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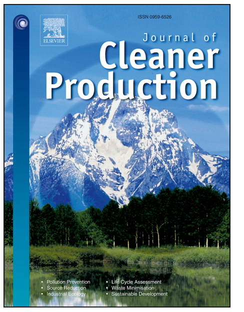

Strengths-Weaknesses-Opportunities-Threats Analysis of Carbon Footprint Indicator and Derived Recommendations

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ABSTRACT

Demand for a low carbon footprint may be a key factor in stimulating innovation, while prompting politicians to promote sustainable consumption. However, the variety of methodological approaches and techniques used to quantify life-cycle emissions prevents their successful and widespread implementation. This study aims to offer recommendations for researchers, policymakers and practitioners seeking to achieve a more consistent approach for carbon footprint analysis. This assessment is made on the basis of a comprehensive Strengths-Weaknesses-Opportunities-Threats or SWOT Analysis of the carbon footprint indicator. It is carried out bringing together the collective experience from the Carbonfeel Project following the Delphi technique principles. The results include the detailed SWOT Analysis from which specific recommendations to cope with the threats and the weaknesses are identified. In particular, results highlight the importance of the integrated approach to combine organizational and product carbon footprinting in order to achieve a more standardized and consistent approach. These recommendations can therefore serve to pave the way for the development of new, specific and highly-detailed guidelines.

KEYWORDS

Corporate carbon footprint; Integrated approach; ISO 14067; ISO 14069; Product carbon footprint; SWOT analysis

1 INTRODUCTION

Human influence on the climate system is clear (IPCC, 2013). In response, the United Nations Framework Convention on Climate Change has developed various initiatives, promoting the creation of national greenhouse gas (GHG) inventories. However, these inventories are built on the premise described by IPCC (1996), including only domestic GHG emissions. Within this framework several countries have reduced domestic emissions, although world GHG emissions continue to grow (Peters et al., 2013). This emphasis on solely domestic emissions is proving ineffective, and particularly in the new context of free-trade agreements.

New schemes based on emissions embedded in imports are therefore needed to implement all the available strategies. In this context, the concept of carbon footprint (CF) has been used to express consumption-based emissions from a territorial point of view (Davis and Caldeira, 2010). Demand for low CF may be a key factor in stimulating innovation while prompting politicians to promote sustainable consumption. The CF indicator now span several scales, allowing the analysis of everyday consumer products through to business, households, cities, counties and countries (Minx et al., 2009; Peters, 2010).

Although the CF indicator has been very successful in terms of reaching a great audience, some researchers have pointed out different problems related to CF analysis (see, e.g. Cagiao et al., 2012; Carballo-Penela et al., 2012; Finkbeiner, 2009; Jensen, 2012; McKinnon, 2010). In particular, one of the most common issues highlighted by researchers is the methodological divergence between product and corporate CF (Alvarez and Rubio, 2015a; Carballo-Penela et al., 2009). This divergence avoids the comparability among methods, reducing the consumer confidence on footprints information. Under these circumstances, there is a need of studies that include a complete assessment of the CF indicator from a strategic management perspective.

Strategic management tools should be considered as a means of objectively devising guidelines for improving the CF indicator, as they offer a competitive and adapted methodology to elaborate strategies. A wide range of strategic management tools have been developed to assist in compiling these intelligent strategies (Rao et al., 2009), including the Strengths-Weaknesses-Opportunities-Threats –or SWOT– analysis, a widely-used tool for achieving both a systematic approach and support for decision making (Kessler, 2013).

1.1. The carbon footprint

Sustainable development indicators are needed to provide a solid basis for decision-making (Čučeka et al., 2012). The CF is a sustainable development indicator which has emerged in the last few years as a general description of the GHG emissions produced by human activities (Wiedmann, 2009). In spite of being one of the most important environmental indicators (Hoekstra and Wiedmann, 2014) there is still some confusion with regard to the meaning of the term, what and how measures (Jensen, 2012; Wiedmann and Minx, 2008).

Wiedmann (2009) states that the CF term could be derived from the ecological footprint (EF) concept, formulated by Wackerangel and Rees (1996). The footprint family indicators are defined as a set of consumption-based indicators that calculate the environmental burdens imposed on the environment by human society (Fang et al., 2014). The CF is worth highlighting among these indicators due to its widespread implementation (Jensen, 2012; Peters, 2010; Wiedmann and Minx, 2008). Since a footprint is a quantitative measure which describes the appropriation of natural resources by humans, in the EF context, the CF represents the land area required to sequester the CO_2 emissions from fossil fuel combustion (Čučeka et al., 2012). This land-based definition of the CF is not the most used by researchers, the media and the public in general nowadays. From a business perspective, it is stated that the CF collects the GHG emissions caused by organizations or the production of goods and services. Although there still exist different definitions of the concept (see Table 1), the CF is usually understood as the full amount of GHG emissions that are caused by an activity (Wiedmann, 2009).

[Table 1 here]

Whereas the existence of different meanings of the term does not seem to be a problem for the development of the indicator, the methodological standardization clearly does. Current CF methodologies can be divided in two scientific fields that have adopted the term after decades of academic development –the Life Cycle Assessment (LCA) and the corporate-based analysis–. These fields have led to the divergence of product and corporate CF. In fact, two of the leading schemes for CF standardisation are the Technical Report (ISO/TR 14067:2013) and the Technical Specification (ISO/TS 14069:2013) (ISO 2013a, 2013b). Both standards have yet to obtain the consensus necessary before they can be considered ISO standards, and will therefore be publicly available for three years in order to resolve any issues and improve their understanding.

The interest in the CF indicator has ended up in a great variety of calculation methodologies and “calculators” of all kinds, leading the public to confusion and hesitation (Cagiao et al., 2014; Wiedmann et al., 2011). As an example of this variety, 62 and 80 different initiatives and methodologies, respectively for product and corporate CF, were identified in 2010 (Ernst & Young France and Quantis, 2010; Marsh-Patrick, 2010). These include, for example, the PAS 2050, Bilan Produit or BP X30-323.

In addition to ISO standards, one of the more successful CF standards is the above-mentioned PAS 2050 (BSI, 2011). Based on process LCA schemes, this standard was developed by the Defra, the BSI and the Carbon Trust.

The European International Reference Life Cycle Data System (ILCD handbook) also contributes to the standardization of CF analysis. This handbook covers all aspects of conducting an LCA, including questions such as: 1) requirements for assessing the emissions and resource consumption associated with a product in terms of impacts on the environment; 2) how to gather data on resource consumptions and emissions that can be attributed to a specific product or 3) how to create LCI data sets regarding emissions and resource consumption (JRC-IES, 2010a).

Under the frame of the Greenhouse Gas Protocol Initiative, the World Resources Institute (WRI) and the World Business Council for sustainable Development (WBCSD) have also developed standards for reporting and accounting GHG emissions from corporations (WRI and WBCSD, 2004); the product life cycle (WRI and WBCSD, 2011a) and the corporate value chain (WRI and WBCSD, 2011b).

The European Commission is also making a great effort in developing standards for products and organizations EF, including the CF indicator. These standards are not finished at this moment but the European Commission has released different documents including a Commission Recommendation to measure and communicate the life cycle environmental performance of products and organizations (European Commission, 2013).

