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Overview of Footprints and Relations between Carbon and Nitrogen Footprints

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This contribution provides an overview of the variety of footprints. The distinction is assessed between indicators of environmental impacts and footprints. Definitions and reviews of generally accepted as well as new footprints are provided. Emphasis is given towards an adversarial relationship between carbon and nitrogen footprints. Biomass energy production is an example where carbon footprint can be significantly reduced, however this is closely linked to an enlarged nitrogen cycle. A case study of domestic wood combustion is used to demonstrate the relation between those footprints where different energy sources (natural gas, coal and fuel oil) are supplemented by biomass combustion. The results prove that the carbon footprint from domestic wood combustion is almost carbon neutral, whilst the nitrogen footprint is ~ 50 % higher compared with coal burning.

1. Introduction

Environmental awareness among societies, governments and industries has risen over recent decades. Increasingly more effort and resources have been put to research regarding environmental studies, including the assessment of different harmful impacts. Environmental impacts are usually defined through Life Cycle Assessment (LCA), which is a procedure for evaluating the total resource consumption and environmental burdens associated with a process, product or activity (ISO, 1997). However the definitions of footprints varies and are often unclearly elucidated. There is no standard and clear definition of a 'footprint', and the difference between indicators of potential environmental impacts (e. g. global warming potential) and footprints (e.g. carbon footprint). Often only one footprint (e.g. carbon) is considered, which can lead to misleading results and incorrect decisions. Namely the analysis of a complete set of environmental impacts should be performed for bioenergy supply chains, in order to obtain a full picture of the advantages and the hazardous drawbacks that a possible technology, process, product or service can exhibit on the environment. The relationship between carbon and nitrogen footprints is especially important. Different research studies have indicated that lower carbon footprints are achieved by utilising biomass,

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when compared to energy generated from fossil sources, but higher amounts of nitrogen are emitted into air and water (Cherubini and Strømman, 2011; Bauer, 2008).

1.1 Indicator of potential environmental impact or footprint?

Indicators of environmental impact dealing with the potential effects and impacts on humans, environmental health and resources come from the Life Cycle Inventories (LCI) (Saur, 1997). Impact potentials - indicators - are quantitative conversions of inventory data based on LCI results and are categorized as: global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), human toxicity potential (HTP), ozone depletion potential (ODP) etc. A 'footprint' is a quantitative measure showing the appropriation of natural resources by human beings (Hoekstra, 2008). The major categories of footprints have been developed to evaluate sustainability of processes, products or services, are carbon, ecological, water, and energy footprints. Definitions of impact potentials are known and included in LCA tools, therefore only the definitions of footprints are presented.

2. Definitions of Footprints

2.1 Carbon footprint (CFP)

CFP has become the most important environmental protection indicator over the last few years (Wiedmann and Minx, 2008; Lam et al., 2010). CFP usually stands for the amount of CO_2 and other greenhouse gases, emitted over the full life cycle of a process or product (UK POST, 2006). The CFP is quantified using indicators as the Global Warming Potential - GWP (EC, 2007), which stands for the quantities of greenhouse gases that contribute to global warming and climate change, by considering a specific time horizon, usually 100 years (IPPC, 2009). The land-based definition of CFP stands for the land area required for the sequestration of atmospheric fossils' CO_2 emissions through aforestation (De Benedetto and Klemeš, 2009). Wiedmann and Minx (2008) proposed that CFP is a measure of exclusive direct and indirect CO_2 emissions over a life cycle. The following questions need to be clarified (Wiedmann and Minx, 2008) because of the many different definitions of CFP,: (i) should only C presented in gas emissions be considered in CFP, (ii) should CFP only consider CO_2, the most abundant and potent greenhouse gas, (iii) should it be restricted to carbon-based gases, (iv) can it include substances which don't have carbon in their molecules (e.g. NO_x), and (v) how should it be measured, in mass unit of CO_2 equivalent, in mass unit of CO_2, per unit of area and possibly per unit of time?

2.2 Ecological footprint (ECOFP)

ECOFP has emerged as the world's premier measurement on humanity's demands of nature (Wackernagel and Rees, 1996). It is defined as a measurement of human demand on land and water areas and it compares human's consumption of resources and absorption of waste, with Earth's ecological capacity to regenerate (GFN, 2010). ECOFP is usually measured in global hectares as the amount of bioproductive space (Hoekstra, 2008) and in global hectares per person (Local Footprints).

2.3 Water footprint (WFP)
WFP stands for the total volume of direct and indirect freshwater used, consumed and/or polluted. A WFP consists of blue (consumption of surface and groundwater), green (consumption of rainwater), and grey water footprint - polluted water sometimes expressed as the volume of water required to dilute pollutants to water quality standards (Mekonnen and Hoekstra, 2010).

2.4 Energy footprint (EFP)
Various definitions exist for an Energy footprint (EFP). The Global Footprint Network (GFN, 2009) defined it as the sum of all areas used to provide non-food and non-feed energy. Palmer (1998) defined it as a measurement of the land required to absorb those CO_2 emissions originating from used energy. A definition of EFP is that it represents the area required to sustain energy consumption and is measured as the area of forest that would be required to absorb the resulting CO_2 emissions, excluding that proportion absorbed by the oceans (WWF, 2002). Another definition is that it corresponds to the demand for non-renewable energy resources (Schindler). The EFP can be measured in local or global hectares, and in units of energy/functional unit.

