the question whether there is a carbon concentration or climate change problem or not. Deriving a maximum 'allowable' amount of GHG emissions (a "Carbon Footprint threshold") would be needed once a 'sustainability threshold' for global warming has been agreed;
- By looking at GHGs only, the Carbon Footprint is not able to track the full palette of human demands on the environment (e.g., resource depletion);
- Substantial effort is needed to create and update a system of MRIO tables and related environmental extensions. Moreover much of the data necessary for producing these tables is not yet available, particularly accurate data on GHG emissions from production sectors in transition and developing countries;
- Currently, no uncertainty studies are available;
- The EE-MRIO accounting framework itself only allows ex-post analyses, based on data of the past, although by its nature accounting often has to look historically backwards. As for most environmental accounting tools, additional scenario and dynamic simulation techniques are required to enable ex-ante assessments;
- Additional, spatially explicit climate change impact models are required to assess the impacts of climate change at sub-national level and below;
- Without the integration of specific process data ('hybridisation'), the resolution of EE-MRIO analysis is limited to the number of sectors, i.e. industry and product groupings, in the model; and
- Hybridisation – required to assess the environmental impacts of single products or processes – entails additional data compilation and computational efforts. Though already pioneered in the 1970s, hybridisation is still rapidly evolving and not standardised.

4.3 Water Footprint

4.3.1 DEFINITION AND RESEARCH QUESTION

The Water Footprint concept was introduced by Arjen Hoekstra in 2002 (Hoekstra, 2003) in response to the need for a consumption-based indicator of freshwater use. The Water Footprint was developed analogous to the Ecological Footprint concept; it accounts for the appropriation of natural capital in terms of the direct and indirect water use activated by the consumption or production of goods and services (Hoekstra, 2007, 2009).

The Water Footprint concept is closely linked to the virtual water concept. Virtual water is defined as the volume of water required to produce a commodity or service. The concept was introduced by Allan in the early 1990s (Allan 1993, 1994) when studying the option of importing virtual water (as opposed to real water) as a partial solution to water scarcity issues in the Middle East. Allan elaborated on the idea of using virtual water import (coming along with food imports) as a tool to release the pressure on the scarcely available domestic water resources.

The Water Footprint is an indicator of water use that looks at both direct and indirect water use of a consumer or producer. The Water Footprint of an individual, community or business is defined as the total volume of freshwater that is used to produce the goods and services consumed by the individual or community or produced by the business (Hoekstra and Chapagain 2008). Water use is measured in terms of water volumes consumed (evaporated or incorporated into the product) and polluted per unit of time. The Water Footprint is a geographically explicit indicator, not only showing volumes of water use and pollution, but also the locations (with nation-level resolution).

Water Footprint can be calculated for a particular product, for any well-defined group of consumers (e.g. an individual, family, village, city, province, state, or nation) or producers (e.g. a public organization, private enterprise, or economic sector). The first assessment of Water Footprints of countries was carried out by Hoekstra and Hung (Hoekstra and Hung 2002). A more extended assessment was done by Chapagain and Hoekstra (Chapagain and Hoekstra 2004).

Three key water components are tracked in the Water Footprint calculation: the blue Water Footprint refers to consumption of blue water resources (surface and ground water); the green Water Footprint refers to consumption of green water resources (rainwater stored in the soil as soil moisture); and the grey Water Footprint refers to pollution and is defined as the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards (Hoekstra et. al, 2009).

The Water Footprint concept is primarily formulated in the research context to illustrate the hidden links between human consumption and water use and between global trade and water resources management. The Water Footprint concept has been brought into water management science in order to show the importance of human consumption and global dimensions in good water governance (Hoekstra, 2007).

A complete description of the Water Footprint methodology is reported in section 7.3 Water Footprint. Source data used in Water Footprint analyses are reported in section 8.3 Water Footprint.

4.3.2 UNITS OF MEASURE

Water use is measured through the Water Footprint method in terms of water volumes consumed (evaporated or incorporated into the product) and polluted per unit of time. Depending on the level of detail that one aims to provide, the Water Footprint can be expressed per day, month, or year (Hoekstra et. al, 2009). The following information provides a summary of units of measure of Water Footprint:

- The Water Footprint of a process is expressed as water volume per unit of time. When divided over the quantity of product resulting from the process (product units per unit of time), it can also be expressed as water volume per product unit.
- The Water Footprint of a product is always expressed as water volume per product unit:
 - water volume per unit of mass (usually m³/ton or liter/kg for products where weight is a good indicator of quantity);
 - water volume per unit of money (for products that are counted in monetary terms rather than in units of weight or energy);
 - water volume per piece (for products that are counted per piece rather than weight);
 - water volume per unit of energy (per kcal for food products, or per joule for electricity or fuels).
- The Water Footprint of a consumer or business is expressed as water volume per unit of time. It can be expressed as water volume per monetary unit when the Water Footprint per unit of time is divided by income (for consumers) or turnover (for businesses). The Water Footprint of a community of consumers can be expressed in terms of water volume per unit of time per capita.

- The Water Footprint within a geographically delineated area is expressed as water volume per unit of time. It can be expressed in terms of water volume per monetary unit when divided over the income in the area.

4.3.3 POLICY USEFULNESS AND MESSAGES FROM WATER FOOTPRINT ACCOUNTING

Total water consumption and pollution are generally regarded as the sum of a multitude of independent water demanding and polluting activities (e.g., agricultural production, industrial, manufacturing, and domestic sectors, etc) (WWAP, 2009). There has been little attention to the fact that, in the end, total water consumption and pollution relate to *what* and *how much*, communities consume and to the structure of the global economy that supplies the various consumer goods and services.

Until the recent past, there have been few thoughts in the science and practice of water management about water consumption and pollution along whole production and supply chains. As a result, there is little awareness about the fact that the organization and characteristics of a production and supply chain does actually strongly influence the volumes (and temporal and spatial distribution) of water consumption and pollution that can be associated with a final consumer product.

Hoekstra and Chapagain (2008) have shown that visualizing the hidden water use behind products can help to understand the global character of fresh water, quantify the effects of consumption and trade on water resources use. This improved understanding can form the basis for the formulation of new strategies of water governance leading to a better management of the globe's freshwater resources (Hoekstra et. al, 2009).

Where final consumers, retailers, food industries, and traders in water-intensive products have traditionally been out of the scope of those who studied or were responsible for good water governance, these players now enter the picture as potential 'change agents'. They can be addressed now not only in their role as direct water user, but also in their role as indirect water user (Hoekstra et. al, 2009).

The Water Footprint can be thus regarded as a comprehensive indicator of freshwater resources appropriation, next to the traditional and restricted measure of water withdrawal. A Water Footprint study can be undertaken for many different reasons (Hoekstra et. al, 2009):

- A national government may be interested in knowing its dependency on foreign water resources or it may be interested to know the sustainability of water use in the areas where water-intensive import products come from;
- A river basin authority may be interested to know whether the aggregated Water Footprint of human activities within the basin violates environmental flow requirements or water quality standards at any time. The river basin authority may also want to know to what extent scarce water resources in the basin are allocated to low-value export crops; and
- A company may be interested to know its dependence on scarce water resources in its supply-chain or how it can contribute to lower the impacts on water systems throughout its supply chain and within its own operations.

Traditionally countries formulate national water plans by looking how to satisfy water users. Even though countries nowadays consider options to reduce water demand in addition to options to increase supply, they generally do not include the global dimension of water management. In this way they do not explicitly consider options to save water

through import of water-intensive products. Many countries have significantly externalized their Water Footprint without considering whether the imported products are related to water depletion or pollution in the producing countries.

Governments can engage with consumers and businesses to work towards sustainable consumer products. National Water Footprint and virtual water trade accounts can serve as relevant inputs to the formulation of various sorts of governmental policy: national or state water policy, river basin policy, environmental policy, agricultural policy, energy policy, trade policy, foreign policy, and development cooperation policy.

4.3.4 STRENGTHS AND WEAKNESSES

The Water Footprint is the “youngest” of the Footprint indicators addressed in this report; yet in the last couple of years official reviews have been performed, by international organizations (IWMI, 2009; OECD, 2010) and the scientific community (Ridoutt and Pfister, 2010), identifying merits and drawbacks of this indicator. Findings from these studies alongside our review of the indicator are reported in this section.

Strengths of the Water Footprint concept as a ‘water use’ indicator are:

- It is not restricted to blue water use (as most of the existing water indicators), but also includes green and grey water¹¹;
- It includes both direct and indirect water use;
- It visualizes the link between (local) consumption and (global) appropriation of water resources;
- It provides a wide perspective on how a consumer or producer relates to the use of freshwater systems;
- It integrates water use and pollution over the complete production chain;
- Water Footprint accounts give spatiotemporally explicit information on how water is appropriated for various human purposes. They can be included in the discussion about sustainable and equitable water use and allocation and also form a fair basis for a local assessment of environmental, social and economic impacts;
- Business Water Footprint accounting offers a different perspective for developing a well-informed corporate water strategy as it goes beyond the sole indicator ‘water withdrawal in the own operations’ used by most companies thus far; and
- It can inform companies regarding a shift in their focus from the operational phase to the supply-chain. As an example, by applying the Water Footprint it is common that companies discover that water demand of their supply-chain is larger than that of their operations. As a result, companies may conclude that it is cost effective to shift investments from efforts to reduce their operational water use to focus upon efforts to reduce their supply-chain Water Footprint and associated risks.

Weaknesses and future challenges for the Water Footprint (Hoekstra et al. 2009) are:

- Lack of required data. A major challenge is therefore to develop more detailed guidelines on what default data can be used when accurate local estimates are not available;

¹¹Distinguishing between blue and green water, for example, is of great value as the hydrological, environmental, and social impacts and the economic opportunity costs of surface and groundwater use differ distinctively from the impacts and costs of rainwater use (Falkenmark and Rockström, 2004; Hoekstra and Chapagain, 2008).

- A practical issue in Water Footprint accounting is to identify what should be included and what could be excluded from the analysis (such truncation problem is also common in Ecological and Carbon Footprint assessments);
- The uncertainties in data used in Water Footprint accounting can be very significant, which means that outcomes should be carefully interpreted. Currently, no uncertainty studies are available;
- In case of the grey Water Footprint, a challenge is to develop guidelines on how to define natural and maximum allowable concentrations. Both should ideally be catchment-specific, but in many cases such data are not available;
- Water stress characterization factors are not included thus limiting the capacity of the Water Footprint to give clear indications on the actual potentials for harm. A recent study by Ridoutt and Pfister (2010) has shown that stress-weighted Water Footprint assessments could potentially give values different from the classic approach. The incorporation of such factors could improve the linking of global consumption to freshwater scarcity (a local and regional concern);
- Water footprint is not a measure of the severity of the local environmental impact of water consumption and pollution. The local environmental impact of a certain amount of water consumption and pollution depends on the vulnerability of the local water system as well as on the number of water consumers and polluters that make use of the same system. In other words, unlike the Ecological and Carbon Footprint, the Water Footprint carries with it no global threshold in environmental services and thus cannot easily be benchmarked.
- The Water Footprint is often communicated as a single figure aggregating blue and green water (and sometimes grey) footprints despite the fact that the impacts of these three water footprints are very different. Use of green water in a production country does not necessarily conflict with access to fresh water by the local population or increase water stress for example whereas a blue water Footprint does.