Finally, the current implementation of the CF indicator applies two techniques to quantify life-cycle emissions. On the one hand, process analysis (PA) is the conventional bottom-up method for LCA used to define and describe the specific operations under consideration (Majeau-Bettez et al., 2011). On the other hand, environmentally extended input-output analysis (IOA) is a top-down approach applied for country-, regional- and corporate-based analysis (Alvarez et al., 2014). It uses economic environmental accounting frameworks to map the structural components of the direct and indirect demand for resources, allowing the quantification of total emissions (i.e. direct and indirect upstream emissions) per economic unit (Minx et al., 2009). Both approaches have significant positive and negative aspects (Alvarez and Rubio, 2015b). For instance, PA is considered appropriate when modelling specific systems (Finkbeiner, 2009), but runs the risk of system boundary incompleteness by excluding important elementary, product and waste flows (Faruk et al., 2001). In contrast, IOA has mostly been mentioned as an approach to overcome data availability issues but it has to address a high level of aggregation (Majeau-Bettez et al., 2011).

1.2. SWOT analysis

The SWOT analysis is a strategic management tool used to evaluate 4 critical areas (strengths, weaknesses, opportunities and threats) involved in a project or in a business venture (Berariu et al., 2011). It specifies the objective of the project and identifies the internal (strengths and weaknesses) and external factors (opportunities and threats) that are favourable and unfavourable to achieving that objective.

SWOT analysis has been extended beyond companies to countries and is used in virtually every published project for planning purposes (Helms and Nixon, 2010). The application of SWOT analysis to sustainable development strategies has been widely covered in the research (Berariu et al., 2011). The latest advances include specific approaches known as Climate SWOT and Sustainability SWOT to assess mitigation and adaptation strategies (Pesonen and Horn, 2014, 2012).

This analysis allows achievable goals and effective objectives to be set for the project. Every SWOT analysis focuses on:

- Strengths: characteristics of the project that give it an advantage over others.
- Weaknesses: characteristics that place the project at a disadvantage relative to others.
- Opportunities: elements the project could exploit to its advantage.
- Threats: elements in the environment that could cause trouble for the project.

Some authors suggest the use of performance-importance matrix which allows to make a ranking with some aspect of the SWOT analysis in order to clarify some relevant aspects and also to make comparative (Pickton and Wright, 1998). The SWOT analysis of the CF indicator could be used to make strategic decisions based in a product and organization footprinting, and opens new opportunities to merge environmental evaluation and strategic business analysis (Viaggi, 2013). Therefore, the SWOT analysis allows to focus on key questions for the development of the CF indicator by comparing strengths and weaknesses and opportunities and threats, making easier the proposal of recommendations to cope with threats and weaknesses.

1.3. Goal and scope

The quantity of literature on the CF indicator produced in recent years makes difficult to collect and analyze all the available information about this indicator. The dispersion of information and the wide number of methodological approaches and topics under analysis can be an obstacle to elaborate efficacious proposals for improving the CF analysis.

Strategic management tools such as SWOT analysis can be mean to collect and analyze information in order to objectively devising recommendations for achieving a specific purpose. The current study aims to contribute to achieve a more consistent approach of footprint analysis by providing solidly-based recommendations for researchers, policymakers and practitioners that help to the global implementation of the indicator. At this moment, to the best of our knowledge, no studies using SWOT analysis of the CF indicator can be identified in the literature.

2. METHOD

The SWOT analysis has been developed following the Delphi technique principles. The Delphi technique is a structured process that uses a series of questionnaires (also referred as rounds) with controlled opinion feedback in order to gain consensus of opinion of a group of experts (Gupta and Clarke, 1996; Pätäri and Sinkkonen, 2014). Consensus of opinion is achieved through multiple iterations between the experts (Hsu and Sandford, 2007).

This technique has been used in different contexts such as business, industry, planning, education, environment, policy analysis or health care research (Gupta and Clarke, 1996), being helpful in situations where individual judgements must be combined to achieve agreement on a particular issue.

One of the strengths of the technique is its ability to organize group communication, allowing the inclusion of informed individuals or experts with different expertise across different locations (McKenna, 1994; Powell, 2003). The technique also avoids situations where powerful individuals could dominate the consensus process (Keeney et al., 2006).

Although Delphi techniques have been interpreted in different forms and no universal guidelines exist (Hasson et al., 2000), the process is typically described as follows. First, an open-ended questionnaire is presented to the panel in order to obtain a first opinion of the experts (also known as participants). Once the questionnaires are returned, the answers are summarized, being designed a new questionnaire based on the responses from the first round (Keeney et al, 2006). This new questionnaire is then returned to each member of the panel, showing the responses of the other participants and the participant’s own response. Once participants see the overall results, they are asked to reconsider their initial response. This process is repeated until consensus is reached[1].

Results of the Delphi studies depend on decisions made by the members of the expert panel. The size of the panel depends on factors such as the magnitude of the problem, and available resources in terms of time and money, existing in the literature a wide variation in the number of members (Powell, 2003).

More than selecting a sample of experts which statistical representativeness from a specific population, the Delphi approach should focus on the qualities of the expert panel. Hence, the sample of participants can be selected considering some predetermined criterion of importance (Hasson et al., 2000).

Delphi users have suggested that the results depend on the experiential knowledge of the expert panel and scientific expertise is a desired quality to increase the credibility with the target audience (Powell, 2003). Diversity in terms of personality, education or professional experience helps to add different perspectives on a problem and a wide base of knowledge (Murphy et al., 1998; Keeney et al., 2006).

In this study the members of the expert panel were selected from the Carbonfeel project. Carbonfeel is a collaborative initiative focused on providing methodological and technological solutions to the processes of calculation, verification, certification and labelling of the CF. A total of 79 organizations from different sectors of activity (business associations, public administrations, certifying agencies, consultancies, non-governmental organizations, foundations, universities, etc.) take part of this initiative. Among them, 18 research entities proactively monitor methodological advances to keep the project up to date (Carbonfeel, 2015).

In order to be a member of the expert panel, Carbonfeel members should meet the following requirements: 1) four years of experience in the CF field, as scientific researchers or consultancy advisors; 2) participating in at least five scientific publications on the CF in the last five years; 3) having a Phd title. These requirements were stablished trying to ensure that the members had enough expertise in the CF analysis and knowledge of the CF indicator and literature.

Only four members of the project met these requirements and they all accepted to participate in the study. These include one person with economics background, one with business management background and two engineers. Two of them had attended to at least one Carbonfeel workshop on CF analysis before joining the panel. Questions with regard to SWOT analysis of the CF were discussed in these workshops by all the participants.

Although a four member panel is a short panel in the Delphi studies context, we did not consider the inclusion of additional members, in order to ensure that the members had enough expertise in the CF analysis. Advantages in terms of required time and resources were considered to keep the initial panel size.

[1] Researchers have suggested that consensus involves levels of agreement between 51% and 80% (Hasson et al., 2000). The required level of agreement in this study is 75%.

Moreover, it is noted that there is little empirical evidence on the effect of the size of the panel on the reliability of the consensus process (Murphy et al., 1998).

