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:04

Carbon and Water Footprints

Concepts, Methodologies and Policy Responses

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Summary

The objective of this study is to analyse the origins and characteristics of the carbon and water footprints in order to understand their similarities and differences and to derive lessons on how society and business can adequately build on the two concepts. We compare the two concepts from a methodological point of view and discuss response mechanisms that have been developed, with the hope that experiences in one field might be able to benefit the other.

The carbon and water footprint concepts were introduced about a decade ago, simultaneously, but independently from one another. The 'carbon footprint' concept has become popular over the past few years – since, more or less, 2005 – and is currently widely accepted and used by the public and media despite its lack of scientifically accepted and universally adopted guidelines: it describes greenhouse gas emission measurement from the narrowest to the widest sense. Several calculation methods and approaches for carbon footprint accounting have been proposed and are being used. Since about 2008, 'water footprint' has also become a popular term. Although the meaning and methodology of the water footprint were well defined in the scientific literature in the early stages of its inception, there is still an immense potential for less rigorous usage of the term, similar to the fate of the carbon footprint. The ambiguity around the concept of the carbon footprint could become a problem for the water footprint concept in the near future. By drawing lessons from the history and progress of the carbon footprint and understanding the development and mechanisms of carbon footprint assessment (both accounting and response formulation), we can help reduce the risk that the water footprint will lose its strict definition, interpretation and usage.

In response to the increasing concern about climate change and global warming, governments, businesses and consumers are considering ways to reduce greenhouse gas emissions. The two main response strategies are reduction and offsetting. *Reduction* refers to undertaking activities in a less carbon-intensive way; *offsetting* refers to taking external actions to compensate for carbon footprints by means of some form of carbon capture or reduction elsewhere (by others). These strategies are applied and supported widely by business and government. However, two issues seriously challenge the effective reduction of humanity's carbon footprint. The first is the absence of a unique definition of the carbon footprint, making reduction targets and statements about carbon neutrality difficult to interpret, and leaving potential for developments to look better than they really are. The second problem is that existing mechanisms for offsetting leave room for creating externalities and rebound effects. In the case of the water footprint, the question of how to respond is still under debate, but it has been recognized that reduction and offsetting strategies can be distinguished here too. The terms 'water neutral' and 'offsetting' have been considered. The strategy of water offsetting may face the same problem as in carbon offsetting, but there is an additional problem: water footprints impact at specific locations and in specific periods of time, and offsetting can only be effective if the offsetting efforts relate to them.

Carbon footprint accounting has been promoted by companies, non-governmental organizations and private initiatives and has not been primarily driven by research. This situation has led to the concept having many definitions, methods of calculation and response formulations. Some companies are responding rapidly to formulate schemes to tout their carbon neutrality, but the response is often driven by the interest in brand and image – many businesses see benefits in using the carbon footprint as a marketing tool rather than as a tool to measure their contribution to climate change. Carbon accounting, labelling and meeting the requirements of reduction or offsetting schemes tend to become goals in themselves rather than supportive instruments to effectively mitigate climate change. Carbon offsets distract attention from the wider, systemic changes and collective political action required to tackle climate change. These insights can be helpful in the search for effective instruments that can contribute to a more efficient, sustainable and equitable use of the globe's water resources.

Global warming and reduction of greenhouse gas emissions are at the top of the environmental policy agenda today. However, the way in which the concept of the carbon footprint has been embraced and interpreted in all possible directions and the fact that reduction schemes are often ill-defined creates unnecessary additional challenges in effectively tackling environmental problems. We argue in this study that the weakness of offsetting in the case of the carbon footprint shows that applying both offsetting and neutrality in the water footprint cannot be effective. A more effective tool may well be direct water footprint reduction targets to be adopted by both government and business.

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1 Introduction

The Earth's climate is changing as a result of anthropogenic activity since the start of the industrial revolution. There is growing scientific evidence that burning fossil fuels contributes to rising temperatures and extreme weather events (Mitchell et al., 2006; Rosenzweig et al., 2001; Solomon et al., 2007). The public and decision-makers have started to recognize the need for action to mitigate global warming (Goodall, 2007). Governments, policy-makers and businesses have been urged to seek ways to reduce greenhouse gas (GHG) emissions in response to growing interest and concern about climate change over the past two decades (Bo et al., 2008; Brenton et al., 2009; Courchene and Allan, 2008; Matthews et al., 2008). This brings the need to understand what activities drive GHG emissions and how they can be effectively reduced. The 'carbon footprint' (CF) concept has become a popular tool to estimate GHG emissions related to human activities (Moss et al., 2008; Wiedmann, 2009; Wiedmann and Minx, 2007).

Climate change has received a lot of attention at international forums among politicians and business leaders in the past decade. Freshwater scarcity has recently become an important subject on the environmental agendas of governments and companies as well. Across the media, decision-makers and the public, there is much talk of a looming 'water crisis', which would have impacts on all sectors of the economy, but would primarily affect food security. Freshwater in sufficient quantity and of adequate quality is not only a prerequisite for human societies but also for natural ecosystems (Costanza and Daly, 1992). The unsustainable use of freshwater resources by humans is manifested all around the world in aquifers gradually becoming depleted, rivers running dry, and water quality deteriorating (Postel, 2000). Overexploitation of water resources for human activities affects societies but also jeopardizes the health of ecosystems. Therefore, there is a growing demand for new approaches and indicators in the field of water resources management that can help find the main drivers of unsustainability and identify solutions towards sustainable water use, satisfying increased demand for food, domestic water supply, and goods and services, but protecting vital ecosystems.

Understanding the consequences of human appropriation of freshwater resources requires an analysis of how much water is needed for human use versus how much is available, where and when (Hoekstra and Chapagain, 2008; Lopez-Gunn and Llamas, 2008). Uncovering the link between consumption and water use is vital to formulate better water governance. The term 'water footprint' (WF) was primarily formulated in the research context, to study the hidden links between human consumption and water use and between global trade and water resources management (Hoekstra, 2003). The concept helps us understand the relationships between production, consumption and trade patterns and water use and the global dimension in good water governance (Hoekstra, 2011).

The WF and CF concepts have similarities; however, their roots and intended purposes differ. The CF was formulated to quantify the contribution of various activities to climate change. The history of the WF lies in the exploration of water use along supply chains and in the search for a tool to understand the global dimension of water as a natural resource. Although each footprint has different roots and characteristics and addresses different research and policy questions, there is a tendency among practitioners in the fields of environmental policy and corporate social responsibility to treat the WF in a similar way as the CF. For example, popular terms such as 'carbon neutral' and 'carbon offsetting' are immediately adapted to 'water neutral' and 'water offsetting' without any particular attention to the appropriateness and applicability of these ideas to water. Similarly, initiatives are taken to develop water labels for products in analogy to carbon labels and to incorporate the WF into Life Cycle Assessment (LCA) for products in the same way as was done with the CF. Most notably, people have a tendency to interpret the numbers of the WF without considering their spatial and temporal characteristics as is commonly done in CF analysis. Each footprint needs to be seen within its appropriate context and interpreted with care as it is built around different research questions and tells a different story.

The objective of this study is to analyse the origins and characteristics of the carbon and water footprints in order to understand their similarities and differences and to derive lessons on how society and business can adequately build on the two concepts. We compare the two concepts from a methodological point of view and discuss response mechanisms that have been developed, with the hope that experiences in one field might be able to benefit the other.

2 Origins of the carbon and water footprint concepts

The carbon and water footprint concepts were introduced about a decade ago, simultaneously, but independently from one another. The CF arose out of the debate on climate change, as a tool to measure GHG emissions. The WF was introduced in the field of water resources management, as a tool to measure water use in relation to consumption patterns. In both cases, the terminology chosen was inspired by the ecological footprint (EF), which had been introduced in the 1990s (Rees, 1992). All footprints measure, in different ways, human appropriation of the planet's natural resources and carrying capacity (Galli et al., 2012; Giljum et al., 2011; Hoekstra, 2009) (Figure 1). The EF measures the use of bioproductive space in hectares; the WF measures the consumption and contamination of freshwater resources in cubic metres per year; and the CF measures the emission of gases that contribute to heating the planet in carbon dioxide (CO_2)-equivalents per unit of time or product. A common property of all footprints is that they can be related to specific activities, products and consumption patterns. Recently, the nitrogen footprint was introduced as a tool to measure the amount of nitrogen released into the environment in relation to consumption (Leach et al., 2012). In this report, we focus on the CF and WF.