5. Reviewing the Footprint Indicators

The aim of this section is to bring clarity around the pre and post OPEN:EU calculation methodologies and, in turn, the strengths and weaknesses of the three Footprint indicators. Section 5.1, tests and compares the indicators according to their pre-OPEN:EU characteristics; please note that the characteristics reported in Table 1 will remain common among each indicator even for the methodologies incorporated during OPEN:EU. Section 5.2 describes the complementary nature of the three indicators and any overlapping properties that exist. Section 5.3 provides a short overview of the alternative Footprint-MRIO model developed by the OPEN:EU project and summarizes the main strengths and weaknesses associated with this new proposed method (see Weinzettel et al., 2011 for further discussion on the post OPEN:EU methodologies).

5.1 Testing and comparing the indicators

The characteristics of the three indicators (Ecological, Carbon, and Water Footprint) included in the Footprint Family are synthesized in Table 1 and serve as a starting point to define the Footprint Family itself and answer, among others, questions such as:

- How, where, and when to use each of the indicators?
- How to use the three indicators together?
- What is the value added of the “Footprint Family?”

We share van den Bergh and Verbruggen’s (1999) position that the search for operational indicators should be guided by a number of specific criteria (e.g., scientific robustness, presence of a clear research question, policy usefulness, etc.) that indicators or set of indicators should meet, and this has been a guiding principle in analyzing the Ecological, Carbon, and Water Footprint.

As any indicator is, by definition, a simplification and modeling of a much more complex reality, sets of indicators such as the Footprint Family or alternative “baskets of indicators” (e.g., Best et al., 2008) should be used in the attempt to cover and track the functioning of a larger scope of the Earth’s ecosystems.

TABLE 1: Footprint Family - summary table (includes traits that will be common to each indicator pre and post OPEN:EU).

	ECOLOGICAL FOOTPRINT	CARBON FOOTPRINT	WATER FOOTPRINT
RESEARCH QUESTION	The amount of the biosphere’s regenerative capacity that is directly and indirectly (i.e. embodied in trade) used by humans (namely Ecological Footprint) compared with how much is available (namely biocapacity), at both local and global scale.	The total amount of GHG emissions (CO ₂ , CH ₄ , N ₂ O, HFC, PFC, and SF ₆) that are directly and indirectly caused by consumption of goods and services or accumulated over the life stages of products.	The human appropriation of the volume of freshwater demanded by human consumption.

	ECOLOGICAL FOOTPRINT	CARBON FOOTPRINT	WATER FOOTPRINT
MAIN MESSAGE	To promote recognition of ecological limits and safeguard the ecosystems' life-supporting services enabling the biosphere to support mankind in the long term.	The consumption-based perspective of the Carbon Footprint complements the production-based accounting approach taken by national GHG inventories (e.g., those considered by the Kyoto Protocol).	The Water Footprint concept is primarily intended to illustrate the hidden links between human consumption and water use and between global trade and water resources management.
DATA AND SOURCES	<ul style="list-style-type: none"> Data on local production, import and export for agricultural, forestry and fisheries products (FAOSTAT, UN Comtrade); Land use data (FAOSTAT, etc); Local and trade-embedded CO₂ emissions (IEA and others); and Land yield (FAOSTAT) and potential crop productivity (provided by the FAO GAEZ model) – this data is needed to express results in units of global hectares. Data on population (FAO) 	<ul style="list-style-type: none"> National economic accounts (supply, use, input-output tables); International trade statistics (UN, OECD, GTAP and others); and Environmental accounts data on GHG emissions (IEA, GTAP, and others). Data on population (World Bank); 	<ul style="list-style-type: none"> Data on population (World Bank); Data on arable lands (FAO) and total renewable water resources and water withdrawals (FAO); Data on international trade in agricultural (PC-TAS) and industrial products (WTO); and Local data on various parameters such as climate, cropping patterns, soil, irrigation, leaching, water quality, pesticides and fertilizers rates, etc. Data on population (FAO)
UNIT OF MEASUREMENT	<ul style="list-style-type: none"> Global hectares (gha) of bioproductive land. Gha is not a measure of area but rather of the ecological production associated with an area; and Results can also be expressed in actual physical hectares. Usually expressed per capita 	<ul style="list-style-type: none"> Kg CO₂ when only CO₂ is included or kg CO₂-e when other GHGs are included as well; and No conversion to an area unit takes place to avoid assumptions and uncertainties. Often expressed per capita 	<ul style="list-style-type: none"> Water volume per unit of time (usually m³/yr) for the Water Footprint of processes; m³/ton or liter/kg for the Water Footprint of products; and Water volume per unit of time for the Water Footprint of a geographical area.
INDICATOR COVERAGE	<ul style="list-style-type: none"> Temporally explicit and multi-dimensional indicator that can be applied to single products, cities, regions, nations and the whole biosphere; Approximately 240 countries for the period 1961-2007 are tracked; of these, approximately 150 countries are published by Global Footprint Network (Ewing et al., 2010a); Documents both direct and indirect human demands for both the source (resource production) and the sink (carbon uptake) capacity of the biosphere; Provides a measure of 	<ul style="list-style-type: none"> Multi-dimensional indicator that can be applied to products, processes, companies, industry sectors, individuals, governments, populations, etc.; Currently 73 countries and 14 regions for the year 2001 only are tracked (Hertwich and Peters, 2009), though 113 nations and world regions for the year 2004 could be available by using the GTAP7 database (Wiedmann, 2009) Documents all direct and indirect GHGs emissions due to use 	<ul style="list-style-type: none"> Geographically explicit and multi-dimensional indicator: it can be calculated for products, public organizations, economic sectors, individuals, cities and up to countries; 140 countries for the period 1997-2001 are tracked (Chapagain and Hoekstra, 2004); Documents both the direct and indirect use of natural capital as a source (demand on blue and green waters) and as a sink (grey water to dilute pollution); Measures the 'demand' side only, in terms of freshwater consumed

	ECOLOGICAL FOOTPRINT	CARBON FOOTPRINT	WATER FOOTPRINT
	<p>both human demand and nature supply;</p> <ul style="list-style-type: none"> Provides a clear benchmark; and It has a consumption-based point of view and thus considers trade. 	<p>of resources and products (source);</p> <ul style="list-style-type: none"> Measures the 'demand' side only, in terms of the amount of GHGs emitted; and It has a consumption-based point of view and thus considers trade. 	<p>(by sources) and polluted (by type of pollution) by human activities;</p> <ul style="list-style-type: none"> No benchmark is provided; and It has a consumption-based approach and considers trade.
POLICY USEFULNESS	<ul style="list-style-type: none"> Measures 'overshoot' and identifies the pressures that humanity is placing to various ecosystem services; Monitors societies' progresses towards minimum sustainability criteria (demand \leq supply); Monitor the effectiveness of established resource use and resource efficiency policies; Helps analyzing the consequences of using alternative energies; Communicates the wide range of environmental impacts of different life-styles to the overall public; Track pressure on biodiversity (indirectly); and Illustrates the unequal distribution of resource use and can be used to design international policies aiming at implementing contraction and convergence principles. 	<ul style="list-style-type: none"> Offers an alternative angle for international policy on climate change as it complements the territorial-based approach used by the UNFCCC; Offers a better understanding of countries' responsibility and could facilitate international cooperation and partnerships between developing and developed countries; Identifies alternative levers for reducing GHGs i.e. change in consumption behavior Helps analyzing the consequences of using alternative energies; Can help design an international harmonized price for greenhouse gas emissions; and Illustrates the unequal distribution of energy use and can be used to design international policies aiming at implementing contraction and convergence principles. Can be benchmarked against 2050 targets for total global GHG emissions 	<ul style="list-style-type: none"> Gives a new & global dimension to the concept of water management & governance; Offers nations a better understanding of their dependency on foreign water resources; Offers river basin authorities info on the extent to which scarce water resources are allocated to low-value export crops; Identifies alternative levers for reducing water stress i.e. change in consumption behavior Helps analyzing the consequences of using alternative energies; Offers companies a way to monitor their dependence on scarce water resources alongside their supply-chain; and Illustrates the unequal distribution of water use and can be used to design international policies aiming at implementing contraction and convergence principles
STRENGTHS	<ul style="list-style-type: none"> Allows benchmarking human demand for renewable resources and carbon uptake capacity with nature supply and determining clear targets. Provides an aggregated assessment of multiple anthropogenic pressures; 	<ul style="list-style-type: none"> Allows for a comprehensive assessment of human contribution to GHG emissions; and Consistent with standards of economic and environmental 	<ul style="list-style-type: none"> Represents the spatial distribution of a country's water "demand"; Expands traditional measures of water withdrawal (green and grey waters also included); and

	ECOLOGICAL FOOTPRINT	CARBON FOOTPRINT	WATER FOOTPRINT
	<ul style="list-style-type: none"> and • Easy to communicate and understand with a strong conservation message. 	<ul style="list-style-type: none"> accounting. • Consistent emissions data available for the majority of countries. 	<ul style="list-style-type: none"> • Visualizes the link between (local) consumption and (global) appropriation of freshwater. Integrates water use and pollution over the production chain.
WEAKNESSES	<ul style="list-style-type: none"> • Cannot cover all aspects of sustainability, neither all environmental concerns, especially those for which no regenerative capacity exists (including abiotic resources); • Shows pressures that could lead to degradation of natural capital (e.g. reduced quality of land or reduced biodiversity), but does not predict this degradation; and • Not geographically explicit; • Some underlying assumptions are controversial, though documented. 	<ul style="list-style-type: none"> • Cannot track the full palette of human demands on the environment • Additional impact assessment models are needed to analyze the impact of climate change at both national and sub-national levels; • Efforts needed to set up and update a system of MRIO tables and related environmental extensions; and • No specific "Carbon Footprint threshold" is provided yet, though a 'sustainability threshold' for global warming has been agreed. 	<ul style="list-style-type: none"> • Only tracks human demand on freshwater; • It relies on local data frequently unavailable and/or hard to collect. • It suffers from possible truncation errors; • No uncertainty studies are available, though uncertainty can be significant; • Grey water calculation heavily relies on assumptions and estimations; • No water stress characterization factors are included; • No benchmark is provided; • Implications of blue water and green water use very different – difficult to communicate.
COMPLEMENTARY PROPERTIES IN THE FOOTPRINT FAMILY	<ul style="list-style-type: none"> • Uses a consumer-based approach to track human pressures on the planet in terms of the aggregate demand that resource-consumption and CO₂ emissions places on the ecological assets. 	<ul style="list-style-type: none"> • Uses a consumer-based approach to track human pressures on the planet in terms of total GHG emissions and human contribution to climate change. 	<ul style="list-style-type: none"> • Uses a consumer-based approach to track human pressures on the planet in terms of the water volumes required for human consumption.