The following lines describe the Delphi approach followed in the present study. First, the members of the panel were told about the characteristics and objectives of the study. Then, they were introduced in the SWOT analysis, receiving general information to understand the differences between strengths, weaknesses, threats and opportunities.

Second, the participants were asked to think about the main strengths, weaknesses, threats and opportunities of the CF indicator. This first round was structured allowing participants complete freedom in their responses.

The answers of the first round were summarized and sent back to all the members of the panel. Then, every expert sent a new list. In this stage, some participants showed disagreement with regard to one of the initial strengths pointed out by an expert, which was finally removed, since there was not consensus about its inclusion. Furthermore, one of the initial weaknesses was considered a threat by the majority of experts.

Once these considerations were taken into account, the answers were sent again to all the participants. In the third round, two experts suggested two new strengths, one opportunity and three weaknesses. The answers were sent again to all the participants and the final list was obtained in the fourth round.

3 RESULTS

Figure 1 below shows the summary diagram of the strengths, weaknesses, opportunities and threats presented below.

[Figure 1 here]

3.1 Strengths

The CF indicator's considerable strengths derive from the fact that it is easy to understand (based on physical units which do not require specific knowledge); globally communicable (widely disseminated in all the mass media); of global interest (climate change affects everybody without exclusion); broadly applicable (valid for the eco-label of all types of activities); and easy to implement for specific and effective strategies (impacts are measured in quantitative units) (Carballo-Penela, 2010; Roca and Searcy, 2012).

Since over 75% of GHG emissions can be attributed directly or indirectly to consumers (Heal, 2011), strategies based on consumer demand are seen as being most effective for mitigating climate change (Murray, 2010). This efficiency is based on the so-called multiplier effect that transmits the demand for a low CF to all the links in the supply and value chains (Caldés et al., 2009; Carbonfeel, 2013).

Mitigation strategies based on the use of the CF indicator are highly efficient in terms of cost reduction. This is due the multiplier effect described above, and to the fact that (1) changes in consumption patterns and production processes tend to persist over time (Carbonfeel, 2013); and (2) the analysis of the marginal GHG abatement cost curves such as those developed by Mckinsey & Company (2010) show that strategies based on reducing the CF indicator are cheaper than investing in a wide range of technological advances.

The new CF approach based on the integrated method, also known as organisation-product-based-life-cycle assessment, can be applied to any human activity (organisation, event, product, service) (Cagiao et al., 2011). Therefore, this approach may help the full economic and social immersion of the CF indicator.

The new hybrid methods[2] can exploit synergies from the divergence in PA and IOA (Wiedmann and Minx, 2008; Wiedmann, 2009). Specific developments include their speed and easy implementation. As long as these hybrid methods provide more stringency analysis they should be welcomed (Alvarez et al., 2015a; Weidema et al., 2008).

Besides, with the use of CF methodologies, there is the possibility to obtain the emissions of each stage in a supply chain, what could simplify the process to obtain the CF of a product level. This will allow companies to prioritise the reduction of emissions in those areas where the emissions are higher in the supply chain (McKinnon, 2010).

3.2 Weaknesses

One of the main weaknesses is the insufficient accuracy of the data and methods to permit detailed and disaggregated product CF. Even if the companies could obtain accurately and cost-effectively data, the process of labelling the products still faces major problems (McKinnon, 2010; Reap et al., 2008). This could not be necessarily the case when it comes to using a product CF for internal purposes such as obtaining savings both environmentally and economically (McKinnon, 2010).

The spatial variability of the supply and transport chains, in addition to local environmental uniqueness, enlarges the previously mentioned weakness (Reap et al., 2008).

The different ways of dealing with CF and LCA issues such as: 1) the scope of considered emissions; 2) how to specify cut-off criteria; 3) the system boundaries; 4) the inclusion of offsetting; 5) how to define end-of life scenarios; 6) the allocation of coproducts; 7) how to deal with carbon storage and carbon sequestration; 8) the consideration of capital goods or 9) the inclusion of emissions from land use change, increases the differences between the existing CF methodologies (Finkbeiner, 2009).

The CF indicator considers climate change as a single impact category. This restrictive environmental assessment (which does not consider resource

[2] Hybrid methods offer a solution that would exploit the advantages of PA and IOA (Suh and Nakamura, 2007). These methods cover the entire spectrum of possible combinations from pure PA to pure IOA.

depletion, acidification, toxicity, and so on) may limit the effectiveness of the sustainability assessment. A number of studies show that decisions made considering solely GHG emissions cannot be successful based on a comprehensive environmental perspective in 20% of cases (Weidema et al., 2008). Other analyses developed over 4,000 products show a lower correlation between CF and toxicity (Laurent et al., 2012).

3.3 Opportunities

Investors are increasingly interested in companies that incorporate sustainability strategies, as evidenced by the reports in the Carbon Disclosure Project. The number of investors grew from 35 with assets of $4.5 trillion in 2003, to 655 with assets of $78 billion in 2012 (CDP, 2013).

Many of the tools and databases for CF quantification are freely available. Several governments and transnational organisations publish their tools and guidelines free on registration (GHG Protocol, 2014). As example, the international organisations WRI and WBCSD offer a large quantity of relevant information (WRI & WBCSD, 2015, 2011b). Similarly, the European reference Life-Cycle Database, the ILCD handbook, the freely available standard PAS2050 and the like.

Goods and services listed as green or environmentally friendly are considered a solid future value. The economic crisis in the European Union has not prevented the growth of green economic sectors (e.g. renewable energy), which have seen an annual growth rate of over 25% (Rademaekers et al., 2012). Companies that stay one step ahead of the planned legislation are expected to be in a better position in the future (Carballo-Penela, 2010). The implementation of CF labels could help companies to achieve environmental savings and market differentiation related to more efficient use of materials and energy (Pagell and Wu, 2009; Wiedmann and Lenzen, 2008), presenting competitive opportunities likely to contribute to persistent competitive advantage[3].

Environmental marketing differentiation and savings related to more efficient use of materials and energy along the supply chain are relevant questions that should be considered (Wiedmann and Lenzen, 2008).

Apart from the positive consumer feedback, which is hard to predict (Edwards-Jones et al., 2009), it is worth considering that the world market share of environmentally friendly goods and services was 4.2 billion euros (6% of world Gross Domestic Product). This share is larger in developed countries (21% of the U.S. Gross Domestic Product), and may rise substantially in emerging countries (European Commission, 2014).

CF offers the potential to get life cycle approaches into decision making context which pure LCA did not reach yet. It may offer the opportunity to increase the

[3] Pagell and Wu (2009) point out that environmental success requires the need alignment between the economic and noneconomic elements of sustainability.

audience and to make the companies and consumers more aware about the global warming problem (Finkbeiner, 2009; Jensen, 2012).

If the companies and products CF calculations are audited by independent agencies, this will allow the CF indicator to be a cost-effective measure to deal with some mistrusts about the underestimation of the emissions (McKinnon, 2010).

The proposal made by some governments about compulsory personal annual carbon amount of CO_2 allowance to emit, makes necessary a personal carbon trade market. The CF indicator could be a helpful tool to achieve this goal (McKinnon, 2010).