2.1 The carbon footprint

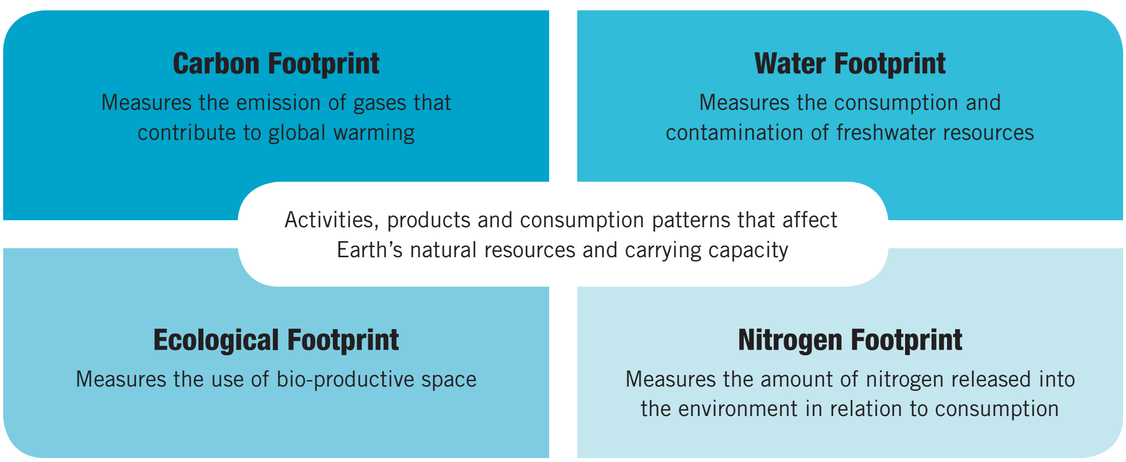
Concern about climate change started with the scientific recognition of the relationship between CO_2 emissions and global warming. The increasing worldwide interest in the causes and consequences of climate change, and in exploring ways to respond, resulted in the formation of the Intergovernmental Panel on Climate Change (IPCC) in 1988. The IPCC was the first worldwide effort to create awareness of global warming and to feed scientific insights on climate change to governments. The IPCC released its first assessment report in 1990 (Houghton et al., 1990). This report played an important role in the establishment of the United Nations Framework Convention on Climate Change (UNFCCC), an international environmental treaty with the goal of stabilizing GHG concentrations in the atmosphere at a level that prevents dangerous anthropogenic interference with the climate system. Efforts under the UNFCCC led to the Kyoto Protocol (UN, 1998), an international agreement to cut GHG emissions, with specific reduction targets by country, signed in December 1997 and entered into force in 2005. The overall goal was a collective reduction of GHG emissions by 5.2% in 2012 compared to the emission levels of 1990.

To achieve its goal, the Kyoto Protocol installed a system for emissions trading and some mechanisms to allow for offsetting GHG emissions. The system of emissions trading (the 'carbon market') allows countries to sell unused emission permits to countries that are over their targets. In addition to trade in emission permits (so-called assigned amount units [AAUs]), the Kyoto Protocol also allows trade in credits that can be obtained through various offsetting mechanisms:

1. Clean Development Mechanism (CDM): an industrialized country with an emission-reduction or emission-limitation commitment can implement emission-reduction projects in developing countries. In this way, the country earns saleable certified emission reduction credits (CERs).

Figure 1

Footprint concepts



2. Joint Implementation (JI): an industrialized or in-transition country with an emission-reduction or emission-limitation commitment can earn emission reduction units (ERUs) from an emission-reduction or emission-removal project in another industrialized country or a country in transition.
3. A mechanism that allows countries to earn removal units (RMUs) through projects that sequester CO_2, such as reforestation.

CERs, ERUs and RMUs are all expressed in CO_2-equivalents and can all be traded on the carbon market and counted by a country towards meeting its Kyoto target. Parallel to the formal carbon market under the Kyoto Protocol, in which companies, governments and other entities buy emission rights or carbon offsets to comply with caps on the total amount of CO_2 they are allowed to emit, another, voluntary, carbon market has grown, in which individuals, companies and governments purchase carbon offsets to voluntarily mitigate their GHG emissions. The CF is increasingly used as the stick by which to measure the volume of GHG emissions related to specific activities or products.

The CF can be seen as an offspring of the EF concept, which was developed by Wackernagel and Rees (1996). The EF, expressed in hectares, includes a component that represents the area required to sequester enough carbon emissions to avoid an increase in atmospheric CO_2 (Wackernagel et al., 2002). In this sense, the EF 'includes' a carbon footprint (expressed in hectares). However, the focus on land requirement in the EF is not very helpful if the interest is not so much in land requirement but more directly in the volume of CO_2 and other GHG emissions. Thus, in response to the interest of governments and companies in GHG emissions and global warming, the CF has become a modified, independent concept, expressed in terms of emitted CO_2-equivalents (East, 2008; Moss et al., 2008). It is not clear when and by whom the term CF was used for the first time, but it is found in newspaper articles as early as the year 2000 (Biddle, 2000; Sorensen, 2000). According to Safire (2008), it was an enormous BP media campaign in 2005 that gave a big boost to wider use of the concept. By then, we can also see the term being used in the scientific literature (e.g. Haefeli and Telnes, 2005). In the library of publications in the *Web of Science*, the CF is mentioned for the first time in January 2007, in a letter to *Nature* (Hammond, 2007).

Despite its popularity and use in commerce, there is no universally accepted definition of CF. Today it describes the narrowest to the widest interpretation of GHG emission measurement (East, 2008; Finkbeiner, 2009; Pandey et al., 2011; Peters, 2010; Wiedmann and Minx, 2007). Although the Kyoto Protocol does not use the term (the Protocol was conceived long before the CF), it would make some sense to be able to take this formal international agreement as a reference for the definition of the CF, because measuring GHG emissions is at the core of the Protocol. However, the Kyoto Protocol is primarily a political construct, not a scientific effort to define in a comprehensive and systematic manner how to quantify direct and indirect GHG emissions in relation to activities, products and consumption patterns (for example, it has openings to discount certain emissions that intuitively should be counted).

The CF concept has been defined mainly by private organizations and businesses (Kleiner, 2007; Wiedmann and Minx, 2007). The scientific community jumped on the train in 2007, after the concept had already started to spread in business and commerce. The most extensive survey on the definition of the CF was done by Wiedmann and Minx (2007). Their research shows that the available studies do not offer uniformity in the definitions and methodology of the CF. They suggest the definition of CF is 'a measure of the exclusive total amount of CO_2 emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product'. Pandey et al. (2011) describe the CF as 'the quantity of GHGs expressed in terms of CO_2-equivalent, emitted into the atmosphere by an individual, organization, process, product, or event from within a specified boundary'. In both cases, the definition does not allow for subtractions as a result of offsetting. In practice, however, companies tend to claim that carbon offsetting reduces their CF. Furthermore, in practice it is not always clear whether CFs communicated refer only to direct GHG emissions or indirect ones as well – scientists generally define the CF of a product as including both direct and indirect emissions. Both in science and in practice, the term is applied to different entities: single processes, whole supply chains (or all life-cycle stages) of products, individual consumers, populations, companies, industry sectors, and all sorts of activities and organizations.

2.2 The water footprint

The WF concept is primarily rooted in the desire to illustrate the hidden links between human consumption and water use and between global trade and water resources management (Hoekstra and Chapagain, 2007, 2008). The WF was developed as an analogy to the EF concept. It was first introduced by Hoekstra in 2002 to provide a consumption-based indicator of water use (Hoekstra, 2003). It is an indicator of freshwater use that shows direct *and indirect* water use of a producer or consumer. The first assessment of national WFs was carried out by Hoekstra and Hung (2002). A more extended assessment was done by Hoekstra and Chapagain (2007, 2008) and a third, even more detailed, assessment was done by Hoekstra and Mekonnen (2012*a*).

Unlike the CF, which emerged in practice, the WF was born in science. The WF started to gain broad interest from about 2008, the year in which the Water Footprint Network (WFN) was established – a network of academic institutions, governments, non-governmental organizations, companies, investors and UN institutions. One of the aims of the Network is to ensure the establishment of one common language and a coherent and scientifically sound framework for Water Footprint Assessment (WFA) that serves different interests; for example, WFA for products and companies, but also national WFA.