5.2 Complementary and overlapping properties

The three indicators of the Footprint Family complement one another in assessing human pressure on the planet from a consumer-based angle. The Ecological Footprint focuses on the aggregate demand that resource consumption places on the planet's ecological assets; thus recognizing the existence of limits to our growth and trying to measure them. The Water Footprint focuses on the human appropriation of natural capital in terms of fresh water volumes required for human consumption; it is primarily intended to illustrate the hidden links between consumption activities and water use. Finally, the Carbon Footprint focuses on the total amount of GHGs released due to resource-consumption activities; by complementing the production-based accounting approach taken by national GHG inventories, the Carbon Footprint provides a better understanding of humans' contribution to GHG emissions.

A partial overlap exists between the Ecological and the Carbon Footprint as human-induced CO₂ emissions are tracked by both methodologies. However, both methodologies go beyond the sole CO₂ investigation as the Carbon Footprint also tracks the release of

additional GHGs (usually CO₂, CH₄, N₂O, HFC, PFC, and SF₆) and the Ecological Footprint expands its area of investigation by looking at human demand for food, fibers, wood products, etc.

With respect to the Ecological and Water Footprints, a partial overlap also exists between these two indicators since water is tracked by both methodologies. But while direct and indirect freshwater requirements are clearly tracked by the Water Footprint indicator, the water issue is only indirectly tracked by the Ecological Footprint, which is able to provide limited information to back up water policies. As recognized by Kitzes et al. (2009), freshwater is a natural resource cycling through the biosphere, whose availability or scarcity influence the regenerative capacity (biocapacity) of the planet; however, water is not itself a creation of the biosphere for which the planet has a regenerative capacity. As such the direct Ecological Footprint of a given quantity of water cannot be calculated in the same manner as a quantity of crop or wood product, though it is possible to measure the Ecological Footprint embedded in the provisioning of water (Lenzen et al., 2003). The combined use of both Ecological and Water Footprint indicators as in the Footprint Family is thus deemed to be the best approach to develop a multi-criteria decision making process and arrive at optimal decisions.

The Ecological, Carbon, and Water Footprint are characterized by a wide spatial coverage and scale of applicability: they can all be applied to single products, cities, regions, nations and up to the whole planet. In terms of time coverage, the Ecological Footprint was found to be the most comprehensive as it covers a 1961-2007 time period, while values exist for the year 2001 and an averaged 1997-2001 period only for the Carbon¹² and Water Footprint, respectively. Updated time coverage for Water and Carbon Footprint results is expected to be released soon; however this updated set of data was not yet available at the time of producing this report.

All three indicators illustrate the unequal distribution of resource use and/or related impacts between the inhabitants of different world regions and could thus be linked to policy debates in the development policy area, oriented at concepts such as "Contraction and Convergence," "Environmental Justice," or "Fair Share".

The three indicators are all able to track both direct and indirect human demands, enabling for a clear understanding of the 'hidden/invisible' human-induced sources of pressure; however, only the Ecological and Water Footprint were found to be able to account for both the **source** (resource production) and **sink** (waste assimilation) capacity of the planet. Lastly, the Ecological Footprint was found to be the sole indicator with the ability to provide a clear **ecological benchmark** (biocapacity) to test human pressure against, although a benchmark for the Carbon Footprint indicator is intended to be developed in the OPEN:EU project on the basis of the 2 °C sustainability threshold for global warming.

¹² More extensive time series Carbon Footprint results are available for some nations such as the UK – see Wiedmann et al., 2008.

5.3 Comparing pre and post OPEN:EU accounting 'methods'

Existing Carbon Footprint accounts (Hertwich and Peters, 2009) utilize a MRIO model to allocate emissions to consumption, similar to that being implemented in OPEN:EU. The Ecological Footprint and Water Footprint, on the other hand, have been historically calculated using process-based Life Cycle Assessment (LCA) data and physical quantities of traded goods.

The benefit of a purely physical flow LCA-type of approach—where economic data is not introduced into the models—is that the product resolution is much higher and the physical flows are tracked directly. However, the weakness of this approach is that physical flow datasets are less prevalent and developed than the economic flows related to the same products and the physical flow data sets only track goods, excluding services, which are arguably becoming increasingly important. These physical flow accounts also do not completely link with the supply chain or the economic activities that are driving the resource or waste flows. Unlike MRIO approaches, the LCA approach usually does not have 100% coverage of the economy and are arguably more uncertain; it includes the LCA processes of the more important products consumed by a country and more important flows of traded goods.

Integrating the Ecological, Carbon, and Water Footprint accounts with an MRIO model both allows a strong coverage of the economy and enables an inter-industry analysis of the linkages across multiple economies. However, while the integration of environmental and economic accounts is extremely valuable, approximations are required as part of the calculation to utilize economic flows as a proxy for the physical flows. Moreover, the use of Input-Output tables with Footprint Indicators causes a decreased resolution, because of the shift from detailed product-level (currently utilized by both the National Footprint Accounts and the Water Footprint Accounts) to aggregated sectoral-level assessments (required for the MRIO analyses).

As reported in section 4. [M](#), the OPEN:EU project has been focusing on the “Footprint Family” of indicators in an attempt to both define its conceptual framework and develop a model to harmonize the methodologies and improve the rigor and consistency of their calculation. The OPEN:EU project has attempted to go beyond the “classical” IO-Footprint approaches that have been proposed in the past (see Wiedmann 2009 for a comprehensive lists of previous analyses), because of the use of a multi-regional input-output model and by maintaining a high level of detail in commodity classification when integrating existing accounts for ecological and water footprints within a more complete but less detailed MRIO framework (Weinzettel et al., 2011).

All three indicators will benefit in terms of comparability from being calculated and presented in a consistent framework. This will allow for more intuitive examination of the relationship between their respective subject areas, and will help understand trade-offs between them.

However, the indicator integration will impact on the indicators’ temporal and geographical coverage. The Ecological, Carbon, and Water Footprints are currently available over different periods of time (1961-2007, 2001, and 1997-2001, respectively) and for different countries (more than 200 countries, 73 countries and 14 regions, and 140 countries, respectively). Once aligned under the OPEN:EU model, the three

indicators will follow the MRIO base year discussed in the “MRIO Technical Report” as well as its country coverage (Hertwich and Peters, 2010). Two multi-regional input-output model are currently available and considered for the OPEN:EU project: EXIOPOL and GTAP 7. The base year for EXIOPOL is 2000 while GTAP 7 is 2004. The number of countries included in the model is 43 (EU-27 +16) plus rest of the world for EXIOPOL and 113 countries for GTAP 7 (see Hertwich and Peters, 2010). GTAP 7 is currently being implemented in the OPEN:EU Footprint-MRIO model at the time of producing this report. However, the model has been designed in such a way that it can be easily extended to incorporate bespoke research or datasets, as required by policy-makers in the future.

Given the importance of representing the Ecological, Carbon, and Water Footprints over time and the policy-useful information that such time trends could provide, additional research will be needed to manage the trade off between increased methodological robustness and decreased temporal and geographical coverage (except for Carbon Footprint analyses).

A summary of the main strengths and weaknesses associated with the new proposed method is reported in Table 2 below.

TABLE 2: Footprint Family - summary table (post OPEN:EU).

	ECOLOGICAL FOOTPRINT	CARBON FOOTPRINT	WATER FOOTPRINT
STRENGTHS	<ul style="list-style-type: none"> Provides an aggregate indicator of the biological resource requirements of economic flows (see also section 4.1.3 Policy usefulness and messages from Ecological Footprint accounting); and Geographic specificity, at the national level, in connecting resource demands to consumption. 	<ul style="list-style-type: none"> Increased geographic and product/sector resolution 	<ul style="list-style-type: none"> More comprehensively captures indirect water use, covering the entire supply chain.
WEAKNESS	<ul style="list-style-type: none"> Time series estimates no longer calculated by same method as detailed single-year model; Lacking geographic specificity, at the sub-national level, in connecting resource demands to consumption; Still does not provide direct links to land or ecosystem degradation; and Efforts needed to set up and update a 	<ul style="list-style-type: none"> Efforts needed to set up and update a system of MRIO tables and related environmental extensions 	<ul style="list-style-type: none"> Aggregation of certain sectors; and Efforts needed to set up and update a system of MRIO tables and related environmental extensions

	ECOLOGICAL FOOTPRINT	CARBON FOOTPRINT	WATER FOOTPRINT
	system of MRIO tables and related environmental extensions		

6. Towards a Definition of the Footprint Family and its Appropriate Use

Achieving sustainability depends on a number of critical issues, hence the need for several key indicators as fully recognized by the OPEN:EU project. The selection of indicators depends on the circumstances and can only be evaluated by understanding the critical questions that need to be addressed. Building on these premises, and on the need for indicators to be used and interpreted jointly, this section aims to provide a clear definition of the "Footprint Family" of indicators. Its most appropriate use in tracking human pressure on the planet as well as its usefulness in policy making will be discussed in the following sections.

The combination of indicators presented in this research is not the first attempt at a combined Footprint approach for the assessment of the environmental impact of productions (Burger et al., 2009; Giljum et al., 2009c; Patrizi, 2009; Niccolucci et al., 2010). However, this is to our knowledge the first study that clearly provides a definition to the Footprint Family of indicators in its wider range of applicability. And the OPEN:EU project is the first project to jointly use the Footprint Family at a national level to complementarily track human pressure on the planet and find ways to reduce it.

6.1 The Footprint Family: definition and scope

The Footprint Family of indicators introduced in this study is intended to assist policy makers as well as academics, CSOs, and other practitioners in understanding the pressures human activities place on the biosphere.

The need for developing such a family of indicators originates from the understanding that, when used in isolation, each of these indicators is able to capture just one limited aspect of the full complexity of sustainable development. As a result, there is a lack in the indicators realm of methods and tools with which to fully illustrate the links between economic growth and environmental degradation to policy makers, CSOs and the public.

The Footprint Family proposed here can thus be used to improve researchers' ability to track the current resource consumption and the impact this consumption generates, highlight the main drivers of it (therefore providing information on the areas where actions are needed), suggest solutions, and finally quantify, through the EUREAPA tool, the outcomes of specific policies undertaken to reduce the negative environmental impacts of natural resource consumption (see WP4 deliverable "EUREAPA technical report"). However, it is important to stress the fact that key sustainability-related topics such as human health, social development and well-being cannot be monitored using the Footprint Family. Knowing how people are developing and what their lifestyles are like is equally important when considering a sustainable economy – if global human development is prevented or wellbeing is negatively affected, no economy could be considered to be sustainable or progressive.

The three indicators selected are all characterized by the capacity to represent the environmental consequences of human activities, though they are built around different

research questions and tell different stories. By looking at the amount of bioproductive area people demand because of resource consumption and waste emission, the Ecological Footprint can be used to inform on the pressure placed on the *biosphere*. By quantifying the effect of resource consumption on carbon emissions, the Carbon Footprint informs on the pressure humanity places on the *atmosphere*. Lastly, by tracking real and hidden water flows, Water Footprint can be used to inform on the pressure humans place on the *hydrosphere*.