3.4 Threats

System boundaries are often among the greatest threats in CF quantification. In product CF, the commonly-used PA requires the participation of all the elements involved in the product life-cycle. The difficulty of obtaining all this data requires the threshold for significance –i.e. cut-off criteria– to be defined and justified before the assessment. These boundaries and thresholds may vary subjectively with each analyst, and therefore compromise the consistency and comparability of results. In corporate CF, the quantification of so-called indirect emissions or scope 3[4] emissions is voluntary (WRI & WBCSD, 2011b). According to some authors (e.g. Matthews et al., 2008), these emissions are in some cases higher than 70% of the total emissions associated to an organisation or product. Scope 3 emissions are therefore required to ensure relevance, consistency and comparability.

The lack of integration between product and corporate CF could be the main threat. The CF indicator has been largely extended through two different approaches: (1) corporate CF, developed under schemes designed according to ISO 14064-1, the GHG Protocol and the Emissions Trading Directive –among the main references (EC, 2004; ISO, 2006a; WRI and WBCSD, 2004)– and quantified by compiling corporate inventories built with activity data; and (2) product CF, developed under the LCA guidelines, a method that explores how the delivery of or demand for a specific product or service sets off processes that may cause environmental impacts (ISO, 2006b), and quantified by compiling process inventories. Evidence of this non-integration is the publication of the two different standardisation schemes, ISO/TR 14067:2013 and ISO/TS 14069:2013 (ISO, 2013a, 2013b). The ISO/TR 14067 derived from the ISO 14040:2006 and ISO 14044:2006 used for LCA (ISO, 2006b, 2006c). In turn, ISO/TS derived from the GHG Protocol Corporate Standard. Given these circumstances, consumers receive information under two different approaches, which hinders the successful implementation of the CF indicator due to the lack of integration between both approaches (Alvarez et al., 2015b).

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[4] According to the Greenhouse Gas Protocol Corporate Standard scope 3 emissions include indirect emissions which are a consequence of the activities of the company, but occur from sources not owned or controlled by the organization.

Despite the well-detailed guidelines based on the ISO standard that help researchers and managers in the effort of homogenization (see as example, (JRC-IES, 2010b), international standards for CF implementation such as those developed by ISO do not provide a specific framework for the use of sources or communication programmes. For example, the result of an assessment can depend upon which database you decided to use. Furthermore, in connection with communication, there are currently more than 450 eco-labels in the world (Ecolabel Index, 2015). Although these figures reveal a substantial interest in environmental assessment, the proliferation of methodologies, communication programmes and eco-labels pose a serious problem for consumer confidence in the results (Hoekstra and Wiedmann, 2014).

Additionally, some authors state that the CF indicator is not the right proxy to support sustainable production and consumption (Finkbeiner, 2009). On the other hand, there are not enough CF studies audited in order to know the behaviour of corporate and customers after knowing the total amount of CO_2 emissions (McKinnon, 2010; Jensen, 2012).

Economic and financial crises (such as the global crisis triggered by the collapse of the U.S. subprime mortgage market) are an obstacle for companies investing in CF implementation and environmental protection in general (Lowellyne, 2015).

4 DISCUSSION

4.1. Recommendations

The SWOT analysis enables the design of recommendations that ameliorate the weaknesses and threats and enhance the strengths and opportunities. Four recommendations have been considered to address (1) climate change as a single impact category, (2) system boundaries and thresholds, (3) proliferation of methodologies and communications programmes and (4) methodological divergence.

The weakness derived from considering climate change as a single impact category can be solved through a strategy based on two important concepts: (1) EF and (2) Critical Load. The EF allows different impact categories to be incorporated in a consumption-based perspective (JRC-IES, 2011). This indicator is currently highlighted in European policies using both product and organisation approaches (European Commission, 2013). The concept of Critical Load may be useful for obtaining equivalences between environmental impacts and ecological footprint. It measures the maximum levels (e.g. acidifying compounds) before sufficient changes are caused that harm the long-term structure and functioning of the particular ecosystem. This concept can transform the environmental impacts into areas of biologically productive land and water so the impact can be assumed by the ecosystem[5]. The consideration of GHG emissions and absorption factors for land-use activities enables the final equivalence between ecological footprint and CF. In other words, it would

[5] Rodríguez-Lado and Macías (2006) includes examples relating to critical acidification load.

basically make the CF indicator like a LCA in which all midpoints (acidification, human toxicity, etc.) would be characterized in tones of CO_2 equivalents.

System boundaries and thresholds which do not vary subjectively according to the analysts' criteria can be implemented through two strategies: (1) IOA and (2) objective cut-off rules. Recent European research programmes have led to important advances in IOA, which includes high detailed multi-regional databases (Wood et al., 2015). The objective cut-off rules can be done in two ways: first, by further reinforcing the use of specific and clearly stated Product Category Rules and Corporate Category Rules. Current efforts are not sufficient, as an example, all assessments in the electrical sector should be based on the same product category rule, with no distinction between renewable and fossil technologies (Schmincke et al., 2007). Second, corporate annual accounts could be used as a mandatory framework to assess corporate CF, as a) these reports reflect annual activity, and b) this information is mandatory for all legal corporations.

The proliferation of methodologies and communication programmes can be solved through two possible strategies. First, communication programmes need information about the choice of standards, methods and databases applied to quantify CF; this can be used to assess consistency and support relevance and comparability in CF quantification and communication. Second, the proliferation can be reduced through international agreements within the International Organization for Standardization. Initiatives of particular note include the recent work developed within the ISO 14072.

4.2. Integrated approach

The methodological divergence of product CF and corporate CF has led to the development of new approaches that are valid for both domains. Various initiatives can be classified under the integrated approach (Cagiao et al., 2011). These are currently underway in Spain (Carballo-Penela and Doménech, 2010), United Kingdom (Wiedmann et al., 2011a), Germany (Schaltegger and Csutora, 2012), Italy (Scipioni et al., 2012) and the United States (Suh and Lippiatt, 2012). Since convergence between product and corporate CF is a key point for enabling comparability and gaining consumer confidence, it is important to design a single valid approach for both product and corporate CF (including events, services, territory, etc.).

The existence of an integrated approach valid for both product and corporate footprint could help to deal with some weaknesses and strengths of the indicator. This approach combines both product and corporate CF methods. First, it calculates an in-depth corporate CF, and then distributes it among the processes of the products and services dispatched to the market. Process mapping is used to allocate the correct weight of each product and service. Under the integrated approach, the accumulated product CF from products and services dispatched by a corporate entity is equal to the corporate CF. This is considered a key point in dealing with the lack of convergence between product and corporate CF. In addition, the integrated approach may solve the risk of system boundary incompleteness, since corporate CF clearly defines boundaries and thresholds avoiding subjectivity of analysts' criteria.

The guidelines for this approach should take into account the consensus already achieved in the technical specification ISO/TS 14067 and technical report ISO/TR 14069. Figure 2 shows the relation between both standards in order to develop a single methodological framework with which to implement the integrated approach and to allow the application of the CF indicator under a single approach valid for both product and corporate CF.