In 2009, about seven years after the first use of the WF concept, the WFN published the first version of the global standard for WFA. Two years later the second version was published (Hoekstra et al., 2011). This standard, which was produced in a process of consultations with organizations and researchers worldwide and subjected to scientific peer review, has comprehensive definitions and methods for WF accounting. It shows how WFs are calculated for individual processes and products, as well as for consumers, nations and businesses. It also includes methods for WF sustainability assessment and a list of WF response options. As could be expected, the definitions and methods have been challenged (Wichelns, 2011), but no alternative methodological framework has been developed (unlike in the case of the CF). The WFN standard contains definitions of the WF, of process steps, products, producers and consumers, as well as of the WF within a geographically delineated area. The WF is, in general, an indicator of freshwater appropriation, measured in terms of water volumes consumed (evaporated or incorporated into a product) and polluted per unit of time. The WF concept is further defined more specifically for a particular process or product, and for any well-defined group of consumers (e.g. individual, family, village, city, province, state, nation) or producers (e.g. public organization, private enterprise, economic sector). From a producer and consumer perspective, the WF is an indicator of both their direct and their indirect water use. The WF is a geographically and temporally explicit indicator, showing not only volumes of water use and pollution, but also their locations.

3 Comparison of the carbon and water footprints from a methodological viewpoint

The carbon and water footprint concepts complement each other, addressing different environmental issues: climate change and freshwater scarcity. Although there are similarities in the way both footprints are defined and calculated, they differ in important ways as well (Table 1). The location and timing within the year of GHG emissions, for example, are not relevant, whereas location and timing of water consumption and pollution matter critically. It is important to understand the similarities and differences between the two footprints for formulation of wise policy responses. This understanding can help decision-makers recognize to what extent the type of mitigation policies that have been formulated for one footprint can be applied to the other.

Table 1

Comparison of carbon and water footprints

	CARBON FOOTPRINT (CF)	WATER FOOTPRINT (WF)
WHAT IS MEASURED	The anthropogenic emission of greenhouse gases (GHG).	The human appropriation of freshwater resources in terms of volumes of water consumed and polluted.
UNIT OF MEASUREMENT	Mass of carbon dioxide (CO_2)-equivalents per unit of time or per unit of product.	Water volume per unit of time or per unit of product.
SPATIOTEMPORAL DIMENSION	Timing within the year and place of emissions are not specified. It does not matter where and when carbon emissions occur; carbon emission units are interchangeable.	WFs are specified in time and by location. It matters where and when a WF occurs; WF units are not interchangeable. For some uses, total/average WFs are shown, thus leaving out spatiotemporal specifications.
FOOTPRINT COMPONENTS	CF per type of GHG: CO_2, CH_4, N_2O, HFC, PFC, and SF_6. Emissions per type of gas are weighted by their global warming potential before adding.	Blue, green and grey WF. If added, the three components are added without weighting.
ENTITIES FOR WHICH THE FOOTPRINT CAN BE CALCULATED	Processes, products, companies, industry sectors, individual consumers, groups of consumers, geographically delineated areas.	Processes, products, companies, industry sectors, individual consumers, groups of consumers, geographically delineated areas.
CALCULATION METHODS	Bottom-up approach: • For processes, products and small entities • The method of Life Cycle Assessment (LCA) Top-down approach: • For sector, national and global studies • The method of Environmentally Extended Input-Output Analysis (EE-IOA) Hybrid approach: • LCA and EE-IOA for products, nations, organizations	Bottom-up approach: • For processes, products and businesses, but also for sector, national and global studies • The method of bottom-up accounting in Water Footprint Assessment (WFA) • For products, the accounting along supply chains in WFA is similar to the accounting in the Life Cycle Inventory stage of LCA studies Top-down approach: • For sector, national and global studies • The method of top-down accounting in WFA, which is based on drawing national virtual water trade balances • The method of EE-IOA is used as an alternative
SCOPE	1. Direct emissions 2. Indirect emissions from electricity used 3. Other indirect emissions	Always includes direct and indirect WF.
SUSTAINABILITY OF THE FOOTPRINT	Additional information is required to assess the sustainability of the CF. For the planet as a whole, a maximum allowable GHG concentration needs to be estimated, which needs to be translated to a CF cap. For specific processes and products, CF benchmarks can be used.	Additional information is required to assess the sustainability of the WF. Per catchment area, freshwater availability and waste assimilation capacity need to be estimated, which form a WF cap for the catchment. For specific processes and products, WF benchmarks can be used.

3.1 Environmental pressure indicators

Both the CF and the WF are 'pressure indicators' (Rotmans and De Vries, 1997; UNEP, 2012). Environmental pressure indicators measure the human use of natural resources and the anthropogenic emission of compounds into the environment, but they do not show the resulting change in the environment. The CF, for instance, shows GHG emissions, not the resultant higher GHG concentrations in the atmosphere or the subsequent changes in temperature, evaporation, precipitation or sea level. The WF shows the human consumption and contamination of

freshwater resources, not the resultant changes in runoff and water quality in rivers and aquifers. As pressure indicators, the CF and WF show neither resultant environmental changes nor final impacts of those environmental changes on human beings (e.g. health) and ecosystems (e.g. biodiversity), but they are still useful measures of pressure that humans put on the environment for policymakers working to address overexploitation of natural resources and the planet's carrying capacity. Reduction strategies concerning CF and WF fit within policy aimed to mitigate the causes of environmental change and subsequent societal and ecological impacts. CF reduction, for example, fits within a policy of climate change mitigation. For climate change *adaptation*, other measures and indicators would need to be used. Similarly, WF reduction suits a policy to lessen water scarcity and water quality deterioration. For *coping* with increased water scarcity and contaminated water, other measures and indicators are better suited.

3.2 Units of measurement

The CF is expressed in mass units (e.g. kg or tonnes) per unit of time (generally per year). The CF of a product is expressed in mass units per unit of product. In cases in which only CO_2 is included in the calculation, the unit is kg CO_2; if other GHGs are included, the unit is kg CO_2-equivalents (CO_2-e). CO_2-equivalents are calculated by multiplying the various GHG emissions by their 100-year global warming potential. In most cases, the six GHGs identified by the Kyoto Protocol are included in the analysis: CO_2, CH_4, N_2O, HFC, PFC and SF_6. However, there is no common understanding and agreement of which gases should be included in CF studies (East, 2008; Kleiner, 2007). The selection of gases depends on the standard followed and the scope and type of the CF study. Although some studies suggest to include only CO_2 (Wiedmann and Minx, 2007), the common understanding and direction in CF calculations is to include all six Kyoto Protocol gases (Pandey et al., 2011; Peters, 2010).

The WF is measured in terms of water volume (e.g. L or m^3) per unit of time (e.g. day, month, year). A product WF is expressed as a water volume per unit of product. The amount of product can be measured in various ways; for example, in terms of mass, volume, number of pieces, monetary value or energy content. Mekonnen and Hoekstra (2012) quantify and compare, for instance, the water footprint of various crop and animal products in terms of L per kg, L per kcal, L per g of protein, and L per g of fat content.

3.3 Spatial and temporal dimensions

When determining CFs, GHG emissions are usually estimated with the help of emission factors. Emission factors are available for a wide range of processes (WRI and WBCSD, 2004). Most CF studies are based on global average data on emissions per unit of good or service. However, national emission factors have also been introduced to reflect divergent local characteristics (Solomon et al., 2007). WFs provide spatiotemporally explicit information on how water is appropriated for various human purposes. In WF accounting, the approach is to use local productivities (Mekonnen and Hoekstra, 2011, 2012). Obviously, at the global level it does not matter whether footprint analysis is carried out on the basis of local or global average productivities, because adding the results obtained with local data will yield the same global result as an analysis based on global average data. But on a national level, the result will differ when local productivities are used instead of global averages.

It does not matter where and when carbon emissions occur; carbon emission units are therefore interchangeable. This is fundamentally different for the WF: it matters where and when a WF occurs. WF units are therefore not interchangeable. This is particularly relevant in the discussion about offsetting. For example, the WF in one catchment cannot be compensated for by offsetting activities to reduce the WF in another catchment.

3.4 Footprint components

The CF comprises as many components as GHGs that have been included in the analysis. The emissions per type of gas are weighted by their global warming potential. In contrast, the WF always consists of three components:

- **Blue WF:** The consumption of 'blue' water resources (surface water and groundwater).
- **Green WF:** The consumption of 'green' water resources (rainwater stored in the soil as soil moisture).
- **Grey WF:** This 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., 2011).

'Consumption' refers to the loss of water from the available ground–surface water body in a catchment area, which happens when water evaporates, is incorporated into a product, or is transported to another catchment area or the sea.