These three indicators can therefore be regarded as complementary in the sustainability debate and the Footprint Family as a tool able to track human pressures on various life-supporting compartments of the Earth (*biosphere*, *atmosphere*, and *hydrosphere*) and from various angles. The use of the Footprint Family of indicators goes in the direction of multidisciplinary sustainability assessments. This does not mean that the Footprint Family is a fully inclusive and comprehensive basket of indicators nor that it should be considered as the sole tool decision makers should rely on. However, if Europe, or any other region, is to truly address sustainable development then decision makers will need different tools and sets of indicators, one of which could be the Footprint Family. The Footprint Family could also be included in larger comprehensive sets of indicators on sustainable development or sustainable consumption and production, for example the set being developed by the European Environment Agency (ETC/SCP 2010). In reducing resource consumption while improving economic well-being, all compartments (*biosphere*, *atmosphere*, and *hydrosphere*) need to be taken into account and trade-offs understood to avoid additional cost, or worse, inadvertently undoing progress in one sector by not accounting for direct and indirect implications of actions in another sector.

BOX 1: the Footprint Family of indicators – definition

We define the Footprint Family of indicators as a set of accounting tool characterized by a consumption-based perspective able to track human *pressure* on the surrounding environment, where pressure is defined as appropriation of biological natural resources and CO₂ uptake, emission of GHGs, and consumption and pollution of global freshwater resources.

Three key ecosystem compartments are monitored, namely the *biosphere*, *atmosphere*, and *hydrosphere* through the Ecological, Carbon, and Water Footprint, respectively.

The Footprint Family has a wide range of applicability as it can be applied at scales ranging from a single product, a process, a sector, up to individual, cities, countries, and the whole world¹³.

The Footprint Family provides an answer to three specific research questions (how much of the biosphere's regenerative capacity and the global freshwater volumes is consumed and polluted by humans due to our activities and to what extent mankind is contributing to GHG emissions¹⁴) and helps to more comprehensively monitor the environmental pillar of sustainability.

The Footprint Family only addresses the environmental pillar of sustainable development and in addition does not cover some key environmental issues such as toxicity, non-renewable resource use, soil quality and land degradation, nuclear wastes, etc.

¹³ Although the range of applicability of the Footprint Family is theoretically wide, in the OPEN:EU project it will only be used to quantify the Footprint of nations or regions.

¹⁴ Additional analyses would be needed to inform on the extent to which such emissions could contribute to climate change.

6.2 The Footprint Family: Appropriate Use

The information reported throughout this report has helped to define the methodology as well as the specific, though confined, research question of the Ecological, Carbon, and Water Footprint indicators. In various sections of this report, it has been highlighted that no single indicator per se is able to comprehensively monitor (progress towards) sustainability and that, taken alone, each of the Footprint Indicators reflects only one part of the whole “sustainability” picture and cannot be used as a stand-alone indicator.

For instance, although the issues tracked by the Ecological Footprint are clearly relevant to sustainability, the messages that can be derived from Ecological Footprint accounting will only provide some of the information relevant for EU policy goals (e.g. no information is provided on health, social and economic issues or the consumption of non-renewable resources), meaning that complementary indicators are needed¹⁵.

For instance, the Carbon Footprint is required to assess all direct and indirect GHG emission from all type of sources, and it is considered complete for such GHG accounting. However, the range of human-induced pressures on the environment is much broader than just GHG emissions: by including the Ecological and Water Footprint, the Footprint Family of indicators thus provides a better overarching picture of the human pressure on the natural environment and its key compartments (namely *biosphere*, *atmosphere*, and *hydrosphere*), where indicators compensate for each other's flaws and complement each other in assessing trade-offs as well as real pressure reductions rather than just pressure shifting from one compartment to the others. As the case of biofuels has illustrated, the intention to decrease GHG emissions through substitution of fossil fuels through biomass leads to rapidly growing demand for water and fertile land.

Table 3 below equates each of the three Footprint Indicators and the Footprint Family to the various European (and international) policy objectives in an attempt to identify which indicator can best address the specific environmental issues EU policy makers have to face, as well as the value added of addressing such issues with the whole Footprint Family suite of indicators. The table states the policies for which each indicator is fully relevant, partly relevant or not relevant at all. However, this does not imply that the policies could sufficiently be informed by these indicators or that the indicators could model the impacts of these policies. Furthermore, it has to be noted that neither all policies nor all policy fields are captured in this table but only the most relevant ones. Please refer to Figure 2 – the Indicator-Policy Radar – for a more visual representation of indicators policy coverage.

¹⁵ It has to be acknowledged that among the three Footprint Indicators, the Ecological Footprint draws the bigger picture and it is thus believed to be the most informative of the three if used alone.

TABLE 3: Indicator-Policy Matrix. This summary table shows which indicator may help decision makers to inform their decisions in each policy area (post OPEN:EU). Further details for each policy are provided in text below.

	ECOLOGICAL FOOTPRINT	CARBON FOOTPRINT	WATER FOOTPRINT	FOOTPRINT FAMILY
EU GENERAL POLICY OBJECTIVES				
EU SDS	Partly	Partly	Partly	Partly
EU 6EAP	Partly	Partly	Partly	Partly
Thematic Strategy on air pollution (TS Air)	Not at all	Partly	Not at all	Partly
Thematic Strategy on the marine environment (TS Marine)	Not at all	Not at all	Partly	Partly
Thematic Strategy on the prevention and recycling of waste - (TS Waste)	Partly	Not at all	Not at all	Partly
Thematic Strategy on the sustainable use of natural resources - (TS Resources)	Partly	Partly	Partly	Partly
Thematic Strategy on the urban environment (TS Urban)	Not at all	Not at all	Not at all	Not at all
Thematic Strategy on the sustainable use of pesticides (TS Pesticides)	Not at all	Not at all	Not at all	Not at all
Thematic Strategy on soil protection (TS Soil)	Not at all	Not at all	Not at all	Not at all
LISBON STRATEGY (2005)	Not at all	Not at all	Not at all	Not at all
EUROPE 2020	Partly	Partly	Partly	Partly

	ECOLOGICAL FOOTPRINT	CARBON FOOTPRINT	WATER FOOTPRINT	FOOTPRINT FAMILY
EU SPECIFIC POLICY OBJECTIVES				
Directive on renewable energy (Directive 2009/28/EC)	Partly	Partly	Not at all	Partly
The Forestry Strategy	Partly	Not at all	Not at all	Partly
The Forest Action Plan	Partly	Not at all	Not at all	Partly
Water Framework Directive (WFD)	Not at all	Not at all	Partly	Partly
Drinking Water Directive (DWD)	Not at all	Not at all	Not at all	Not at all
Bathing Water Directive	Not at all	Not at all	Not at all	Not at all
Urban Waste Water Directive	Not at all	Not at all	Not at all	Not at all
Nitrates Directive	Not at all	Not at all	Not at all	Not at all
Groundwater Directive	Not at all	Not at all	Not at all	Not at all
Communication "Addressing the challenge of water scarcity and droughts"	Not at all	Not at all	Partly	Partly
Floods Directive	Not at all	Not at all	Not at all	Not at all
Marine Strategy Framework Directive	Not at all	Not at all	Not at all	Not at all

	ECOLOGICAL FOOTPRINT	CARBON FOOTPRINT	WATER FOOTPRINT	FOOTPRINT FAMILY
Common Fisheries Policy (CFP)	Partly	Not at all	Not at all	Partly
Kyoto Protocol	Not at all	Partly	Not at all	Partly
European Climate Change Programme (ECCP)	Not at all	Partly	Not at all	Partly
European Union Greenhouse Gas Emission Trading System (EU ETS)	Not at all	Partly	Not at all	Partly
20-20-20 targets	Not at all	Partly	Not at all	Partly
Common Agricultural Policy (CAP)	Partly	Partly	Partly	Partly
Directive on the conservation of natural habitats and of wild fauna and flora (Directive 92/43/EEC)	Marginally	Not at all	Marginally	Marginally
Directive on the conservation of wild birds (Directive 2009/147/EC)	Marginally	Not at all	Not at all	Marginally
INTERNATIONAL GENERAL POLICY OBJECTIVES				
Convention on Biological Diversity - CBD	Partly	Not at all	Not at all	Partly
UN Development Goals (MDGs)	Partly	Partly	Partly	Partly
INTERNATIONAL SPECIFIC POLICY OBJECTIVES				
International Panel for Sustainable Resource Management – (IPSRM)	Partly	Not at all	Partly	Partly

	ECOLOGICAL FOOTPRINT	CARBON FOOTPRINT	WATER FOOTPRINT	FOOTPRINT FAMILY
Marrakech Process	Partly	Partly	Partly	Partly

Concerning the EU SDS (Sustainable Development Strategy), the Ecological, Carbon, and Water Footprint are partly suitable to inform policy makers since they contain information relevant for the EU SDS but do not cover all the policy fields that are relevant for the strategy (see Knoblauch and Neubauer, 2010). Consequently, even the Footprint Family is not able to inform on all the different aspects of the EU SDS. In particular, out of the seven key challenges included in the EU SDS, only three (climate change and clean energy; sustainable production and consumption; conservation and management of natural resources) can be informed by the Footprint Family, while the other four (sustainable transport; public health; social inclusion, demography and migration; and global poverty and sustainable development challenges) are not covered. The Footprint Family is thus only partially suitable to inform policy makers on the EU SDS.

The same is true for the EU 6EAP (Sixth Environmental Action Programme), which has a broad scope. Some of the aspects are covered through the Ecological, Carbon, and Water Footprints but none of the indicators covers all aspects. In particular, the 6EAP focuses on the following four key priority areas: climate change; nature and biodiversity; environment, health and quality of life; natural resources and wastes. The Ecological Footprint is suitable to inform to some extent on natural resources and wastes and partly on environment, health and quality of life (i.e., when used in combination with Human Development Index data); the Carbon Footprint is at least partly suitable to inform about climate change (strictly speaking, the Carbon Footprint only informs about GHG emissions, not about climate change); and finally the Water Footprint is suitable to partly inform about natural resources and waste since water is also a natural resource. However, the aspect of health and quality of life is covered by none of the indicators.

Out of the seven Thematic Strategies (TS) within the 6EAP four can partly be informed by the Footprint Family: the Carbon Footprint can partly inform the TS on air pollution and the TS on the sustainable use of natural resources, the Water Footprint can partly inform the TS on the marine environment and the Ecological Footprint can only indirectly inform the TS on the prevention and recycling of waste by addressing the overexploitation issue. The TS on the sustainable use of natural resources can partly be informed by the Ecological Footprint (see also Best et al., 2008 for a full review of the potential role of this indicator in addressing the thematic strategies on the sustainable use of natural resources) and as regards water by the Water Footprint. By contrast, the remaining three TSs (TS on the urban environment, TS on the sustainable use of pesticides and TS on soil protection) can be informed neither by the single Footprint indicators nor by the Footprint Family.

The 2005 Lisbon Strategy primarily focused on social and economic aspects. As a result, none of the Footprint Indicators is suitable to inform policy makers for this strategy. In contrast, the Europe 2020 Strategy includes environmental and climate targets. The Ecological, Water and Carbon Footprint were found to be partly suitable to inform on the headline targets of the renewed strategy. More precisely, the Carbon Footprint

adequately informs on the headline target to reduce the GHG emissions while the Ecological and Water Footprint sufficiently inform the flagship initiative on a "Resource Efficient Europe". However, most of the headline targets and flagship initiatives focus on issues that cannot be informed by the Footprint Family (e.g. employment rates, share of early school leavers, poverty, youth, internet, etc.).