[Figure 2 here]

The implementation of the integrated approach must clearly define the specific inventories to be quantified. Corporate inventories are easier to compile than product inventories, as product inventories may include different entities in the supply or value chain. This statement is reinforced by McKinnon (2010) which consider that product-level carbon auditing and labelling is a “wasteful distraction”. The first step is therefore to assess the corporate CF from a bottom-up perspective enabling the partial product CF (i.e. from cradle to gate) to be developed from a top-down perspective. The use of IOA in corporate CF assessment allows the inclusion of indirect upstream emissions related to both the value chain and consequently the supply chain. The structural path analysis developed by Lenzen (2007) can be used to clearly state emissions from different levels of the supply or value chain.

For communication, the integrated approach requires the analysis of the different components detailed in technical specification ISO/TS 14067 and technical report ISO/TR 14069, shown in Figure 3. It is important to note that only partial product CF is assessed, since downstream GHG emissions are not easy to include in IOA. Under this approach, each link in the supply or value chain should quantify its GHG emissions by adding its direct GHG emissions to the indirect upstream emissions. Thus each link can reduce its CF by making changes in the consumption patterns (indirect emissions) or in the patterns of the activity under its control (direct emissions).

[Figure 3 here]

Further guidelines for the integrated approach could include information on voluntary components. Both ISO standards (ISO/TS 14067 and ISO/TR 14069) contain comprehensive information that can be used for this purpose. For example, new components to be taken into account might include carbon storage in products, or emissions from changes in indirect land use. These guidelines could also be improved by adding specifications relating to existing recommendations.

5 CONCLUSIONS

The current knowledge of the CF indicator must be assessed from a strategic point of view. The divergence between product and corporate CF and the different techniques used to quantify life-cycle emissions hinder its successful and global implementation. The SWOT analysis allows this assessment and pays particular attention to internal and external factors that can be used to propose recommendations for its standard implementation. Our analysis highlights the need for studies under the four recommendations described, which could lead to the successful global implementation of the CF indicator based on principles of consistency, relevance and comparability.

The proposed recommendations highlight the need to promote the integrated method as a single approach to CF. This key recommendation can help to solve some of some the threats and weaknesses observed, while reinforcing the strengths and opportunities. The proposed approach for CF also meets the requirements outlined in the leading standards recently published for CF under ISO (2013a, 2013b). These recommendations can therefore serve to pave the way for the development of new, specific and highly-detailed guidelines.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

Alvarez, S., Blanquer, M., Rubio, A., 2014. Carbon footprint using the Compound Method based on Financial Accounts. The case of the School of Forestry Engineering, Technical University of Madrid. J. Clean. Prod. 66, 224–232. doi:10.1016/j.jclepro.2013.11.050

Alvarez, S., Planelles, R., Rubio, A., 2015a. Carbon footprint from helitankers: sustainable decision making in aerial wildfire fighting. Int. J. Wildl. Fire 24. doi:10.1071/WF15011

Alvarez, S., Rubio, A., 2015a. Carbon Footprint in Green Public Procurement: A case study in the services sector. J. Clean. Prod. 93, 159–166. doi:10.1016/j.jclepro.2015.01.048

Alvarez, S., Rubio, A., 2015b. Compound Method Based on Financial Accounts versus Process Life Cycle Analysis in Product Carbon Footprint: a Comparison Using Wood Pallets. Ecol. Indic. 49, 88–94. doi:10.1016/j.ecolind.2014.10.005

Alvarez, S., Sosa, M., Rubio, A., 2015b. Product and corporate carbon footprint using the compound method based on financial accounts. The case of Osorio wind farms. Appl. Energy 139, 196–204. doi:10.1016/j.apenergy.2014.11.039

Berariu, R., Munteanu, M., Condurache, G., Butnaru, R., 2011. Analysis of Sustainable Development Strategies Using SWOT, in: Proceedings of the 2nd Review of Management and Economic Engineering Management Conference: Management of Crisis or Crisis of Management? pp. 217–224.

BSI (British Standard Institute), 2011. Publicly Available Specification 2050: 2011 Specification for the assessment of the life cycle greenhouse gas emissions of goods and services.

Cagiao, J., Labella Hidalgo, S., Carballo-Penela, A., Gómez Meijide, B., 2012. A New Perspective for Labeling the Carbon Footprint Against Climate Change, in: Singh, D.B.R. (Ed.), Global Warming - Impacts and Future Perspectives. InTech, p. 39. doi:10.5772/2599

Cagiao, J., Meijide, B.G., Penela, A.C., Hidalgo, S.L., 2014. Carbonfeel Project: Calculation, Verification, Certification and Labeling of the Carbon Footprint. Low Carbon Econ. 05, 65–79. doi:10.4236/lce.2014.52008

Caldés, N., Varela, M., Santamaría, M., Sáez, R., 2009. Economic impact of solar thermal electricity deployment in Spain. Energy Policy 37, 1628–1636.

Carballo-Penela, A., 2010. Desarrollo sostenible y ecoetiquetado de bienes y servicios. AENOR, Madrid.

Carballo-Penela, A., Doménech, J., 2010. Managing the carbon footprint of products: the contribution of the method composed of financial statements (MC3). Int. J. Life Cycle Anal. 3, 962–969. doi:10.1007/s11367-010-0230-1

Carballo-Penela, A., García-Negro, M.D.C., Doménech, J.L., 2009. A Methodological Proposal for Corporate Carbon Footprint and Its Application to a Wine-Producing Company in Galicia, Spain. Sustainability 1, 302–318. doi:10.3390/su1020302

Carballo-Penela, A., Mateo-Mantecón, I., Doménech, J.L., Coto-Millán, P., 2012. From the motorways of the sea to the green corridors' carbon footprint: the case of a port in Spain. J. Environ. Plan. Manag. 55, 765–782. doi:10.1080/09640568.2011.627422

Carbon Trust, 2006. Carbon footprints in the supply chain: the next step for business, ReportNumber CTC616. London, UK.

CDP (Carbon Disclosure Project), 2013. Global 500 Climate Change Report 2013. United Kingdom.

Čučeka, L., Klemeša;, J.J., Kravanjab, Z., 2012. A Review of Footprint analysis tools for monitoring impacts on sustainability. J. Clean. Prod. 34, 9–20.

Ecolabel Index, 2015. Ecolabel Index | Who's deciding what's green? [WWW Document]. URL http://www.ecolabelindex.com/

Edwards-Jones, G., Plassmann, K., York, E.H., Hounsome, B., Jones, D.L., Milà i Canals, L., 2009. Vulnerability of exporting nations to the development of a carbon label in the United Kingdom. Environ. Sci. Policy

12, 479–490. doi:10.1016/j.envsci.2008.10.005

Ernst & Young France and Quantis, 2010. Product Carbon Footprinting – a Study on Methodologies and Initiatives.

European Commission, 2014. Facts and Figures [WWW Document]. Single Mark. Green Prod. Initiat. URL http://ec.europa.eu/environment/eussd/smgp/facts_and_figures_en.htm

European Commission, 2013. Commission Recommendation (2013/179/EU) on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations. Annex II: Product En- vironmental Footprint (PEF) guide. Off. J. Eur. Union 56. doi:10.3000/19770677.L_2013.124.eng

European Commission, 2004. Commission Decision of 29 January 2004 establishing guidelines for the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council. J. Eur. Union 59, 1–74.