The WF is often presented as one aggregate number; in that case, the three WF components are added without weighting. It has been recognized that although this approach may be sufficient for awareness raising, for the purpose of policy formulation it is essential to clearly distinguish the three WF components. In its definitive form, the WF is a multidimensional indicator of water use, explicitly showing water consumption (green and blue WF) and pollution (grey WF) as a function of space and time.

Some researchers from the LCA community have proposed adding WF components after multiplying each with a local weighting factor to account for differences in local impact, thus obtaining 'litres water-equivalent' (Pfister and Hellweg, 2009; Ridoutt and Pfister, 2010*a*; Ridoutt et al., 2009). By taking blue water scarcity in a catchment as the weighting factor, a blue WF in a water-abundant catchment would count less than a similar blue WF in a water-scarce area. This idea of weighting was undoubtedly inspired by the weighting of different GHGs in CF calculations, but this approach is based on a misunderstanding of the water scarcity issue. The WF does not aim to reveal the local hydrological impact of water consumption; it aims to measure the use of freshwater resources, which is helpful in determining how to allocate water among competing demands. One litre of water used does not become more or less than one litre according to the degree of water scarcity in a catchment. Weighting the WF in two locations based on local water scarcity is like weighting oil consumption in two locations based on the scarcity of local oil reserves – it does not make sense (Hoekstra et al., 2011). Furthermore, if the WF of a product or company were to be calculated by multiplying consumed volumes by local water scarcity, another problem arises: because water scarcity in a catchment is defined as the total WF in the catchment divided by the water availability, the WF of a product produced in a certain catchment would increase (or decrease) if *other users* in that catchment increased (or decreased) their WF. This way of measurement is counterintuitive (i.e. how can you explain that 'my WF depends on your WF') and does not offer a proper incentive for companies to reduce their WF – if companies would reduce *their* WF, they would reduce the WF of others as well. Unfortunately, the idea of weighting water volumes based on local water scarcity seems to be rather persistent in the LCA community (Berger and Finkbeiner, 2010). The confusion is that some researchers in that community treat the WF as an environmental impact indicator, while in fact it is an environmental pressure indicator, measuring the intensity of resource use.

3.5 Entities for which the footprints can be calculated

The CF and WF are similar in that the concepts can be applied to a wide variety of entities. In both cases, the basic building block is the footprint of a process. Based on the CF or WF of a process, the CF or WF of a product can be calculated by summing the CFs or WFs over the steps of its supply chain or life cycle. By summing the CFs or WFs of the products produced or consumed, the CF or WF of a company, an industrial sector, an individual consumer, or a group of consumers can be assessed. The total CF or WF occurring within a certain geographically delineated area (e.g. the territory of a country) is obtained by summing the CFs or WFs of the activities within that area. The WF concept has been applied to assess the WF of national consumption from its inception on (Hoekstra and Hung, 2002), while the CF concept originally was applied to products and has only more recently been applied to national consumption (Hertwich and Peters, 2009).

3.6 Calculation methods

Although the CF is widely used as a yardstick, there is little uniformity in its calculation methods. The main differences are in:

- the scope of the study (indirect emissions are often excluded)
- the gases included
- the weighting of these gases to arrive at CO_2-equivalents
- the system boundaries chosen to determine how to truncate the analysis of emissions in the supply chain

There is also no unanimity on whether offsetting is valid as a way to reduce CF, and if so, how certain offsetting activities can be counted.

Alternative calculation methods and standards have been formulated by different organizations (Kenny and

Gray, 2009; Padgett et al., 2008; Pandey et al., 2011; Wiedmann and Minx, 2007). At the product level, CF standardization has been under discussion and several organizations have published their own guidelines and standards. The *Publicly Available Specifications 2050* of the British Standards Institution was one of the first standards describing calculation methods for product CFs – they were first published in 2008 and updated three years later (BSI, 2011). This standard describes the calculation of GHG emissions of goods and services based on the LCA approach. Other standards in wide use are the *GHG Protocol* of the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) (2004) and their recently published *Product Life Cycle Accounting and Reporting Standard* (2011). The International Organization for Standardization (ISO) is currently developing a product CF standard known as ISO 14067 (ISO, 2012*a*). Other ISO standards related to the CF are ISO 14040 on Life Cycle Assessment (ISO, 2006*a*) and ISO 14064 on Greenhouse Gases (ISO, 2006*b*). The Japanese Industrial Standards Committee published a *Basic Guideline of the Carbon Footprint of Products* (JISC, 2009).

The three main approaches used to calculate CFs are the bottom-up, top-down and hybrid approaches (Matthews et al., 2008; Peters, 2010; Wiedmann and Minx, 2007). The bottom-up approach is based on LCA, a method that estimates the environmental impact of products by 'cradle to grave' analysis. This method is mainly used for estimation of the CF of products and small entities (Finkbeiner, 2009; Peters, 2010; Schmidt, 2009; SETAC, 2008; Sinden, 2009; Weidema et al., 2008). There are numerous examples of this method being applied to the CF calculation of specific products: computers (O'Connell and Stutz, 2010), newspapers and magazines (Boguski, 2010), and animal products (Edwards-Jones et al., 2009; Flysjö et al., 2011). Although the bottom-up approach produces results with a relatively high level of precision, it is data-demanding and brings system boundary and truncation problems (Wiedmann, 2009).

The top-down approach is used for calculating the CF of large entities such as sectors, countries and regions. Environmentally Extended Input-Output Analysis (EE-IOA) is the main method for top-down calculations (Minx et al., 2009; Pandey et al., 2011; Wiedmann, 2009). Such analysis makes use of an economic input-output model, which represents the interdependencies between different sectors and final consumption in the national economy or between the sectors in different national economies. An input-output model contains a matrix that shows how the output of one industry is an input to another. It also includes imports and exports and final consumption. Inputs and outputs are expressed in monetary terms: the model shows the value of economic transactions between different sectors in an economy. A monetary input-output model can be extended with environment-related information for each sector, such as its emissions and natural resource use, thus allowing for EE-IOA. At the national level, EE-IOA is based only on national input and output tables, which can bring significant errors into CF analysis (Minx et al., 2009). The introduction of multi-regional input-output models has solved this problem. However, two major challenges remain: (i) the relatively coarse schematization of the economy in input-output models (whereby economic activities with rather different natural resource use and emission intensities are part of one sector) and (ii) the approximation of (often unknown) physical flows between sectors by the (known) inter-sector monetary flows (which ignores the fact that traded goods and services between sectors are not homogeneous). National CF studies based on EE-IOA have been carried out, for example, for the United Kingdom (Druckman and Jackson, 2009; Wiedmann et al., 2010), Australia (Wood and Dey, 2009), Japan (Nansai et al., 2009), Brazil (Machado et al., 2001), the United States of America (Weber and Matthews, 2008) and China (Chen and Chen, 2010; Zhao et al., 2009). Global assessments of national CFs have been carried out by Hertwich and Peters (2009) and Wilting and Vringer (2009).

The hybrid approach to CF accounting combines the specificity of process analysis (using LCA) with the system completeness of EE-IOA (Lenzen and Crawford, 2009). This approach retains the detail and accuracy of the bottom-up approach (which is especially relevant in carbon-intensive sectors). In the hybrid approach, first- and second-order process data are collected for the product or service and higher order requirements are covered by input-output analysis (Wiedmann and Minx, 2007).

In WF accounting, there is only one standard: the *Global Water Footprint Standard* published by the WFN in 2009 and revised in 2011 (Hoekstra et al., 2011). This standard covers comprehensive definitions and methods for WFA. WFA has four stages: (i) setting goals and scope; (ii) accounting; (iii) assessing sustainability; and (iv) formulating responses. The standard covers methods for the calculation of the WF of processes, products, companies, consumers, and consumer groups (e.g. people of a nation), and also includes guidelines for sustainability assessment and response formulation. The WFs of single process steps form the basic building blocks of all WF accounts. The WF of a product, for example, is the aggregate of the WFs of the relevant process steps. The WF within a geographically delineated area is equal to the sum of the WFs of all processes taking place within that area (Hoekstra et al., 2011). According to the standard, offsetting activities cannot be counted as WF reduction. Furthermore, the term WF can be used only to refer to

the sum of direct and indirect WFs, so that no confusion can arise as to the scope of the term. Companies can refer to their *direct (operational) WF*, which excludes their *indirect (supply-chain) WF*.