The Directive on renewable energy (Directive 2009/28/EC), the Forestry Strategy as well as the Forest Action Plan are all resource related policies (see also Knoblauch and Neubauer 2010). Being a renewable-resource accounting tool, the Ecological Footprint can thus be used to some extent to address these policies. However, it cannot be used to inform on non-renewable resources and, given it is an aggregated indicator, it can only help decision makers grasp the big picture and understand the links between such policies but it may not be suitable to inform policy makers concerning a specific resource (e.g. forests). The Directive on renewable energy is also informed by the Carbon Footprint.

Concerning water use policies, especially the policies addressing water scarcity and resource productivity with regard to water use can partly be informed by the Water Footprint. For instance, Spain is the first country that has included Water Footprint analysis into governmental policy making in the context of the Water Framework Directive (WFD). However, in order to draw conclusions for practical policy from the number provided by the Water Footprint, one would need to compare the existing water resources in the considered country with the water use numbers provided by the Water Footprint. As regards water pollution, specifically the grey Water Footprint informs on the water quantity that would be needed to dilute water polluted for the use of production or providing services to neutralize the pollution; however as reported in section 4.3.4 Strengths and weaknesses, the reliability and robustness of the grey component of the Water Footprint is heavily affected by the lack of proper data.

The Common Fisheries Policy (CFP) sets out which Member State is allowed to catch which type of fish and which amount of that fish. As it includes demand for, and supply of, fishing grounds in its accounting structure (see section 7.1 Ecological Footprint), the Ecological Footprint could potentially be the only one of the three indicators suitable to address the CFP. However, since the indicator is an aggregated one, it can help decision makers grasp the big picture but it may not be suitable to inform policy makers concerning a specific resource (e.g. fish stocks). Moreover, the current fishing grounds Ecological Footprint and biocapacity trends are not able to show overfishing and fish stock depletion. As such additional research is mandatory (Ewing et al., 2010a; Kitzes et al., 2009a) to improve the fishing ground calculation before the Ecological Footprint can be used to inform the CFP. Preliminary attempts in this direction have been initiated in the United Arab Emirates via collaboration between Global Footprint Network and government bodies (Hartman et al., 2010).

The climate related policies mentioned in Table 3 can all be partly informed by the Carbon Footprint since it measures the emissions of the six GHGs but still they need to be interpreted in context (i.e. their reduction needs to be analyzed in a time series) to derive information on climate change.

Regarding the Convention on Biological Diversity (CBD) the Ecological Footprint has officially been included in the list of indicator that the 2010 Biodiversity Indicator Partnership (BIP) has used to monitor world governments progress toward the 2010

biodiversity target set by the CBD in 2002. The BIP approaches biodiversity with a Pressure-State-Benefit-Response framework and the Ecological Footprint is one of the indicators of pressure officially used (Butchart et al., 2010). Extending biodiversity assessments to also account for the role of human pressures on ecosystems and biodiversity is becoming a shared approach within CBD. The Ecological Footprint is thus linked to the biodiversity issue in that it is one of the measures of the human pressure on ecosystems which in turn impacts upon the degradation of biodiversity; as such time series Ecological Footprint assessments constitute a way to measure how this pressure has changed over time. Finally, the CBD 2011-2020 Strategic Plan for biodiversity (CBD, 2010) has been agreed in October 2010 at the CBD COP10 meeting in Nagoya. The Strategic Plan includes 20 headline targets for 2015 or 2020, organized under five strategic goals, to monitor progresses towards the implementation of the plan. As suggested by the Biodiversity Indicator Partnership (BIP, 2010), the Ecological Footprint is believed to be highly suitable to inform on Target 4 – *"By 2020, at the latest, Governments, business and stakeholders at all levels have taken steps to achieve or have implemented plans for sustainable production and consumption and have kept the impacts of use of natural resources well within safe ecological limits"* of the Strategic Goal A – *"Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society"*.

All of the Footprint Indicators as well as the Footprint Family are partly suited to inform policy makers on the UN Millennium Development Goals. Particularly Goal 7, Ensure Environmental Sustainability, refers to resource use/deforestation, climate change and drinking water – all of which are issues that can be informed by the three indicators. Because of its ability to analyze the extent of the global ecological assets each country is using compared to what is available, the Ecological Footprint can inform on issues such as equity in resource accessibility and use; this, in turn, can be used to partially inform on MDG 8 - Develop a global partnership for development. However, since the Development Goals are quite broad in their scope, the indicators are not suited to fully inform policy makers on all issues addressed therein. Moreover, the other Goals (Eradicate extreme poverty and hunger (1), Achieve universal primary education (2), Promote gender equality and empower women (3), Reduce child mortality (4), Improve maternal health (5), Combat HIV/AIDS, and Malaria and other diseases (6)) cannot be informed by the Footprint Family.

The International Panel for Sustainable Resource Management observes among others the exploitation of resources. Consequently, the Ecological Footprint is partly suitable to inform stakeholders concerned with the panel (particularly for what concern exploitation of renewable resources), the Water Footprint informs about the issues related to water use and productivity. These indicators cannot fully inform this panel with respect to all resources, but offer a partial assessment, that does not include details upon non-renewables or sufficient level of detail for fish stocks, for example. By contrast, the Carbon Footprint is not dealing with this topic at all and consequently cannot inform stakeholders on the issue.

The Marrakech Process is about sustainable consumption and production. The Ecological Footprint, the Water Footprint, and the Carbon Footprint are dealing with consumption and production, the first concerning the bioproductive land appropriation, the second concerning water use, and the third regarding the emissions perspective and can consequently inform the process. Moreover, the Footprint Family will be able to inform these processes since it links the information on consumption and production, i.e. traces

the Footprint along the supply chain. The MRIO model used in the OPEN:EU project provides the advantage of taking into account full production chains with technologies specific to country of origin and of individual production processes. Grouped within such MRIO model, the Footprint Family is able to connect consumption of products and services with various forms of pressure due to the production phase worldwide.

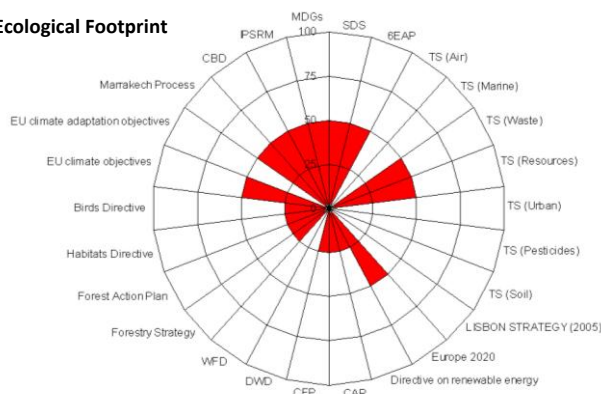
Since the adoption of the Health Check, new challenges have been highlighted for the future Common Agricultural Policy (CAP), which brought environmental issues in a stronger focus of European agriculture: climate change, the need for better water management, the affects upon biodiversity, and the production of green energy. Activities and measures resulting from these challenges and further debated within the currently ongoing CAP reform process can marginally be informed by the Ecological, Carbon, and Water Footprint as well as the whole Footprint Family.

Furthermore, the Directive on the conservation of natural habitats and of wild fauna and flora (Directive 92/43/EEC), the Habitats Directive, aims to protect different land and water habitats and species. The Habitats Directive can only be informed by the Ecological and Water Footprint indirectly and to a minor extent in that such indicators show the aggregate pressure humans place on various ecosystems and habitats.

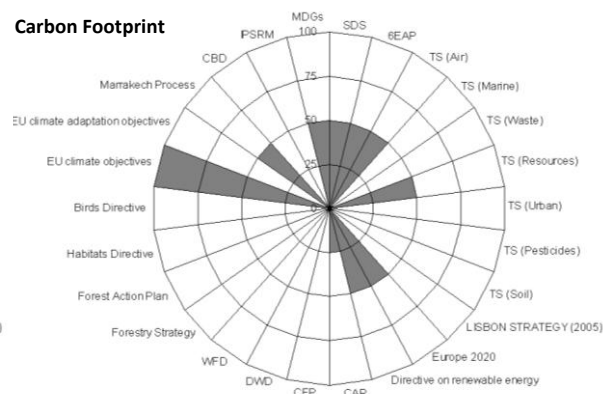
Last but not least, the Directive on the conservation of wild birds (Directive 2009/147/EC), the Birds Directive, is about establishing protected areas for birds thus focusing on land protected for them. The policy could be potentially informed by the Ecological Footprint if this indicators could be made available and utilized at a very localized level, for example for specific areas such as individual wetlands areas – as a measure of growing human pressure - but not by the other indicators. Currently such a localized focus is not available and many of the relationships between Ecological Footprint and biodiversity have been explored only in a theoretical and qualitative way. Additional research is mandatory to determine whether such relationships can be established from a quantitative point of view and the outcomes strong enough to be significant to inform policies.

We acknowledge that the Ecological and Water Footprint only indirectly inform policy makers on the Habitats and Birds directives and that, most likely, only theoretical and qualitative information can currently be provided; however, the role of these indicators in informing on the pressures upon biodiversity is worth mentioning in light of the fact that more and more, in the coming years, conservation strategies will need to be coupled with strategies for addressing the underlying causes of biodiversity loss as reported in the CBD Strategic Plan for Biodiversity, 2011-2020 (CBD, 2010).

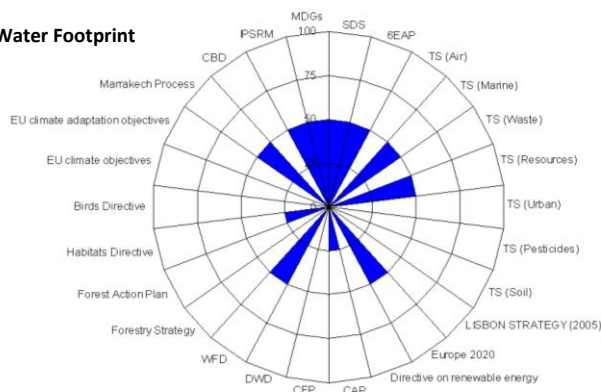
Ecological Footprint



Carbon Footprint



Water Footprint



Footprint Family

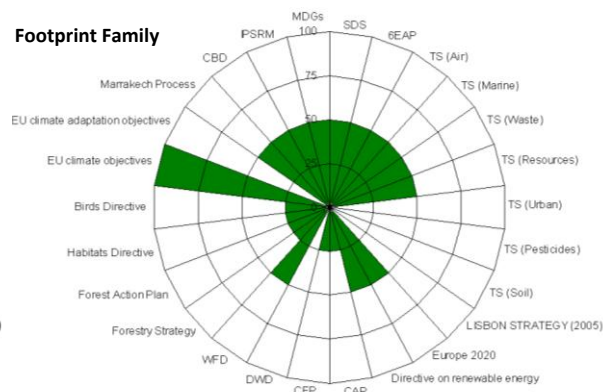


Figure 2: Indicator-Policy Radar. It summarizes the range of applicability and the depth of the assessment for each of the Footprint indicators as well as the whole Footprint Family. For any given policy, the radar highlights whether the indicator is able to address such policy *fully* (100), *sufficiently* (75), *partly* (50), *marginally* (25) or *not at all* (0).