Fang, K., Heijungs, R., de Snoo, G.R., 2014. Theoretical exploration for the combination of the ecological, energy, carbon, and water footprints: Overview of a footprint family. Ecol. Indic. 36, 508–518.

Faruk, A.C., Lamming, R.C., Cousins, P.D., Bowen, F.E., 2001. Analyzing, Mapping, and Managing Environmental Impacts along Supply Chains. J. Ind. Ecol. 5, 13–36. doi:10.1162/10881980152830114

Finkbeiner, M., 2009. Carbon footprinting—opportunities and threats. Int. J. Life Cycle Assess. 14, 91–94. doi:10.1007/s11367-009-0064-x

Galli, A., Wiedmann, T., Ercin, E., Knoblauch, D., Ewing, B., Giljum, S., 2012. Integrating Ecological, Carbon and Water footprint into a “Footprint Family” of indicators: Definition and role in tracking human pressure on the planet. Ecol. Indic. 16, 100–112. doi:10.1016/j.ecolind.2011.06.017

GFN (Global Footprint Network), 2007. Footprint term glossary.

GHG Protocol, 2014. Third Party Databases. Available [WWW Document]. URL http://www.ghgprotocol.org/Third-Party-Databases

Gupta, U.G., Clarke, R.E., 1996. Theory and applications of the Delphi technique: A bibliography (1975–1994). Technol. Forecast. Soc. Change 53, 185–211. doi:10.1016/S0040-1625(96)00094-7

Hasson, F., Keeney, S., McKenna, H., 2000. Research guidelines for the Delphi survey technique. J. Adv. Nurs. 32, 1008–15.

Heal, S., 2011. Radical Disruptions of Value Chains. Beril. Germany.

Helms, M.M., Nixon, J., 2010. Exploring SWOT analysis - where are we now?: A review of academic research from the last decade. J. Strateg. Manag. 3, 215–51.

Hertwich, E.G., Peters, G.P., 2009. Carbon Footprint of Nations: A Global, Trade-Linked Analysis. Environ. Sci. Technol. 43, 6414–6420. doi:10.1021/es803496a

Hoekstra, A.Y., Wiedmann, T.O., 2014. Humanity's unsustainable environmental footprint. Science. 344, 1114–1117. doi:10.1126/science.1248365

Hsu, C., Sandford, B., 2007. The Delphi Technique: Making Sense of Consensus. Pract. Assessment, Res. Eval. 12, 1–8.

IPCC (Intergovernmental Panel on Climate Change), 2013. Working Group I Contribution to the IPCC Fifth Assessment Report (Ar5), Climate Change 2013: The Physical Science Basis. Final Draft Underlying Scientific-Technical Assessment.

IPCC (Intergovernmental Panel on Climate Change), 1996. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change. Japan.

ISO (International Organization for Standardization), 2013a. ISO/TR 14069:2013 - Greenhouse gases - Quantification and reporting of greenhouse gas emissions for organizations - Guidance for the application of ISO 14064-1. Switzerland, Geneva.

ISO (International Organization for Standardization), 2013b. ISO/TS 14067:2013 Greenhouse gases - Carbon footprint of products - Requierements and guidelines for quantification and communication. Switzerland, Geneva.

ISO (International Organization for Standardization), 2006a. ISO14064-1:2006 - Greenhouse gases. Part 1: Specification with Guidance at the Organization Level for Quantification and Reporting of Greenhouse Gas Emissions and Removals. Switzerland, Geneva.

ISO (International Organization for Standardization), 2006b. ISO 14040: 2006 - Environmental management - life cycle assessment - principles and framework. Switzerland, Geneva.

Jensen, J.K., 2012. Product carbon footprint developments and gaps. Int. J.

Phys. Distrib. Logist. Manag. 42, 338–354. doi:10.1108/09600031211231326

JRC-IES (Joint Research Centre - Institute for Environment and Sustainability), 2011. Analysis of Existing Environmental Footprint Methodologies for Products and Organizations: Recommendations, Rationale, and Alignment.

JRC-IES (Joint Research Center - Institute for Environmental and Sustentability), 2010a. ILCD handbook. General guide for life cycle assessment—detailed guidance.

JRC-IES (Joint Research Center - Institute for Environmental and Sustentability), 2010b. International Reference Life Cycle Data System. ILCD Handbook.

Keeney, S., Hasson, F., McKenna, H., 2006. Consulting the oracle: ten lessons from using the Delphi technique in nursing research. J. Adv. Nurs. 53, 205–12. doi:10.1111/j.1365-2648.2006.03716.x

Kessler, E.H., 2013. Encyclopedia of Management Theory SWOT Analysis Framework. doi:10.4135/9781452276090

Laurent, A., Olsen, S.I., Hauschild, M.Z., 2012. Limitations of carbon footprint as indicator of environmental sustainability. Environ. Sci. Technol. 46, 4100–4108. doi:10.1021/es204163f

Lenzen, M., 2007. Structural path analysis of ecosystem networks. Ecol. Modell. 200, 334–342.

Majeau-Bettez, G., Strømman, A.H., Hertwich, E.G., 2011. Evaluation of process- and input-output-based life cycle inventory data with regard to truncation and aggregation issues. Environ. Sci. Technol. 45, 10170–10177. doi:10.1021/es201308x

Marsh-Patrick, A., 2010. Company GHG Emissions Reporting – a Study on Methods and Initiatives, Initiatives.

Matthews, H.S., Hendrickson, C.T., Weber, C.L., 2008. The importance of carbon footprint estimation boundaries. Environ. Sci. Technol. 42, 5839–42.

McKenna, H.P., 1994. The Delphi technique: a worthwhile research approach for nursing? J. Adv. Nurs. 19, 1221–5.

McKinnon, A.C., 2010. Product level carbon auditing of supply chains. Int. J. Phys. Distrib. Logist. Manag. 40, 42–60. doi:10.1108/09600031011018037

Mckinsey & Company, 2010. Impact of the financial crisis on carbon economics:

Version 2.1 of the global greenhouse gas abatement cost curve.

Minx, J.C., Wiedmann, T., Wood, R., Peters, G.P., Lenzen, M., Owen, a., Scott, K., Barrett, J., Hubacek, K., Baiocchi, G., Paul, a., Dawkins, E., Briggs, J., Guan, D., Suh, S., Ackerman, F., 2009. Input–Output Analysis and Carbon Footprinting: an Overview of Applications, Economic Systems Research. doi:10.1080/09535310903541298

Murphy, M.K., Black, N.A., Lamping, D.L., McKee, C.M., Sanderson, C.F., Askham, J., Marteau, T., 1998. Consensus development methods, and their use in clinical guideline development. Health Technol. Assess. 2, i–iv, 1–88.

Murray, E., 2010. There is evidence that Product Carbon Footprint labels help reduce greenhouse gas emissions across product lifecycles. Does Carbon Label. Work.

Pagell, M., Wu, Z., 2009. Building a more complete theory of sustainable supply chain management using case studies of 10 exemplars. J. Supply Chain Manag. 45, 37–56. doi:10.1111/j.1745-493X.2009.03162.x

Parliamentary Office of Science and Technology (POST), 2006. Carbon footprint of electricity generation. London, UK.