The ISO has taken the initiative, under its Technical Committee on Life Cycle Assessment, to develop a standard related to the WF: ISO 14046 (ISO, 2012*b*). By its position under the LCA committee, the scope will be limited to processes and products and align to the LCA methodology as formulated in other ISO standards in the LCA field. By focussing on procedural issues rather than calculation methods, the standard will probably (and hopefully) not be in conflict with the *Global Water Footprint Standard* published by the WFN.

There are two approaches for WFA: bottom-up and top-down (Hoekstra et al., 2011). No hybrid approach has been developed, although recently there has been an initiative in this direction (Ewing et al., 2012). The bottom-up approach can be used for all sorts of WF accounts. When calculating the WF of products with the bottom-up approach, the accounting over supply chains is done in the same way as in a Life Cycle Inventory in LCA studies. There are product WF studies based on the bottom-up approach for a large variety of crop products (Mekonnen and Hoekstra, 2011) and farm animal products (Mekonnen and Hoekstra, 2012). More specific product studies have been carried out for cotton (Chapagain et al., 2006), coffee and tea (Chapagain and Hoekstra, 2007; Jefferies et al., 2012), biofuels (Gerbens-Leenes et al., 2009), pizza and pasta (Aldaya and Hoekstra, 2010), wheat (Mekonnen and Hoekstra, 2010), soft drinks (Ercin et al., 2011), rice (Chapagain and Hoekstra, 2011), soy products (Ercin et al., 2012*a*) and margarine (Jefferies et al., 2012). The bottom-up approach can also be applied for the calculation of the WF of companies, sectors, nations and regions. The WF of the consumers in a country, for example, can be calculated by multiplying all the goods and services consumed by the inhabitants of the country by the respective water needs for those goods and services (Hoekstra and Mekonnen, 2012*a*).

The bottom-up approach is generic and precise and can be applied for all WF calculations. However, it can be data-demanding, especially for large entities (as with the CF bottom-up approach). For the calculation of the WF of sectors, provinces, nations and regions, the top-down approach can be used as an alternative. This approach is based on input data on WF per entity (e.g. sector, province, nation, river basin) and virtual water flows between these entities. The classic way in which the top-down approach has been applied is based on drawing virtual water balances of countries using trade data and data on WFs of traded commodities (Hoekstra and Chapagain, 2007, 2008). Alternatively, the EE-IOA is nowadays also applied for WF studies (Ewing et al., 2012).

In the classic top-down approach, the WF of the people living in a province, nation or river basin is calculated as the total use of water resources in the area under consideration *plus* the gross virtual water import into the area *minus* the gross virtual water export. Virtual water import is the volume of water used in other countries to make goods and services imported to and consumed within the country considered. Virtual water export is the volume of water used domestically for making export products which are consumed elsewhere (Hoekstra and Chapagain, 2007, 2008). The bottom-up and top-down calculations theoretically result in the same figure, provided there is no product stock change over a year. The advantage of the bottom-up approach is its precision. However, as noted, it is data-intensive and depends on the quality of consumption data. The top-down approach does not require consumption data, but it does require trade data and is therefore vulnerable to the quality of that data (Van Oel et al., 2009). The top-down approach was used in all of the early national WF studies, but recent studies tend to use the bottom-up approach (Hoekstra and Mekonnen, 2012*a*; Ercin et al., 2012*b*).

Input-output modelling has been used as an alternative tool for top-down WF calculations for sectors and nations (Daniels et al., 2011; Duarte and Yang, 2011). It has been used mainly for national WF studies – China (Guan and Hubacek, 2007; Hubacek et al., 2009; Zhang et al., 2011*b*; Zhao et al., 2009), Japan (Horie et al., 2011), Spain (Cazcarro et al., 2011) and Mexico (López-Morales and Duchin, 2011) – but also for areas and cities – Andalusia (Velázquez, 2006; Dietzenbacher and Velázquez, 2007), Beijing (Zhang et al., 2011*a*), Zhangye City (Wang et al., 2009) and for the Yellow River Basin (Feng et al., 2012). A global study with a multi-regional input-output model was done by Feng et al. (2011), who compared the top-down approach with bottom-up techniques.

3.7 Scope

For corporate CF accounting, three scopes have been defined (WRI and WBCSD, 2004):

- Scope 1 refers to the accounting of *direct* GHG emissions, which occur from sources that are owned or controlled by the company (e.g. the emissions from combustion in owned or controlled boilers, furnaces, vehicles).
- Scope 2 refers to accounting of *indirect* GHG emissions from the generation of purchased electricity used by the company.
- Scope 3 refers to other indirect GHG emissions, which are a consequence of the activities of the company, but occur from sources not owned or controlled by it (e.g. extraction and production of purchased materials, transportation of purchased fuels) (Matthews et al., 2008).

The distinction between direct and indirect is also made in WF accounting. The total WF of a consumer or producer refers, by definition, to the sum of the direct (operational) and indirect (supply-chain) WFs of the consumer or producer. Without specification, the term WF refers to the sum of direct and indirect WFs. The distinction between scopes 2 and 3 as applied in CF accounting is not useful in WF accounting.

3.8 Sustainability of the carbon and water footprints

As indicators of pressure on the planet, the CF and WF by themselves tell little about impact. They need to be compared with the planet's carrying capacity. The global CF needs to be seen relative to the maximum sustainable global CF (the 'carbon cap'), which depends on the amount of GHGs that can be assimilated without causing more than a certain maximum degree of global warming (Solomon et al., 2007). The sustainability of the WF needs to be evaluated per river basin: the WF in a catchment needs to be seen relative to the maximum sustainable WF in the area. This explains why it is relevant to know where the WF is located. The maximum sustainable WF in a catchment depends on the runoff and environmental flow requirements in the area (Hoekstra et al., 2011, 2012; Ridoutt and Pfister, 2010*b*). The global maximum sustainable WF is equal to the sum of the local maximum sustainable WFs. In order to have a more practical guide for assessing sustainability at the level of individual processes and products, process- and product-specific benchmarks for CF and WF can be developed (Groenenberg and Blok, 2002; Zwart et al., 2010).

4 Comparison of responses to the carbon and water footprints

In response to the increasing concern about climate change, governments, businesses and consumers are considering ways to decrease the CF of activities and products. The two main response strategies are reduction and offsetting. *Reduction* refers to doing things in a less carbon-intensive way – achieved through increasing carbon efficiency by applying low-carbon technology, which has less GHG emission per unit of production – or ceasing certain activities of production or consumption altogether. *Offsetting* refers to taking external actions to compensate for a certain CF by means of some form of carbon capture or reduction elsewhere by others. If the CF of a certain activity is offset 100%, it is sometimes claimed that the activity is 'carbon neutral'. The concepts of carbon offsetting and neutrality are applied and supported widely by business, government and individual consumers (Kollmuss et al., 2008; Moss et al., 2008; Murray and Dey, 2009).

Whereas various CF reduction and offsetting mechanisms have already been developed and implemented, WF response mechanisms are still being explored. The broad public interest in the WF is more recent than the interest in the CF. It is not surprising that the same types of policy response that have been developed for the CF are now proposed for the WF, and there are many analogous terms in the two fields: CF reduction vs WF reduction; carbon efficiency vs water efficiency; carbon offsetting vs water offsetting; carbon neutral vs water neutral; carbon cap vs water footprint cap; carbon permits vs water footprint permits; and carbon labelling vs water labelling. All of these concepts are new in the field of water resources management except for 'water efficiency', which has been applied for decades – but even this takes on a new dimension: whereas it generally referred to water productivity at field level or within a factory, a supply-chain perspective is now added.

Cross-fertilization occurs when insights and concepts from the sphere of climate change mitigation are translated to the sphere of water. This can be fruitful, but also bears risks. Water is not the same as carbon, so it should be questioned whether solutions for carbon can be copied for water. Furthermore, not all 'solutions' that have been developed for carbon appear to be effective, so they should be critically evaluated before being applied elsewhere. Hoekstra (2008) notes that, undoubtedly, there will be a great market for water offsetting and water neutrality, comparable to the market for carbon offsetting and neutrality, but the extent to which this market will become effective in contributing to a more efficient, sustainable and equitable use of the globe's water resources will depend on the rules of the market. Without agreed definitions and guidelines on what counts as water offsetting and neutrality, the terms are most likely to end up as catchwords for raising funds for charity projects in the water sector rather than as effective means to achieve measurable overall WF reductions.