2.5 Emission footprint (EMPF)
EMFP stands for the quantity of product's or service's emissions into the air, water, and soil. EMFPs are calculated on a per area basis (De Benedetto and Klemeš, 2009).

2.6 Nitrogen footprint (NFP)
NFP is a measure of the amount of reactive nitrogen (all N species except N_2) released into the environment as a result of human activities (N-print, 2010). It causes an imbalance within the N cycle. The excess N in the ecosystems causes eutrophication, enhanced greenhouse effect, biodiversity loss, acidification etc. The total NFP is calculated as the amount of reactive N released into the environment as a result of human activities.

2.7 Land footprint (LFP)
LFP includes sub-footprints, the Forest footprint (the forest area required to produce the consumed forest products (WWF, 2002), the Agricultural land footprint (the agricultural land area used to grow biomass (Kissinger and Gottlieb, 2010)), the built-up land footprint (land areas covered by human infrastructures, Scotland's footprint), the Grazing land footprint (land used for livestock, WWF Japan and GFN, 2010).

2.8 Social footprint (SFP)
SFP is a measurement for quantifying the social sustainability performance of an organization. It deals with impacts on anthro-capital (human, social and constructed) (Center for Sustainable Organizations, 2009).

2.9 Other environmental and social footprints
Other environmental footprints, that are not widely known, are: the Work environmental footprint - the number of lost days at work per unit of product (De Benedetto and Klemeš, 2009), the Phosphorus footprint (addresses phosphorus imbalances in the crops, Lott et al., 2009), the Fishing-grounds footprint (addresses sustainable catches for a variety of fish species, WWF Japan and GFN, 2010), etc.

3. Carbon (CFP) and Nitrogen (NFP) Footprints

CFP and NFP have increased significantly in the last century as a result of human activities. CFP is associated with the burning of fossil fuels - coal, natural gas, and crude oil, while NFP increases as a result of artificial nitrogen fertilization, manure run-off, the burning of biomass and fuels, and the planting of legumes. CFP is well-known, while NFP is not yet common (Bakshi and Singh, 2011). The global CO_2 growth rate in the air is around 2 ppm/y and is mainly caused by fossil fuel combustion (75 %) and increased emissions from deforestation and land usage (25 %) (WMO, 2009). The total amount of reactive N created by human activities has increased ninefold over the last 100 y, mostly in the second half of the 20th century due to the increased use of fertilizers. It is expected to have increased by a further 64 % in 2050 (Millenium Ecosystem Assessment, 2005). CO_2 is a cause of global warming and climate change (Hamilton, 2008). Nitrogen fertilization leads to the contamination of drinking water, algal blooms, eutrophication, etc. NO_x emissions can lead to smog, acid-rain, haze and climate change. The deposition of N, P and other contaminants is expected to have an impact on the biodiversity. N pollution damages ecosystems and affects human health, including respiratory diseases and the risk of birth defects (N-Print, 2010).

4. A Case Study of Domestic Biomass Combustion

Fossil-fueled heat and electricity production is one of the major anthropogenic sources of CO_2 emissions today, and is responsible for the ongoing climate change to a great extent (Bauer, 2008). Biomass as a fuel has advantages on CFP and GHG emissions as the CO_2 emitted during biomass combustion is absorbed during the biomass growth. However, heat from burning biomass (wood) shows the highest NO_x emissions. CFP is composed only of direct and indirect CO_2 emissions, as proposed by Wiedmann and Minx (2008). NFP accounts for NO_x, which represent the majority of N emissions (NH_3, NO_x, N_2O). CFPs and NFPs from the combustion of wood, natural gas, fuel oil and coal are presented in Table 1. Both the CFPs and NFPs were mostly obtained using the LCA software GaBi 4.3 (PI International) and the Ecoinvent database (Ecoinvent Centre).

Table 1: Emissions of CO_2 and NO_x into the air for different types of fuel (kg/MWh)

	Wood logs	Natural gas	Fuel oil	Coal
CO_2	5 – 15	220 – 280	300 – 350	400 – 500
NO_x	0.75 – 0.85	0.1 – 0.25	0.25 – 0.35	0.45 – 0.6

CFP and NFP from biomass- and fossil-fueled appliances differentiate depending on the emission control at the power plants, the origins of the fossil fuels, the transportation mode and the distance of wood to user (Bauer, 2008). NO_x emissions vary significantly among combustion facilities depending on their design and control. CFP from domestic wood combustion is almost carbon neutral, and coal has the highest CO_2 emissions. Concerning NO_x emissions, natural gas shows the best performance of all fuel alternatives. Oil and coal burning causes relatively low direct NO_x emissions. Wood fuel has higher NO_x emissions due to their high nitrogen content.

5. Conclusions

This contribution overviewed and provided definitions for the various footprints found in literature. Unlike many previous works, this paper focused on the possible adversarial relationships among different footprints. The case study of domestic heating clearly showed this relation. The lowest CFP was obtained by wood burning but, on the other hand, the highest NFP compared to fossil alternatives. If only one or a limited number of footprints are evaluated, it can lead to inaccurate conclusions resulting in incorrect decisions.

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