Pätäri, S., Sinkkonen, K., 2014. Energy Service Companies and Energy Performance Contracting: is there a need to renew the business model? Insights from a Delphi study. J. Clean. Prod. 66, 264–271. doi:10.1016/j.jclepro.2013.10.017

Pesonen, H.-L., Horn, S., 2014. Evaluating the climate SWOT as a tool for defining climate strategies for business. J. Clean. Prod. 64, 562–571. doi:10.1016/j.jclepro.2013.10.013

Pesonen, H.-L., Horn, S., 2012. Evaluating the Sustainability SWOT as a streamlined tool for life cycle sustainability assessment. Int. J. Life Cycle Assess. 18, 1780–1792. doi:10.1007/s11367-012-0456-1

Peters, G.P., 2010. Carbon footprints and embodied carbon at multiple scales. Curr. Opin. Environ. Sustain. 2, 245–250. doi:10.1016/j.cosust.2010.05.004

Peters, G.P., Andrew, R.M., Boden, T., Canadell, J.G., Ciais, P., Le Quéré, C., Marland, G., Raupach, M.R., Wilson, C., 2013. The challenge to keep global warming below 2 ℃. Nat. Clim. Chang. 3, 4–6. doi:10.1038/nclimate1783

Pickton, D.W., Wright, S., 1998. What’s SWOT in strategic analysis? John

Wiley.

Powell, C., 2003. The Delphi technique: myths and realities. J. Adv. Nurs. 41, 376–82.

Rademaekers, K., Laan, J. van der, Widerberg, O., Zaki, S., Klaassens, E., Smith, M., Steenkamp, C., 2012. The number of Jobs dependent on the Environment and Resource Efficiency improvements. Rotterdam. The Netherlands.

Rao, C.A., Rao, B.P., Sivaramakrishna, K., 2009. Strategic Management and Business Policy. Excel Books India.

Reap, J., Roman, F., Duncan, S., Bras, B., 2008. A survey of unresolved problems in life cycle assessment. Int. J. Life Cycle Assess. 13, 290–300. doi:10.1007/s11367-008-0008-x

Roca, L.C., Searcy, C., 2012. An analysis of indicators disclosed in corporate sustainability reports. J. Clean. Prod. 20, 103–118. doi:10.1016/j.jclepro.2011.08.002

Schaltegger, S., Csutora, M., 2012. Carbon accounting for sustainability and management. Status quo and challenges. J. Clean. Prod. 36, 1–16. doi:10.1016/j.jclepro.2012.06.024.Schmincke, E., Capello, C., Holmquist, L., Le-Bouldch, D., Frischknecht, R., Raadal, H., 2007. PCR 2004:02 Electricity and district heating generation.

Scipioni, A., Manzardo, A., Mazzi, A., Mastrobuono, M., 2012. Monitoring the carbon footprint of products: a methodological proposal. J. Clean. Prod. 36, 94–101.

Suh, S., Lippiatt, B.C., 2012. Framework for hybrid life cycle inventory databases: a case study on the Building for Environmental and Economic Sustainability (BEES) database. Int. J. Life Cycle Assess. 17, 604–612. doi:10.1007/s11367-012-0393-z

Suh, S., Nakamura, S., 2007. Five years in the area of input-output and hybrid LCA. Int. J. Life Cycle Assess. 12, 351–352. doi:10.1065/lca2007.08.358

Viaggi, D., 2013. Developing Improved Tools for the Economic Analysis of Innovations in the Bioeconomy: Towards a Life Cycle-Strengths-Weaknesses-Opportunities-Threats (LC-SWOT) Concept? J. Manag. Strateg. 4, p17. doi:10.5430/jms.v4n2p17

Wackernagel, M., Rees, W.E., 1996. Our Ecological Footprint. New Soc. Publ. New Society Publishers.

Weidema, B.P., Thrane, M., Christensen, P., Schmidt, J., Løkke, S., 2008. Carbon Footprint. J. Ind. Ecol. 12, 3–6. doi:10.1111/j.1530-9290.2008.00005.x

Wiedmann, T., 2009. Editorial: Carbon Footprint and Input–Output Analysis – an Introduction. Econ. Syst. Res. 21, 175–186. doi:10.1080/09535310903541256

Wiedmann, T., Lenzen, M., 2008. Unravelling the Impacts of Supply Chains—A New Triple-Bottom-Line Accounting Approach and Software Tool, in: Schaltegger, S., Bennett, M., Burritt, R.L., Jasch, C. (Eds.), Environmental Management Accounting for Cleaner Production, Eco-Efficiency in Industry and Science. Springer Netherlands, Dordrecht, pp. 65–90. doi:10.1007/978-1-4020-8913-8

Wiedmann, T., Minx, J., 2008. A Definition of " Carbon Footprint ," in: C. C. Pertsova, Ecological Economics Research Trends: Chapter 1, Pp. 1-11. Nova Science Publishers. NY, USA.

Wiedmann, T., Suh, S., Feng, K., Lenzen, M., Acquaye, A., Scott, K., Barrett, J., 2011. Application of Hybrid Life Cycle Approaches to Emerging Energy Technologies À The Case of Wind Power in the UK. Environ. Sci. Technol. 45, 5900–5907. doi:10.1021/es2007287

Wood, R., Stadler, K., Bulavskaya, T., Lutter, S., Giljum, S., de Koning, A., Kuenen, J., Schütz, H., Acosta-Fernández, J., Usubiaga, A., Simas, M., Ivanova, O., Weinzettel, J., Schmidt, J., Merciai, S., Tukker, A., 2015. Global Sustainability Accounting—Developing EXIOBASE for Multi-Regional Footprint Analysis. Sustainability 7, 138–163. doi:10.3390/su7010138

WRI & WBCSD (World Resources Institute and World Business Council for Sustainable Development), 2015. GHG Protocol Scope 2 Guidance. USA.

WRI & WBCSD (World Resources Institute and World Business Council for Sustainable Development), 2011a. Product Life Cycle Accounting and Reporting Standard. USA.

WRI & WBCSD (World Resources Institute and World Business Council for Sustainable Development), 2011b. Corporate Value Chain (Scope 3) Accounting and Reporting Standard. USA.

WRI & WBCSD (World Resources Institute and World Business Council for Sustainable Development), 2004. The GHG Protocol. A Corporate Accounting and Reporting Standard. USA.