4.1 The need for reduction: Maximum sustainable footprint levels

There is a general acknowledgment that humanity's CF and WF have surpassed sustainable levels and that society must make efforts to reduce them, but it appears to be quite difficult to establish unambiguous and agreed upon maximum sustainable levels for these footprints. Knowing their ceilings is instrumental in formulating reduction strategies. The maximum sustainable level for the global anthropogenic CF depends on the maximum allowable global temperature increase, which in turn depends on the societal and ecological impacts that are expected at different degrees of global warming. At the United Nations Climate Change Conference in Copenhagen in 2009, note was taken of the scientific view that the increase in global temperature should be below two degrees Celsius. If governments would sign up to such a target – which they did not do – there would be a basis for establishing a maximum concentration of GHGs in the atmosphere, and then a maximum CF in order to remain below this maximum concentration. This in itself is not an easy task. The challenge has long been framed as one of stabilizing GHG concentrations at particular levels, such as 550, 450 or even 350 parts per million (p.p.m.) CO_2-equivalents.

Recently, several researchers have proposed an alternative view, in which the mitigation challenge is framed as that of putting a cap on total cumulative GHG emissions since the start of the industrial revolution (Allen et al., 2009; Matthews et al., 2009). This proposal is built on the insight that the total allowable emissions for climate stabilization do not depend on the timing of those emissions. It has been estimated that the peak warming above pre-industrial temperatures would be limited to two degrees Celsius with a 50% probability of success if cumulative CO_2 emissions are capped at 1000 trillion tonnes of carbon, more than half of which already has been emitted (Allen et al., 2009; Raupach, 2009). From this perspective, the maximum sustainable CF cannot be formulated as a certain ceiling to the annual CF, but should be seen as a maximum budget we can spend between today and, say, the end of this century – which means that the maximum CF should continually decline and ultimately reach zero.

But even before this new insight on the required cap to humanity's CF, there was already broad scientific consensus that anthropogenic GHG emissions are currently far beyond the level required to achieve a maximum of two degrees Celsius global warming (Solomon et al., 2007). Although the commitments made by governments in the Kyoto Protocol to reduce national GHG emissions by certain percentages are not nearly sufficient in the view of a two-degree target, the *idea* of setting a cap to GHG emissions has been institutionalized, which is probably the biggest achievement of the Protocol. Future focus should be on sticking to that idea and further negotiating the level of national caps (and even reducing caps over time), and on the mechanisms to be installed to ensure that caps are not exceeded.

In contrast, even the idea of a maximum sustainable WF has not yet been politically debated. As in the case of the CF, it is not easy to define what the maximum sustainable WF of humanity is – and for the WF, another level of complexity is that the maximum sustainable global WF is the sum of the maximum sustainable WFs in all the river basins of the world. Furthermore, timing within the year is a factor. As shown by Hoekstra et al. (2012), unsustainable WFs become manifest during certain periods of the year (generally when water availability is relatively low while the WF is relatively large), so maximum sustainable WFs have to be established per catchment on a monthly rather than an annual basis. Little research has been done on assessing the maximum sustainable global WF. Ridoutt and Pfister (2010*b*) argue that the global WF must be reduced by about half to reach a sustainable level of water utilization and they consider such a target realistic given the potential for water productivity improvements in agriculture and industry and the steps that could be taken to limit food chain waste.

A question often posed in the context of WF reduction is whether it is relevant to reduce WFs in water-abundant river basins (e.g. Wichelns, 2011; Ridoutt and Huang, 2012). Reducing the aggregate WF in the most water-scarce catchments deserves priority indeed, but this requires global action. As argued by Hoekstra and Mekonnen (2012*b*), an important component of the solution to over-exploitation of blue freshwater resources in water-stressed catchments is to increase water productivities (reduce product WFs) in water-abundant areas. Because water-intensive commodities can be traded internationally, wise allocation of freshwater resources to alternative purposes is a question with a global dimension (Hoekstra, 2011). Water-abundant areas often show low water productivities (tonnes per m^3) and thus large product WFs (m^3 per tonne). Even though the local environmental impacts of water use in these areas can be small, it would be a mistake to leave them out of the scope of water policy.

4.2 Reduction of footprints by increasing carbon and water efficiency

Carbon efficiency is a popular term referring to the CF per unit of Gross Domestic Product (GDP) in an economy, or more specifically to the CF of specific sectors or activities, always per unit of production. A related term is energy efficiency. Companies and governments usually translate the need for CF reduction into a need to increase energy efficiency in industry, transportation and households, assuming that decreased energy use per unit of good or service produced automatically translates into reduced GHG emissions. There is also the recognition that we need to shift from carbon-intensive forms of energy like coal and oil to less carbon-intensive forms like gas or, even better, renewable forms of energy like wind, solar, hydro or bioenergy.

Although the strategies of increasing energy efficiency and shifting to renewables seem quite straightforward, they are not always as effective in reducing GHG emissions as we would expect. In practice, increasing energy efficiency does not necessarily correlate to an overall reduction in energy use. More efficient production means that the same can be produced with less energy, but it also means that more can be produced with the same energy. Increased energy efficiency may thus contribute to increasing levels of production and consumption. This is called the 'rebound effect', which describes increases in resource or energy efficiency that do not result in a corresponding decrease in resource or energy use (Berkhout et al., 2000). Many researchers have addressed this issue and concluded that increasing energy efficiency will not be sufficient for reaching GHG emission reduction targets (Binswanger, 2001; Birol and Keppler, 2000; Brännlund et al., 2007; Herring and Roy, 2007; Hertwich, 2005; Roy, 2000). Whether a shift from fossil fuels to renewable energy will result in a corresponding decrease in the CF can be questioned in a similar way. Many renewable energy projects concern investments in energy production for new activities; such projects may simply add to the total energy use and not replace fossil energy use.

The feasibility of achieving increased carbon efficiency depends on available technology, market conditions, and the role governments play in promoting the shift towards a low-carbon economy. The IPCC distinguishes between three different 'emission reduction potentials' (Metz et al., 2007):

- *Market potential* is the reduction potential based on private costs and private discount rates. It reflects what is possible from a microeconomic perspective.
- *Economic potential* is the reduction potential based on social costs and benefits and social discount rates. It reflects what is feasible from a macroeconomic perspective.
- *Technical potential* is the amount by which it is possible to reduce GHG emissions by implementing a technology or practice that has already been demonstrated. It is not limited by cost constraints, but by practical and physical limits, such as the available technologies and the rate at which these technologies may be employed (Van Vuuren et al., 2009).

The IPCC distinction between market, economic and technical potential for CF reduction can be a useful approach in the discussion of WF reduction. What is technically possible regarding WF reduction receives some attention in the *Water Footprint Assessment Manual*. It introduces the terms 'zero blue WF' and 'zero grey WF' for the industrial sector, referring to the possibility in most industries to fully close the water cycle and nullify chemical loads to ambient water bodies (Hoekstra et al., 2011). The huge variation in WFs for crop production shows that there is substantial potential for productivity increase and WF reduction (CAWMA, 2007; Mekonnen and Hoekstra, 2011; Zwart et al., 2010). Examples of increased water efficiency in agriculture are use of drip irrigation instead of sprinklers (reducing the blue WF) and replacement of conventional by organic farming (reducing the grey WF). It would be useful to develop WF benchmarks for various activities (processes) and end products in order to set WF reduction targets by process and product.

The rebound effect discussed for the CF can be relevant when increasing water efficiency (McGlade et al., 2012).

Reducing the WF of activities in a river basin will contribute to lessening the pressure on the basin's water resources only when the reduced WF per unit of activity is not nullified by a simultaneous increase in production.

4.3 Reduction of footprints by changing production and consumption patterns

It is acknowledged that increasing efficiencies can be only part of the solution for reducing carbon and water footprints. Existing production and consumption patterns carry an inherent dependence on energy and water that cannot be addressed by increasing efficiencies alone. On the production side, for example, the international character of many supply chains leads to an inherent dependency on energy for transport. The energy demand can be reduced only if the supply chains are restructured such that less long-distance transport is involved. Existing production patterns are often inherently water-intensive as well; a good example is the common practice of intensive crop production in areas that are short of rain. The blue water footprint of crops can be reduced only if worldwide crop production is better aligned to where there is sufficient rain. Consumption patterns need attention as well. The relatively large contribution of meat and dairy consumption to humanity's CF – Steinfeld et al. (2006) estimate that the livestock sector is responsible for 18% of anthropogenic GHG emissions – can be reduced only if people reverse the current trend towards eating more meat and dairy. Replacement of a meat-heavy meal by a vegetarian or a meat-light meal will also help to substantially lower the WF (Mekonnen and Hoekstra, 2012). Not using first-generation biofuels or at least avoiding biofuels from the most water-intensive crops will help as well (Gerbens-Leenes et al., 2009).