For a more comprehensive assessment of the policy usefulness of the Footprint Family, including issues such as a) the policy fields addressed by each indicator (considering both EU specific and international environmental policies); b) what are the issues fully, partly or not at all address by each indicators; c) the complementary properties of each indicator in the Footprint Family; and d) the value added of the “Footprint Family” compared to single indicators, we recommend interested readers to review the technical report for WP 6 of the OPEN:EU Project titled “Pre-modelling analysis of the Footprint family of indicators in EU and international policy contexts” (Knoblauch and Neubauer, 2010).

Readers interested in further learning about the integrated Footprint-MRIO model that has been developed for use in the OPEN:EU Project are encouraged to read the technical report for WP 2 of the OPEN:EU Project titled “Footprint Family Technical Report” (Weinzettel et al., 2011).

Finally, readers interested to learn more about the programming and capabilities of the EUREAPA tool are encouraged to consult work, activities and technical reports for both WP4 (“EUREAPA technical report”) and WP5 (“EUREAPA development report”) of the OPEN:EU Project.

7. Appendix A: Calculation Methodologies

7.1 Ecological Footprint

The Ecological Footprint measures appropriated biocapacity, expressed in global average bioproductive hectares (see section 4.1.2 Units of measure) for cropland, grazing land, forest land, fishing grounds, built-up land and carbon uptake land (to accommodate the carbon Footprint). All manufacturing processes rely on the use of biocapacity, to provide material inputs and remove wastes at various points in the production chain. Thus all products carry with them an embodied Footprint, and international trade flows in fact can be seen as flows of appropriated biocapacity (Ewing et al., 2010b).

According to the most updated Ecological Footprint calculation methodology (Ewing et al., 2010b), for each land use type, the Ecological Footprint of consumption (EF_C) is calculated as

$$EF_C = EF_P + EF_I - EF_E \quad (\text{Eq. 1})$$

where EF_P is the Ecological Footprint of production and EF_I and EF_E are the Footprints embodied in imported and exported commodity flows, respectively. The National Footprint Accounts calculate the Footprint of apparent consumption, as data on stock changes for various commodities are generally not available. One of the advantages of calculating Ecological Footprints at the national level is that detailed production and trade data allow the Footprints of goods to be properly allocated to consumers.

Irrespective of the component we are looking at (production, import or export), Ecological Footprint, EF , in global hectares, is calculated as

$$EF = \frac{P}{Y_N} \cdot YF \cdot EQF \quad (\text{Eq. 2})$$

where P is the amount of a product harvested or CO_2 emitted, Y_N is the national average yield for P , and YF and EQF are the yield factor and equivalence factor, respectively, for the land use type in question. Yield factors serve the purpose of scaling national to global productivity within a given land use type, while equivalence factors are used to weight the different land use types based on their relative bioproductivity (see section 4.1.2 Units of measure).

Ecological Footprint assessments aim to measure appropriation of biocapacity by final demand, but the Footprint is tallied at the point of primary harvest or waste uptake. Thus, tracking the embodied Footprint in derived products is essential in assigning the Footprint of production to the end uses it serves.

Primary and derived goods are related by product specific extraction rates. The extraction rate for a derived product, $EXTR_D$, is used to calculate its effective yield as follows:

$$Y_D = Y_P \cdot EXTR_D \quad (\text{Eq. 3})$$

where Y_p and Y_D are the yield for the primary product and the effective yield for the derived product, respectively.

Usually, $EXTR_D$ is simply the mass ratio of derived product to primary input required. This ratio is known as the technical conversion factor (FAO, 2000) for the derived product, denoted TCF_D below. There are few cases where multiple derived products are created simultaneously from the same primary product. Soybean oil and soybean cake, for example, are both extracted simultaneously from the same primary product, in this case soybean. Summing the primary product equivalents would lead to double counting, so the Footprint of the primary product must be shared between the simultaneously derived goods. The extraction rate for a derived good D is given by

$$EXTR_D = \frac{TCF_D}{FAF_D} \quad (\text{Eq. 4})$$

where FAF_D is the Footprint allocation factor. This allocates the Footprint of a primary product between simultaneously derived goods according to the TCF-weighted prices. The prices of derived goods represent their relative contributions to the incentive for the harvest of the primary product. The equation for the Footprint allocation factor of a derived product is

$$FAF_D = \frac{TCF_D V_D}{\sum TCF_i V_i} \quad (\text{Eq. 5})$$

where V_i is the market price of each simultaneous derived product. For a production chain with only one derived product, then, FAF_D is 1 and the extraction rate equals the technical conversion factor.

While the Ecological Footprint quantifies 'human demand', the biocapacity acts as an ecological benchmark and quantifies 'nature supply' for resource production and waste disposal. A country's biocapacity (BC_C) is therefore calculated as the sum of the regenerative capacity available on each land use type (BC), which is in turn calculated as follows:

$$BC = A \cdot YF \cdot EQF \quad \text{with} \quad BC_C = \sum BC \quad (\text{Eq. 6})$$

where A is the area available for a given land use type and YF and EQF are the yield factor and equivalence factor, respectively, for the land use type in question.

As reported in Ewing et al. (2010b), a country's yield factor YF_L , for any given land use type L , is given by

$$YF_L = \frac{\sum_{i \in U} A_{W,i}}{\sum_{i \in U} A_{N,i}} \quad (\text{Eq. 7})$$

where U is the set of all usable primary products that a given land use type yields and $A_{W,i}$ and $A_{N,i}$ are the areas necessary to furnish that country's annually available amount of product i at world and national yields, respectively. These areas are calculated as

$$A_{N,i} = \frac{P_i}{Y_N} \text{ and } A_{W,i} = \frac{P_i}{Y_W} \quad (\text{Eq. 8})$$

where P_i is the total national annual growth of product i and Y_N and Y_W are national and world yields, respectively. Thus $A_{N,i}$ is always the area that produces i within a given country, while $A_{W,i}$ gives the equivalent area of world-average land yielding i .

Most land use types in the Ecological Footprint provide only a single primary product, such as wood from forest land or grass from pasture land. For these, the equation for the yield factor simplifies to

$$YF_L = \frac{Y_N}{Y_W} \quad (\text{Eq. 9})$$

7.2 Carbon Footprint

The prevailing method for national Carbon Footprint accounting is environmentally extended multi-regional input-output analysis (EE-MRIO). In an EE-MRIO model, national input-output tables, representing financial transactions between economic sectors within a country, and trade flow tables, showing the value of exports and imports by country and economic sectors, are linked together in one coherent accounting framework. This core of a combined, multi-national ("multi-regional") inter-industry transaction matrix is furthermore linked to primary (financial) inputs on one hand and final demand (consumer expenditure, capital investment, etc.) on the other hand.

Data for input-output tables are collected by national statistical offices from individual companies, aggregated into sectors. Inputs to production are estimated based on the average inputs to a sector. The benefit of an input-output model is that it tracks the entire supply chain throughout the economy. EE-MRIO tracks impacts, e.g. GHG emissions, along supply chains crossing national borders.

MRIO modelling originated in regional economics to highlight differences in production technologies between sub-national regions within a country, and was only later extended to the multi-national case (see e.g. Leontief and Strout, 1963; Leontief, 1974; Miller and Blair, 2009, Chapter 3). True (full) multi-regional models include trade flow matrices between all countries or regions in the model and are therefore able to track international supply chains across several trading partners as well as feedback effects (Miller, 1969)¹⁶.

Environmental extensions such as pollutants emitted by industrial sectors can be added to the MRIO framework as in the case for the Carbon Footprint. For the technical specification of an environmentally extended MRIO model see e.g. Lenzen et al., 2004; Turner et al., 2007 or Peters and Hertwich, 2009. Environmental MRIO analysis can then be applied to re-allocate these environmental factors to consumers' demand for final products in any country. The result is a set of 'multipliers' that show the total

¹⁶ See Lenzen et al. (2004) and Munksgaard et al. (2009) for a distinction between uni- and multi-directional trade analysis.

environmental load of one unit of final demand and therefore constitute a multi-region life-cycle inventory of a financial transaction up to the point of sale to the final consumer.

This can be used to estimate environmental impacts embodied in consumption of a country or in international trade. When the input-output formalism allocates these emissions to consumption (final demand) in all countries (or regions) in the model, national (or regional) Carbon Footprint values are obtained. Wiedmann et al. (2007, 2009) provides a review of MRIO models used for consumption-based emission and resource accounting.

The following mathematical specification is based on Peters (2008a). According to the standard IOA framework, an accounting balance of monetary flows for one country or region r can be written as (United Nations, 1999):

$$X^r = A^r x^r + y^r + e^r - m^r \quad (\text{Eq. 10})$$

where x is the vector of total economic output in each sector and y is a vector with each element representing final consumption by households, governments, and capital investment in each industry sector (domestic plus imports); e is the vector of total exports, m is the vector of total imports (for both intermediate and final consumption); A is a matrix of intermediate consumption where the columns represent the input from each industry (domestic plus imports) to produce one unit of output for each domestic industry, and Ax is the vector of total intermediate consumption. This balance equation holds in all regions r .

Removing imports from the system and expressing exports as bilateral trade from region r to region s , equation 10 becomes:

$$X^r = A^{rr} x^r + y^{rr} + \sum_s e^{sr} \quad (\text{Eq. 11})$$

The final consumption y^r has been decomposed as:

$$y^r = y^{rr} + \sum_s e^{sr} \quad (\text{Eq. 12})$$

and the intermediate consumption A^r has been decomposed as:

$$A^r = A^{rr} + \sum_s A^{sr} \quad (\text{Eq. 13})$$

where A^{rr} represents the industry requirements of domestically produced products and A^{sr} represents the industry requirements of imported products from region s to region r (not included in equation 12).

Adding direct GHG emissions from industries F and solving equation 11 for x^r , the domestic Carbon Footprint f_{dom}^r of region r (not including imports yet) can be calculated as:

$$f_{dom}^r = F^r x^r = F^r (I - A^{rr})^{-1} \left(y^{rr} + \sum_s e^{sr} \right) \quad (\text{Eq. 14})$$

where I is the identity matrix and F^r is a row vector with each element representing the direct GHG emissions per unit industry output. The domestic Carbon Footprint f^r relates to the production of both the domestic component of final consumption and total exports.

We now add trade to the model. An MRIO model distinguishes between trade that goes to intermediate and final consumption. This can be performed by splitting the bilateral trade data into final consumption, y , and intermediate consumption, z :

$$e^{rs} = z^{rs} + y^{rs} \quad (\text{Eq. 15})$$

The exports to industry can be expressed as

$$z^{rs} = A^{rs} x^s \quad (\text{Eq. 16})$$

where x^s represents the output in region s . By substitution of the decomposed exports into eq. 11 the standard MRIO model results in:

$$X^r = A^{rr} x^r + y^{rr} + \sum_{s \neq r} A^{rs} x^s + \sum_{s \neq r} y^{rs} \quad (\text{Eq. 17})$$

By considering the equation in each country/region the matrix form is obtained and each sub-matrix in the block-matrix represents the interactions between different countries.