Figure captions

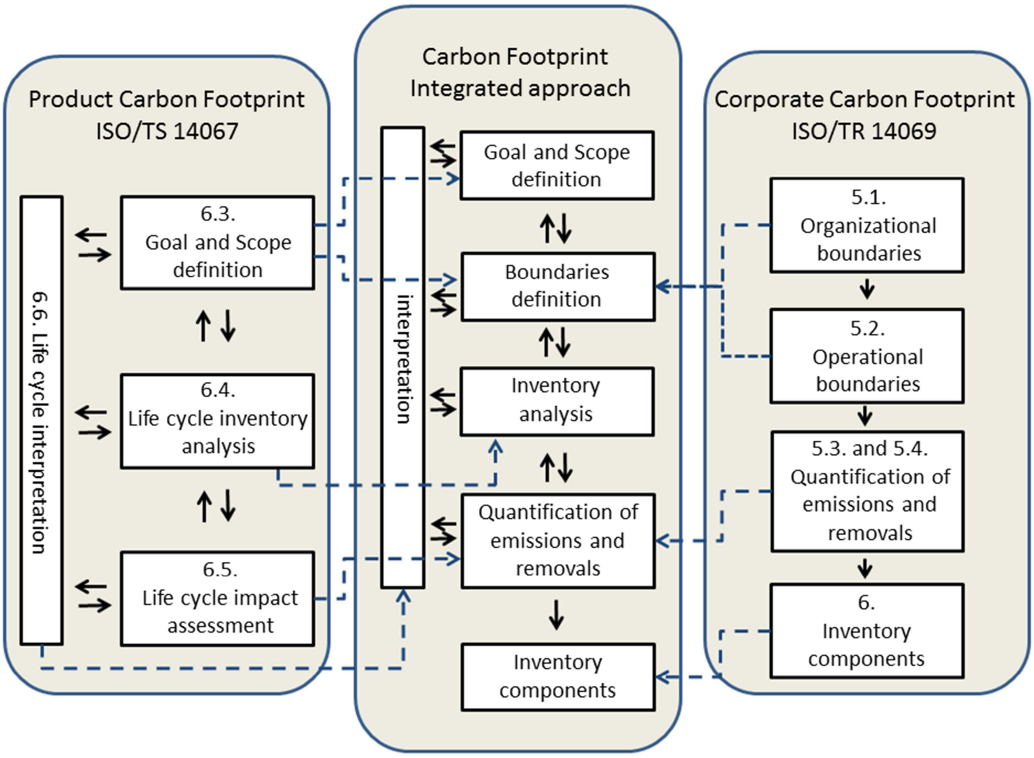
Figure 1. Summary diagram of SWOT analysis of the carbon footprint indicator.

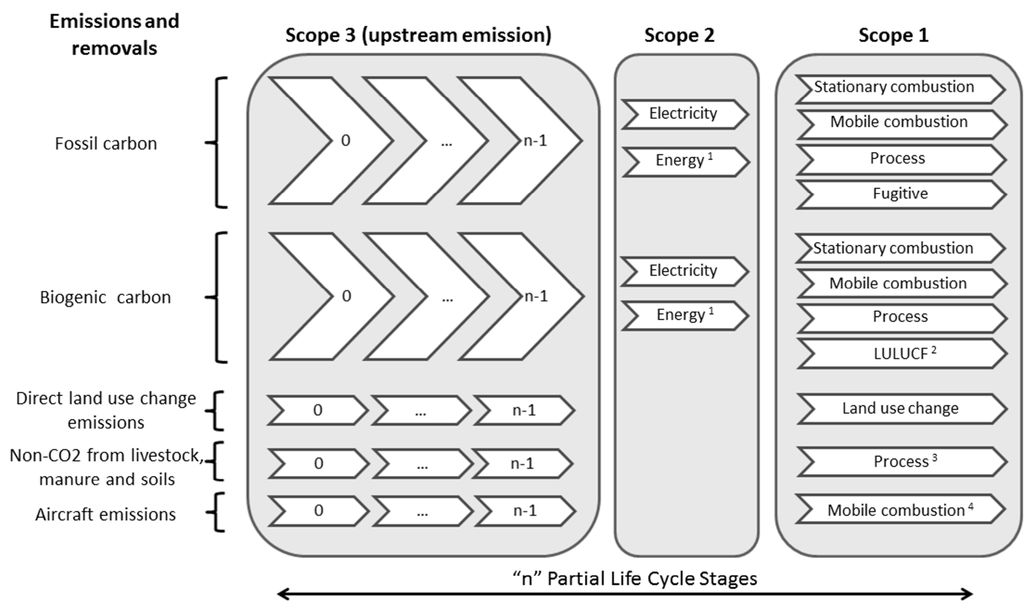
Figure 2. Methodology for Carbon Footprint quantification under the integrated approach and consistency with ISO/TS 14067 and ISO/TR 14069.

Figure 3: Final inventory components required for communicating corporate Carbon Footprint and partial product Carbon Footprint using the integrated approach and maintaining consistency with ISO/TS 14067 and ISO/TR 14069.

Table 1. A summary of some definitions of the CF concept in the literature. Own elaboration from Wiedmann and Minx (2008).

Source	Definition
POST (2006)	"A 'carbon footprint' is the total amount of CO_2 and other greenhouse gases, emitted over the full life cycle of a process or product. It is expressed as grams of CO_2 equivalent per kilowatt hour of generation (gCO_2eq/kWh), which accounts for the different global warming effects of other greenhouse gases."
Carbon Trust (2006)	"…the total emissions of greenhouse gases in carbon equivalents from a product across its life cycle from the production of raw material used in its manufacture, to disposal of the finished product"
GFN (2007)	"…the demand on biocapacity required to sequester (through photosynthesis) the carbon dioxide (CO_2) emissions from fossil fuel combustion"
Wiedmann and Minx (2008)	"The carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the lifestages of a product."
Browne et al. (2009)	"…the land area required to sequester the greenhouse gas emissions associated with the transport, disposal, recycling and/or composting of household waste generated"
Hertwich and Peters (2009)	"…it refers to the mass of cumulated CO_2 emissions, for example, through a supply chain or through the life-cycle of a product, not some sort of measure of area"
Wiedmann (2009)	"…an attempt to capture the full amount of greenhouse gas emissions that are directly and indirectly caused by an activity or are accumulated over the life stages of a product output analysis"


Product Carbon Footprint
ISO/TS 14067
6.6. Life cycle interpretation
6.3.
Goal and Scope
definition
6.4.
Life cycle inventory
analysis
6.5.
Life cycle impact
assessment
Carbon Footprint
Integrated approach
interpretation
Goal and Scope
definition
Boundaries
definition
Inventory
analysis
Quantification of
emissions and
removals
Inventory
components
Corporate Carbon Footprint
ISO/TR 14069
5.1.
Organizational
boundaries
5.2.
Operational
boundaries
5.3. and 5.4.
Quantification of
emissions and
removals
6.
Inventory
components



1: Steam,heating, cooling, compressed air
2: Land use, land use change and forestry
3: Specific case : corporate owner or controller of livestock, manure or soils
4: Specific case : corporate owner or controller of aircrafts

Strengths	Weaknesses
Easy to understand and communicate globally, of global interest, broadly applicable and easy to implement	Insufficient accuracy of the data and methods to permit disaggregated product CF
Simplify the process to obtain CF of products and help to prioritise the reduction of emissions	Variability of the supply chains in addition to local environmental uniqueness
Multiplier effect on the value and supply chain	Different ways of dealing with CF and LCA issues increases the differences between the existing methodologies
Capacity for social and economic immersion	Climate change as a single impact category

Opportunities	Threats
Growth in the number of investors and in green economic sectors	Subjective system boundaries and thresholds
Free methods and databases	Lack of convergence between product CF and corporate CF
Audit CF by independent agencies	Proliferation of methods and communication programmes
Solid future value. Good for differentiating and opening new markets. Good for emerging environmental legislation	Economic and financial crises

Highlights

1. We apply the SWOT analysis on the carbon footprint indicator.

2. We discus recommendations for the standardization of CF analysis

3. We elaborate guidelines for integrated approach to meet new standards.