A reconsideration of production and consumption patterns is much more difficult than implementing measures to increase efficiencies because structural changes affect all sorts of vested interests, while, at least in the short term, efficiency gains benefit all parties. This explains why most of the attention of footprint reduction goes to efficiency and not to total production and consumption volumes. Both producers and consumers generally want to increase the levels of production and consumption, and efficiency gains can be instrumental in that. Because of the rebound effect, CF and WF reduction strategies that are focused on efficiency are likely to fail. Carbon and water efficiency increases need to be coupled with caps on total CFs and WFs.

4.4 Offsetting, neutrality and trading

The idea behind carbon offsetting is that one unit of CO_2-equivalent emitted into the atmosphere in one place from one activity has exactly the same contribution to climate change as another unit emitted elsewhere by another activity. As a result, a certain emission reduction always has the same effect, no matter how or where it is done (Bellassen and Leguet, 2007). Furthermore, there is the underlying idea that one can better reduce an emission elsewhere – if it is easier or cheaper – than reduce one's own emission (Bumpus and Man, 2008).

The practice of carbon offsetting was developed from the flexible mechanism included in the Kyoto Protocol that allows industrial countries to fulfil their obligations to reduce GHG emissions by purchasing emission reductions created by projects elsewhere (Barker and Ekins, 2004; Viguier et al., 2003). This mechanism was created as a result of a market logic, where demand and supply for reductions are created, priced and exchanged internationally and developed further with a parallel voluntary market. A typical example of the voluntary market can be found in the air transport sector: passengers can offset the emissions related to their flight by purchasing reduction credits elsewhere. Another example is offsetting emissions of energy use by buying carbon credits that are generated by renewable energy or forest planting projects (Bellassen and Leguet, 2007; Bumpus and Man, 2008).

Although the offsetting concept is based on some logic, it has unanswered questions that create confusion. Measuring, accounting and verifying are the main concerns, especially in voluntary offsetting. There are no clear definitions of what can count as an offset and no standardized methods to calculate the amount of CF that can be compensated for by a certain offset activity. Murray and Dey (2009), in their study of commercial websites that offer carbon offsets to companies and individuals, found that these enterprises do not have similar values for required offsets; do not have the same inputs and calculation methods; and, even for CF values that are close, do not have the same pricing of the offsets. They concluded that lack of standardization and transparency are the main problems in today's voluntary offset market. Another concern about offsetting is the credibility of sequestration and other carbon credit projects. Finally, offsetting allows polluters to continue emitting, which is the wrong signal to be spreading regarding CF reduction. Together, these concerns place offsetting in a bad light. And there are many indications that both the formal (Kyoto Protocol) and voluntary mechanisms of offsetting have little effect on overall CF reduction (Spash, 2009). The absence of a closed accounting system makes it very difficult to measure the effectiveness of the whole system.

The idea of water offsets (or water credits) is gaining ground in the water community. However, as for carbon offsetting, the concept of water offsetting is still ill-

defined. According to Hoekstra et al. (2011), in general terms it means taking measures to compensate for the negative impacts of the WF that remain after WF reduction measures have been implemented. But the two weak points of the definition are that (i) it does not specify which compensation measures and what level of compensation are good enough to offset a certain WF impact and (ii) it does not specify which impacts should be compensated and how to measure these impacts. An ill-defined concept can be easily misused – measures taken under the banner of 'offsetting' can potentially be a form of 'greenwashing' rather than a real effort aimed at full compensation. Another problem is that WFs and their associated impacts are always local; as has already been discussed in this report, in this respect the WF is markedly different from the CF. The idea of a global offset market does not make sense for water as it does for carbon. An offset for a WF should always occur in the catchment where the WF is located. This brings attention back to a company's own WF and does not allow it to simply buy an offset in a general compensation scheme (Hoekstra et al., 2011).

4.5 The interplay of actors

The challenge of CF reduction lies on the plate of various actors: governments, companies, investors, individual consumers and intergovernmental forums. To limit or reduce GHG emissions, national governments have been using various policies and measures: setting regulations and standards, applying taxes and subsidies, creating carbon credit markets, promoting voluntary actions, instigating research programmes and developing communication tools (Bumpus and Man, 2008; Kollmuss et al., 2008; Koteyko et al., 2010; Metz et al., 2007; Solomon et al., 2007; Stewart and Wiener, 2004; Wara and Victor, 2008). Four criteria are generally applied to evaluate the usefulness of each instrument: (i) environmental effectiveness; (ii) cost-effectiveness; (iii) distributional effects (including equity); and (iv) institutional feasibility (Harrington et al., 2004; Metz et al., 2007). It is important to note that CF-specific policies are not enough to reach CF reduction goals. Policies on poverty reduction, land use, trade, pollution, agriculture, food security and population should all be considered together.

Regulation, legislation and standards are typical instruments used in environmental policy. The effectiveness of regulatory measures and standards depends on their stringency. They can be very effective and useful tools when businesses and consumers do not respond to calls for voluntary action. In the field of CF reduction, such policy instruments have successfully been implemented to promote energy efficiency: the European Union's action for the aviation industry and the US action for registry of emissions under the Consolidated Appropriations Act (2008) are two good examples of how regulation can play an important role (Courchene and Allan, 2008; Pandey et al., 2011). Several more examples can be found for the role of legislation, such as California's Global Warming Solutions Act (2006), which aims to reduce emissions and promote capping (Kossoy and Ambrosi, 2010), and the UK's Low Carbon Transition Plan (DECC, 2009). These examples show that regulatory standards are valuable in emission reduction. They are effective in stimulating consumers and industries to reduce their footprints.

In addition to regulatory intervention, governments can intervene in markets by applying taxes and subsidies, and they can promote consumption patterns that contribute to emission reduction. Taxes on emissions can be effective in terms of both environmental and cost concerns; for example, taxation in Denmark resulted in a 6% reduction and in Norway decreased emissions per unit GDP (Bruvoll and Larsen, 2004). However, they can create distributional and institutional problems (Metz et al., 2007). Taxes can also be ineffective for overall reduction as they provide polluters with an alternative: pay tax and pollute instead of invest in emission reduction. Furthermore, taxes are not popular policy tools, and political constraints and lobbying by industry can make them difficult to implement. Financial incentives are policy tools commonly used by governments to stimulate new technologies. Taxation and market creation also have important roles in technology development and innovation.

Through governmental regulations and policies, companies have started to realize that we are moving towards a carbon-constrained economy (Kleiner, 2007), and they are aware that they will soon face taxation, capping and other regulations related to their GHG emissions. CF calculation and emissions reduction is nowadays high on the agenda of many businesses. The main driver behind their rush to react is to enable continuation of their activities in a carbon-constrained economy and navigation of the new landscape to their advantage. But it is also a reaction to broad public concern over climate change and changes in consumer behaviour – a survey done in the UK showed that 44% of consumers are willing to pay more for low CF products (Pandey et al., 2011). Companies can react to all of these changes; they can see the new business opportunities in a carbon-based economy and create new markets for themselves: carbon trading, consulting, calculating, offsetting, and so forth. The role of business in strategies towards reduction of emissions is significant. Companies can change their production systems and invest in low-carbon technologies, but the financial burden associated with these actions can be immense and companies are not necessarily willing to take on this burden without legislation and changes in consumer choices pushing them to do so.

There is no doubt that communication tools are effective in CF reduction, but they are indirect and thus their effects are hard to quantify. Governments can use awareness and education campaigns to promote sustainable consumption and help consumers make better-informed choices. They can also influence producers to make production more sustainable (Stevens, 2010). In the case of the CF, communication instruments such as product labelling, carbon disclosure and public awareness campaigns are under discussion and several initiatives have been taken.

Carbon labelling of products is one of the tools that companies are starting to use to share CF information with consumers to help them make better-informed choices. Some governments, for example the French, are starting to think about regulation of product labelling. If labelling schemes are well defined and structured and use credible information, labelling could be an effective tool for creating incentives to move towards low-carbon products and supply chains (Brenton et al., 2009). Unfortunately, today's CF does not provide such credibility because it has neither a standard definition nor a standard method of calculation.

With the growing awareness of global warming, individuals have become more concerned about their own actions. Individuals can lower their CFs by lowering their energy use at home and adapting their consumer and other behaviours; for example, buying locally grown food, travelling less, and travelling by bicycle or public transport (Frank et al., 2010; Kollmuss et al., 2008).