A^{rs} is the trade between industries from region r to region s and y^{rs} is the trade from industries in region r to final consumers in region s . The methods used to construct A^{rs} and y^{rs} from e^{rs} are described in Peters (2008a).

The final consumption in each region r is given by the vector

$$c^r = \begin{pmatrix} y^{1r} \\ y^{2r} \\ y^{3r} \\ \vdots \\ y^{mr} \end{pmatrix} \quad (\text{Eq. 18})$$

where y^{rr} is the final consumption produced domestically and y^{rs} is imported final consumption.

Using the MRIO model (solving for x^r) the total national Carbon Footprint f^r (also called consumption-based national emissions inventory) for region r is constructed using the final consumption vector:

$$f^r = F(I - A)^{-1} c^r \quad (\text{Eq. 19})$$

where F is the vector of regional emission intensities in all regions and A represents the block-A matrix that can be derived by eq. 19. A global MRIO model is closed, i.e. total global emissions of production and consumption are the same.

The consumption-based accounting ('Footprint') perspective supported by MRIO modelling therefore has implications on global climate policy, as it alters the amount of emissions attributed to a country, increasing the responsibility for reducing emissions of those countries that are net-importers of embodied emissions (most industrialised countries) and decreasing the responsibilities for net-exporters (most lower income countries) (Bruckner et al., 2010; Peters, 2008a; Peters and Hertwich, 2008a, Hertwich and Peters, 2009).

The Carbon Footprint of a single product (CF_p) can be calculated as follows:

$$CF_p = \sum_{i=1}^n \sum_{j=1}^n GWP_i * Q_{i,j} \quad (\text{Eq. 20})$$

where GWP is the global warming potential of each greenhouse gas i considered and Q is the amount of each GHG i for each input j considered.

7.3 Water Footprint

The methodology for the calculation of one single 'process step' forms the basis of all kind of Water Footprint accounts. The Water Footprints of products, nations or businesses are the sum of the Water Footprint of the processes associated with product, nation or business. The relation between the different sorts of Water Footprints is as follows:

1. The Water Footprint of a product = the sum of the Water Footprints of the process steps taken to produce the product (considering the whole production and supply chain).
2. The Water Footprint of a consumer = the sum of the Water Footprints of all products consumed by the consumer.
3. The Water Footprint of a community = the sum of the Water Footprints of its members.
4. The Water Footprint of national consumption = the sum of the Water Footprints of its inhabitants.
5. The Water Footprint of a business = the sum of the Water Footprints of the final products that the business produces.
6. The Water Footprint within a geographically delineated area (e.g. a municipality, province, state, nation, catchment or river basin) = the sum of the process Water Footprints of all processes taking place in the area.

In this section, we first describe the calculation methodology for the Water Footprint of a single process. Then, the Water Footprint calculation of growing a crop or tree is given as the agricultural and forestry sectors are major water consuming sectors. Finally, the accounting procedure for other sorts of Water Footprints (product Water Footprint, national Water Footprint and business Water Footprint) is described. Further details on the Water Footprint methodology can be found in Hoekstra et al. 2009.

Water Footprint of a process step

The total Water Footprint of a single 'process step' is the sum of the green, blue and grey components:

$$WF_{proc} = WF_{proc,green} + WF_{proc,blue} + WF_{proc,grey} \quad (\text{Eq. 21})$$

The blue Water Footprint component of a process is calculated as:

$$WF_{proc,blue} = \text{BlueWaterEvaporation} + \text{BlueWaterIncorporation} + \text{LostReturnflow} \quad (\text{Eq. 22})$$

The term 'consumptive water use' refers to one of the following four cases: water evaporates; water is incorporated into the product; water does not return to the same catchment area, e.g. it is returned to another catchment area or the sea; water does not return in the same period, e.g. it is withdrawn in a scarce period and returned in a wet period.

The green Water Footprint is the volume of rainwater consumed during the production process. This is particularly relevant for agricultural and forestry products (products based on crops or wood), where it refers to the total rainwater evapotranspiration (from fields and plantations) plus the water incorporated into the harvested crop or wood. The green Water Footprint in a process step is equal to:

$$WF_{proc,green} = \text{GreenWaterEvaporation} + \text{GreenWaterIncorporation} \quad (\text{Eq. 23})$$

The grey Water Footprint is calculated by dividing the pollutant load (L , in mass/time) by the difference between the ambient water quality standard for that pollutant (the maximum acceptable concentration c_{max} , in mass/volume) and its natural concentration in the receiving water body (c_{nat} , in mass/volume).

$$WF_{proc,grey} = \frac{L}{c_{max} - c_{nat}} \quad (\text{Eq. 24})$$

The critical load (L_{crit} , in mass/time) is the load of pollutants that will fully consume the assimilation capacity of the receiving water body. It can be calculated by multiplying the runoff of the water body (R , in volume/time) by the difference between the maximum acceptable and natural concentration:

$$L_{crit} = R \times (c_{max} - c_{nat}) \quad (\text{Eq. 25})$$

In the case that pollutants are part of an effluent discharged into a water body, the pollutant load can be calculated as the effluent volume ($Effl$, in volume/time) multiplied by the difference between the concentration of the pollutant in the effluent (c_{effl} , in mass/volume) and its natural concentration in the receiving water body (c_{nat} , in mass/volume). The grey Water Footprint can then be calculated as follows:

$$WF_{proc,grey} = \frac{L}{c_{max} - c_{nat}} = \frac{Effl \times (c_{effl} - c_{nat})}{c_{max} - c_{nat}} \quad (\text{Eq. 26})$$

For thermal pollution, the grey Water Footprint is now calculated as the difference between the temperature of an effluent flow and the receiving water body ($^{\circ}\text{C}$) times the

effluent volume (volume/time) divided by the maximum acceptable temperature increase (°C).

$$WF_{proc, grey} = \frac{Effl \times \Delta T_{effl}}{\Delta T_{max}} = \frac{Effl \times (T_{effl} - T_{nat})}{T_{max} - T_{nat}} \quad (\text{Eq. 27})$$

The grey Water Footprint is determined by the pollutant that is most critical, i.e. the one that is associated with the largest pollutant-specific grey Water Footprint.

Calculation of the green, blue and grey Water Footprint of growing a crop or tree

The agricultural and forestry sectors are major water consuming sectors, products that involve agriculture or forestry in their production system will often have a significant Water Footprint.

The green component in the process Water Footprint of growing a crop or tree ($WF_{proc, green}$, m³/ton) is calculated as the green component in crop water use (CWU_{green} , m³/ha) divided by the crop yield (Y , ton/ha). The blue component ($WF_{proc, blue}$, m³/ton) is calculated in a similar way:

$$WF_{proc, green} = \frac{CWU_{green}}{Y} \quad (\text{Eq. 28})$$

$$WF_{proc, blue} = \frac{CWU_{blue}}{Y} \quad (\text{Eq. 29})$$

The grey component in the Water Footprint of growing a crop or tree ($WF_{proc, grey}$, m³/ton) is calculated as the chemical application rate per hectare (AR , kg/ha) times the leaching fraction (α) divided by the maximum acceptable concentration (c_{max} , kg/m³) minus the natural concentration for the pollutant considered (c_{nat} , kg/m³) and then divided by the crop yield (Y , ton/ha).

$$WF_{proc, grey} = \frac{(\alpha \times AR) / (c_{max} - c_{nat})}{Y} \quad (\text{Eq. 30})$$

The green and blue components in crop water use (CWU , m³/ha) are calculated by accumulation of daily evapotranspiration (ET , mm/day) over the complete growing period:

$$CWU_{green} = 10 \times \sum_{d=1}^{lgp} ET_{green} \quad (\text{Eq. 31})$$

$$CWU_{blue} = 10 \times \sum_{d=1}^{lgp} ET_{blue} \quad (\text{Eq. 32})$$

in which ET_{green} represents green water evapotranspiration and ET_{blue} blue water evapotranspiration. The factor 10 is meant to convert water depths in mm into water volumes per land surface in m³/ha. The summation is done over the period from the day of planting (day 1) to the day of harvest (lgp stands for length of growing period in days).

Water Footprint of a product

The Water Footprint of a product can be calculated in two alternative ways: with the chain-summation approach or the step-wise accumulative approach.

The chain-summation approach

This can only be applied in the case where a production system produces only one output product. In this particular case, the Water Footprints that can be associated with the various process steps in the production system can all be fully attributed to the product that results from the system.

In this simple production system, the Water Footprint of product p (volume/mass) is equal to the sum of the relevant process Water Footprints divided by the production quantity of product p :

$$WF_{prod}[p] = \frac{\sum_{s=1}^k WF_{proc}[s]}{P[p]} \quad (\text{Eq. 33})$$

in which $WF_{proc}[s]$ is the process Water Footprint of process step s (volume/time), and $P[p]$ the production quantity of product p (mass/time).

The step-wise accumulative approach

This approach is a generic way of calculating the Water Footprint of a product based on the Water Footprints of the input products that were necessary in the last processing step to produce that product and the process Water Footprint of that processing step.

The Water Footprint of output product p is calculated as:

$$WF_{prod}[p] = \left(WF_{proc}[p] + \sum_{i=1}^y \frac{WF_{prod}[i]}{f_p[p,i]} \right) \times f_v[p] \quad (\text{Eq. 34})$$

in which $WF_{prod}[p]$ is the Water Footprint (volume/mass) of output product p , $WF_{prod}[i]$ the Water Footprint of input product i and $WF_{proc}[p]$ the process Water Footprint of the processing step that transforms the y input products into the z output products, expressed in water use per unit of processed product p (volume/mass). Parameter $f_p[p,i]$ is a so-called 'product fraction' and parameter $f_v[p]$ is a 'value fraction'.

The product fraction of an output product p that is processed from an input product i ($f_p[p,i]$, mass/mass) is defined as the quantity of the output product ($w[p]$, mass) obtained per quantity of input product ($w[i]$, mass):

$$f_p[p,i] = \frac{w[p]}{w[i]} \quad (\text{Eq. 35})$$

The value fraction of an output product p ($fv[p]$, monetary unit/monetary unit) is defined as the ratio of the market value of this product to the aggregated market value of all the outputs products ($p=1$ to z) obtained from the input products:

$$f_v[p] = \frac{price[p] \times w[p]}{\sum_{p=1}^z (price[p] \times w[p])} \quad (\text{Eq. 36})$$

in which $price[p]$ refers to the price of product p (monetary unit/mass).