As can be clearly seen from the discussion above, societal response to the CF involves many actors taking their own steps – and by doing so they influence one another, which is an essential element in the overall response. A similar diversity of actor initiatives and mutual influences will probably develop for the WF, but we are at too early a stage to be able to reflect on the various governmental, corporate and civil society initiatives that are currently being taken in the WF field. The Spanish Government has made WF analysis mandatory in the preparation of river basin plans. Many other governments, for example that of South Africa, are in an exploratory stage (Hastings and Pegram, 2012). A great number of companies, most of them multinationals (e.g. Unilever [Jefferies et al., 2012]), have started to compute the WF for some of their products and to explore response strategies. More and more WF calculators are appearing online, the media is picking up the concept, and environmental organizations (e.g. the World Wildlife Fund and The Nature Conservancy) are starting to use the concept in their awareness campaigns.

Based on experience with the CF, it is hard to imagine progress in WF reduction without strong governmental and intergovernmental leadership. Legislation, regulation and standards will likely be necessary to stimulate consumers and industries to reduce their WFs. It will be important that the different WF components are treated individually, and in particular, strict regulations regarding the blue and grey WFs will be necessary to ensure optimal use and allocation of scarce water resources. Taxation can be a policy instrument; however, in reality taxation on one specific criterion is rare and politically very difficult to implement. Subsidies and financial incentives can be helpful instruments to promote new technologies and innovations, efficient use of water, reuse and recycling of water, and better wastewater treatment.

4.6 The water–energy nexus

There is a growing recognition that water policy and energy policy must be somehow related, because energy production requires water, and water supply requires energy. In the past, in fact until today, water and energy policies have mostly been disconnected. Whereas efforts have been undertaken to improve both water use efficiency and energy efficiency, we can observe two interesting trends. First, the water sector is becoming more energy-intensive – think, for example, of the energy needed for pumping groundwater from deeper and deeper sources, for constructing large interbasin water transfer schemes and moving water through them, and for desalination of saltwater or brackish water. Second, the energy sector is becoming more water-intensive – especially because of the increasing focus on biomass as a source of energy (Gerbens-Leenes et al., 2009). All energy scenarios for the coming decades show a shift towards an increased percentage of bioenergy, and thus an increasing WF (Gerbens-Leenes et al., 2012). The challenge is to search for coherent policies that reduce both CF and WF rather than developing energy policies that reduce CF but increase WF (like first-generation biofuels) and water policies that reduce WF but increase CF (like desalination).

5 Lessons to learn

As has been highlighted throughout the report, the CF and WF fields can inform each other in standardization, development, credibility, reduction strategies and policy tools. The main messages and lessons from the study of both concepts can be summarized as follows:

Definitions and methods

The use of the same definitions and methods for each of the CF and the WF across countries and sectors lends credibility to the concepts and is a good basis for setting real reduction targets and being able to verify them. The CF currently has competing and conflicting standards; standardization has failed due to a lack of coordination. In the case of the WF, the efforts of the Water Footprint Network to form a broad coalition of partners and develop a science-based global WF standard in an early stage of its practical use have been successful. The risk of future confusion from potentially competing initiatives (e.g. ISO [2012*b*]) is nevertheless present for the WF.

Reduction schemes

Reduction of the CF and WF through increasing carbon and water efficiencies is important, but the rebound effect must be given due attention. In energy studies, this effect is well known; in water studies the effect has had little attention to date. Alongside efforts to improve efficiencies, efforts to make societies less energy- and water-dependent are an essential ingredient of a good reduction policy.

Offsetting schemes

Offsetting schemes have inherent problems. The offsetting concept is ill-defined and can easily be misused, as illustrated in the sphere of CF offsetting. Without a clear definition, measures taken under the banner of 'offsetting' can potentially be a form of 'greenwashing' rather than a real effort aimed at full compensation. An offset of a WF should always occur in the catchment where the WF is located and in the period when it happens. This means that thinking in terms of general compensation schemes where one can simply 'buy' an offset is not applicable to the WF. In sum, offsetting is not a good option for a water scarcity mitigation strategy.

Regulatory standards

Regulatory standards have been useful and valuable for emissions reduction related to the CF, and governments should be aware that regulation can be an effective instrument in WF reduction as well. Regulation should aim to drive consumers and industries towards reducing their WF. Particularly strict regulations on reducing the blue and grey WF components can play a crucial role in optimal use and allocation of scarce freshwater resources, something that would be hard to achieve with awareness raising programmes and voluntary action alone.

Taxation

In theory, taxation could be a useful policy instrument in WF reduction strategies; however, as experience with the CF has shown, specific taxation on one criterion is rare and politically difficult to implement. Taxation in the WF area will also have additional complexity in implementation due to distributional problems. In sum, taxation does not look like a wise policy tool for WF reduction.

Multi-dimensional policies

For WF reduction, as for CF reduction, policies that address poverty, land use, trade, pollution, agriculture, food security and population should be considered together. CF- and WF-specific policies in isolation are not sufficient to meet reduction goals.

Product labelling

Although the CF and WF concepts can be used in product labelling as a communications tool to raise consumer awareness, their actual figures do not have sufficient information to allow consumers to make well-informed decisions on which products and services to purchase preferentially. Both footprints need to be compared to benchmarks, and for the WF, location and timing is relevant as well. Consumers are likely better served by labels that grade the sustainability of a product from low to high – criteria regarding the CF and WF can be integrated into such designations.

Leadership by government

Experience with the CF shows that for the development of comprehensive policy responses for WF reduction, strong governmental leadership and action will be required. Commitment and regulation are required at the national and international level. Engagement of business through production systems and individuals through consumer behaviour are also essential elements of policy response.

6 Conclusion

The CF has become a widely used concept by society, despite its lack of scientifically accepted and universally adopted guidelines. Stakeholders use the term with loose definition, according to their liking. The WF is becoming popular as well, and there is substantial risk that it will suffer the same problems as the CF. By attempting to understand the mechanisms behind the societal adoption of the CF, this report extracts lessons that may help reduce the risk of the WF losing its strict definition and interpretation.

Reduction and offsetting mechanisms have been applied and supported widely in response to the increasing concern about global warming. However, the effective reduction of humanity's CF is seriously challenged because of three factors. First, the absence of a unique definition of the CF means that reduction targets and statements about carbon neutrality are difficult to interpret; this leaves room for developments appearing better than they really are. Second, the focus on increasing carbon efficiency bears the risk of the rebound effect. Third, existing mechanisms for offsetting are extremely weak; it remains questionable whether or to what extent they actually contribute to the overall reduction of GHG emissions.

Responses for WF reduction are still under question. Water offsetting strategies will face the same problems as those of carbon, but there is a further problem: water offsetting can only be effective if it takes place at the specific location and in the specific period of time when the WF that is to be offset took place. The weakness of offsetting and neutrality mechanisms for the CF shows that applying those concepts to the WF is not a good idea. A more effective tool is probably direct WF reduction targets to be adopted by both governments and companies.

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SIDE PUBLICATIONS SERIES :04

Carbon and Water Footprints

Concepts, Methodologies and Policy Responses

The carbon footprint of activities and products has become a popular concept as governments, businesses and individuals are increasingly aware about climate change and concerned about their own impacts on it. But despite media attention and wide public acceptance, its use as a tool to track and reduce greenhouse gas emissions has serious challenges, from its lack of universal guidelines, to ambiguity in policy responses such as offsetting.

Freshwater scarcity is becoming an important subject on environmental agendas, and with it the water footprint is gaining recognition. This footprint, born in science – to study the hidden links between human consumption and water use and between global trade and water resources management – has had a promising start, with a strict definition and methodology.

There is a tendency among practitioners to treat both footprints in a similar way. But water is not carbon, and although the two footprints have similarities, they differ in important ways and each tells its own story about pressure on the planet.

In this context, *Carbon and Water Footprints* first analyses the origins of the carbon and water footprints. It makes a detailed exploration of the similarities and differences of aspects such as definition, methods of measurement, spatiotemporal dimensions, components, and entities for which the footprints can be calculated. *Carbon and Water Footprints* then discusses the two in terms of accounting and response strategies, investigating for example the setting of sustainable caps and targets for reduction, and the problematic rebound effect encountered with increasing efficiencies.

The aim of *Carbon and Water Footprints* is to draw lessons from each footprint which can help society as a whole build on the two concepts. It also seeks to help decision-makers recognize the need to fully evaluate the effectiveness of a 'solution' to one footprint before applying it to another and potentially creating unnecessary challenges in successfully tackling environmental problems.

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