Water Footprint of national consumption

The Water Footprint of the consumers in a nation ($WF_{cons,nat}$) has two components: the internal Water Footprint and the external Water Footprint.

$$WF_{cons,nat} = WF_{cons,nat,int} + WF_{cons,nat,ext} \quad (\text{Eq. 37})$$

The internal Water Footprint of national consumption ($WF_{cons,nat,int}$) is defined as the use of domestic water resources to produce goods and services consumed by the national population. It is the sum of the Water Footprint within the nation ($WF_{area,nat}$) minus the volume of virtual-water export to other nations insofar as related to the export of products produced with domestic water resources ($V_{e,d}$):

$$WF_{cons,nat,int} = WF_{area,nat} - V_{e,d} \quad (\text{Eq. 38})$$

The external Water Footprint of national consumption ($WF_{cons,nat,ext}$) is defined as the volume of water resources used in other nations to produce goods and services consumed by the population in the nation considered. It is equal to the virtual-water import into the nation (V_i) minus the volume of virtual-water export to other nations as a result of re-export of imported products ($V_{e,r}$):

$$WF_{cons,nat,ext} = V_i - V_{e,r} \quad (\text{Eq. 39})$$

The virtual-water export (V_e) from a nation consists of exported water of domestic origin ($V_{e,d}$) and re-exported water of foreign origin ($V_{e,r}$):

$$V_e = V_{e,d} + V_{e,r} \quad (\text{Eq. 40})$$

The virtual-water import into a nation will partly be consumed, thus constituting the external Water Footprint of national consumption ($WF_{cons,nat,ext}$), and partly be re-exported ($V_{e,r}$):

$$V_i = WF_{cons,nat,ext} + V_{e,r} \quad (\text{Eq. 41})$$

The sum of V_i and $WF_{area,nat}$ is equal to the sum of V_e and $WF_{cons,nat}$. This sum is called the virtual-water budget (V_b) of a nation.

$$\begin{aligned} V_b &= V_i + WF_{area,nat} \\ &= V_e + WF_{cons,nat} \end{aligned} \quad (\text{Eq. 42})$$

Calculation of business Water Footprint

The Water Footprint of a business unit (WF_{bus} , volume/time) is calculated by adding the operational Water Footprint of the business unit and its supply-chain Water Footprint:

$$WF_{bus} = WF_{bus,oper} + WF_{bus,sup} \quad (\text{Eq. 43})$$

Both components consist of a Water Footprint that can be directly associated with the production of the product in the business unit and an overhead Water Footprint:

$$WF_{bus,oper} = WF_{bus,oper,inputs} + WF_{bus,oper,overhead} \quad (\text{Eq. 44})$$

$$WF_{bus,sup} = WF_{bus,sup,inputs} + WF_{bus,sup,overhead} \quad (\text{Eq. 45})$$

The operational Water Footprint is the amount of freshwater used at a specific business unit, i.e. the direct freshwater use. The supply-chain Water Footprint is the amount of freshwater used to produce all the goods and services that form the input of production at the specific business unit, i.e. the indirect freshwater use. The overhead Water Footprint is defined as the Water Footprint pertaining to the general activities for running a business and to the general goods and services consumed by the business. The term 'overhead Water Footprint' is used to identify water consumption that is necessary for the continued functioning of the business but that does not directly relate to the production of one particular product.

8. Appendix B: data and sources

8.1 Ecological Footprint

Data from international statistical databases (e.g., UN FAO, UN Comtrade, IEA, etc.) are used by Global Footprint Network to calculate a set of accounts known as the National Footprint Accounts, reporting both Footprint and biocapacity values for more than 150 countries around the world (Kitzes et al., 2008, 2009).

The National Footprint Accounts utilize approximately 50 million data points, primarily based on international datasets published by the United Nations Food and Agriculture Organization (FAOSTAT), United Nations Commodity Trade Statistics Database (UN Comtrade), International Energy Agency (IEA), and Global Agro-Ecological Zones 2000 (IIASA and FAO, 2000).

Production statistics for agricultural, forestry and fisheries primary and derived products¹⁷ are obtained from the FAO ProdSTAT, FAO ForesSTAT, and FAO FishSTAT Statistical Database, while import and export statistics for the same set of products are obtained from FAO TradeSTAT. Data are presented in the FAO commodity classifications and HS+ commodity classifications where possible. HS+ is an extended version of HS 2002 created by FAO to provide increased resolution and harmonize the FAO and HS commodity classifications. Production statistics for carbon dioxide emissions are obtained from the International Energy Agency¹⁸, while CO₂ emissions embodied in traded goods are estimated starting from UN Comtrade data on international commodities trade and Global Footprint Network's internal embodied energy library.

Yields are based on regeneration rates for all land use types except cropland; cropland yields are calculated for each crop using the ratio of crops produced and harvest area. Grazing land yields are the average above-ground net primary production for grassland. Forest yields are calculated using net annual increment which is the gross annual increment less that of the natural losses to the growing stock due to natural mortality, disease, etc. Fishing grounds yields are calculated for each species as the product of the inverse primary production rate and available primary productivity (Kitzes et al. 2009).

This data is then used in the National Footprint Accounts framework to calculate the demand on each of the six considered land types (cropland, grazing land, fishing ground, forest land, built-up land, and carbon uptake land to accommodate the carbon Footprint). This allows for the observation and measurement of the human demand on the biosphere and its ecosystem composition.

For each country, the aggregate total Ecological Footprint is then calculated by adding up the demand on each land type and used as a communication tool and to inform policy makers. Total National Ecological Footprint values in the NFA are thus analogous to GDP in the economic System of National Accounts and the availability of a single calculated figure allows the Ecological Footprint to measure and aggregate phenomena that are otherwise difficult to quantify (Schaefer et al., 2006).

¹⁷ In the National Footprint Accounts, 2009 Edition (NFA 2009), there is production data for 164 crop products, 41 livestock products, 33 forest products and 1439 fish products expressed in tonnes produced per year.

¹⁸ In the NFA 2009, there is emission data for 45 products and categories expressed in tonnes of carbon dioxide emissions per year.

8.2 Carbon Footprint

The main data elements of a consistent multi-national framework for consumption-based Carbon Footprint accounting are:

- National economic accounts indentifying financial transactions between producing and consuming entities (supply, use, input-output tables);
- International trade statistics covering bilateral trade in goods and services in monetary (and possibly physical) units; and
- Environmental accounts providing GHG emissions data by economic sector and country.

Compilations of supranational data from (national) economic and environmental accounts provide a solid basis for the data required by an EE-MRIO model. Standardised input-output datasets are available from Eurostat, OECD, and GTAP; trade data are compiled by the UN, OECD, GTAP, and others; and environmental data are provided by IEA, GTAP, and others. The latter ones, however, only comprise GHG emissions and land use data (e.g. GTAP) which is the reason why national environmental accounts (NAMEA, SEEA) are irreplaceable when it comes to providing additional environmental pressure and impact data. National economic and environmental accounts also provide more detail for GHG sectoral data and are therefore in most cases superior to the aforementioned supranational sources.

8.3 Water Footprint

In the current national Water Footprint accounts, data on population are drawn from the World Bank online database (World Bank, 2004). In cases where the population data are not available in this database, FAO (FAOSTAT, 2009d) is used as alternative data source. Arable land data is taken from FAO (FAOSTAT, 2009d). Data on total renewable water resources and water withdrawals per country are taken from FAO (FAO, 2009e). Data on gross national income, gross domestic production, and added value in industrial sectors are drawn from the World Bank's on-line database (World Bank, 2004). Data on international trade in agricultural products have been taken from the Personal Computer Trade Analysis System (PC-TAS, 2004) of the International Trade Centre. Data on international trade in industrial products have been taken from the World Trade Organization (WTO, 2004a, b).

The following data sources are given for the calculation of the Water Footprint of growing a crop (Hoekstra et. al, 2009):

- Climate data: The calculation should be done using climate data from the nearest and most representative meteorological station(s) located near the crop field considered or within or near the crop-producing region considered. For regions with more than one climate station, one can make calculations for each station and weigh the outputs. The climate database CLIMWAT 2.0 (FAO, 2009a) provides the climatic data needed in the appropriate format required by the CROPWAT 8.0 model. The database does not provide data for specific years, but 30-year averages. Another source is LocClim 1.1 (FAO, 2005), which provides estimates of average climatic conditions at locations for which no observations are available. One can also use grid-based climate databases. Monthly values of major climatic parameters with a spatial resolution of 30 arc minute can be obtained from CRU TS-2.1 through the CGIAR-CSI GeoPortal (Mitchell and Jones, 2005). The US

National Climatic Data Centre provides daily climatic data for a large number of stations globally (NCDC, 2009). In addition, FAO provides through its GeoNetwork website long-term average precipitation and reference evapotranspiration with a spatial resolution of 10 arc minute (FAO, 2009g).

- Crop parameters: Crop coefficients and cropping pattern (planting and harvesting dates) can best be taken from local data. The crop variety and suitable growing period for a particular type of crop largely depends upon the climate and many other factors such as local customs, traditions, social structure, existing norms and policies. Therefore, the most reliable crop data are the data obtained from local agricultural research stations. Global databases that can be used are: Allen et al. (1998, Tables 11-12), FAO (2009b), USDA (1994). FAO's online Global Information and Early Warning system (GIEWS) provides crop calendars for major crops for developing countries. One can access the zipped crop calendar images for each continent directly from the web (FAO, 2009f).
- Crop maps: Crop harvest areas and yields for 175 crops at 5 arc minute grid cell resolution are available from the website of the Land Use and Global Environmental Change research group, Department of Geography and Earth System Science Program, McGill University (Monfreda et al., 2008).
- Soil maps: ISRIC-WISE provides a global data set for derived soil properties both at 5 arc minute and 30 arc minute resolution (Batjes, 2006). In addition, the FAO GeoNetwork website provides maximum available soil moisture data at 5 arc minute resolution (FAO, 2009h). When applying the 'irrigation schedule option' in the CROPWAT model, one needs soil data; if no soil data are available we advise to choose 'medium soil' as a default.
- Irrigation maps: The Global Map of Irrigation Areas (GMIA) version 4.0.1 (Siebert et al., 2007) with a spatial resolution of 5 arc minute defines areas equipped for irrigation. Irrigation maps for 26 major crops both at 5 and 30 arc minute resolutions can be obtained from University of Frankfurt website (Portmann et al., 2008, 2009). These data also provide rain-fed crop growing areas for the same 26 crops.
- Fertilizers application rates: Preferably one uses local data. A useful global database is FertiStat (FAO, 2009c). IFA (2009) provides annual fertilizer consumption per country. Heffer (2009) provides fertilizer use per crop for major crop types and major countries.
- Pesticides application rates: Preferably one uses local data. NASS (2009) provides an online database for the USA with chemical use per crop. CropLife Foundation (2006) provides a database on pesticides use in the USA. Eurostat (2007) gives data for Europe.
- Leaching fraction: No databases available. One will have to work with experimental data from field studies and make rough assumptions. One can assume 10% for nitrogen fertilizers, following Chapagain et al. (2006b).
- Ambient water quality standards: Preferably use local standards as regulated in legislation. If no ambient water quality standards are available and the water body is to be suitable for drinking, one can decide to apply drinking water standards. See for instance EU (2000) and EPA (2005). A compilation can be found in MacDonald et al. (2000).
- Natural concentrations in receiving water bodies: In more or less pristine rivers, one can assume that natural concentrations are equal to the actual concentrations and thus rely on long-term daily or monthly averages as measured in a nearby measuring station. For disturbed rivers, one will have to rely on historical records or model studies. For some parts of the world good studies are available; for the USA see for instance Clark et al. (2000) and Smith et al. (2003). As a reference, a global database on actual (not natural) concentrations is available through UNEP (2009). When no information is available, assume the natural concentration according to the best estimate or to be zero.

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