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ScienceDirect

Procedia CIRP 107 (2022) 869–875

www.elsevier.com/locate/procedia

55th CIRP Conference on Manufacturing Systems

Carbon accounting management in complex manufacturing supply chains: A structured framework approach

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Abstract

Improving the management of carbon emissions in the drive to Net-Zero can involve both complex measurements and the development of cleaner technologies, which is a demanding challenge for both the private and public sectors. Specifically, within complex and often sensitive supply chains such as aerospace manufacturing, accounting for carbon management requires quantification of the extended enterprise's direct and indirect emissions as a system. Currently however, there is a lack of standardised methods for carbon accounting suitable for use in the measurement and auditing of carbon performance both in the production process as well as in the supply chain. This research presents a structured framework-based approach, that could facilitate accurate, consistent and simplified management of carbon scoping, measurement and reporting, across complex extended supply chains. The proposed five step approach sets a thematic orientation for future customisation of carbon accounting tools at every step of the framework.

Keywords: Carbon accounting; suppply chain; aerospace manufacturing; Net-Zero; GHG

1. Introduction

Carbon accounting, also known as greenhouse gas (GHG) accounting, maps the amount of carbon dioxide equivalent (CO_2e) emitted by any organization [1]. It finds its application at national level, state level, organizational level and even project level. In this accounting method, carbon is treated as a commodity to be traded in carbon markets as a credit. Multiple product-based applications of carbon accounting can be seen in national inventories, corporate environmental reports, and carbon footprint calculators. It also helps identify factors that directly impact climate change and thereby can be deemed to be of invaluable support in devising policies that can mitigate this impact.

Carbon accounting ideally should be seen as an end-to-end approach to support science-based targets and decision making. In both for-profit and non-profit organizations, carbon accounting is used to map and quantify GHG released as part of their direct production activities, utilities, and their affiliated supply chains. The ultimate objective of carbon accounting is to ensure reduction in emissions and utilize energy wisely [2].

10.1016/j.procir.2022.05.077

There is however a pre-requisite in the following capabilities to ensure that the end objective is met [3]:

- Easy access to real time historical energy-usage data.
- Granular visibility of the entire manufacturing process and related emissions.
- Support from senior leadership to focus on increasing the transparency of emissions data.
- Access to benchmark relevant industry-sector data.

Over the last decade, a flurry of carbon calculators, emission reporting guidelines, standards and certifications in the carbon accounting ecosystem have been developed. [4]

Some of the most ubiquitous terminology used in this domain is shown in Table 1.

Table 1 : Terms used in carbon accounting [5]

Term	Definition
Standard	Formal, highly regarded document establishing uniform multi-jurisdictional rules (e.g., International Organization for Standardization [ISO] standards).
Framework	Guidance on a product or activity that unifies existing methods and fills gaps required to report required metrics.
Disclosure Platform	Voluntary or mandatory medium for reporting carbon emissions information.
Sustainability Reports	Emissions information developed and released by a company.
Certification	Qualification conveyed by a third party to certify that a product meets certain criteria.

This paper enlists the most important tools that are currently being used and attempts to create an end-to-end framework for carbon accounting for deployment in complex supply chains. This is especially pertinent to the aerospace manufacturing industry as the drive to "Net-Zero" necessitates sophisticated carbon management and accounting, given the emerging trend of transitioning from vertical to horizontal integration of supply chains in this sector. [6] Therefore, the above-mentioned pre-requisites for holistic carbon accounting need to be incorporated in the accounting framework to support such transition in the industry. The paper is divided into three sections. The first section is a literature review which presents an introduction with insights into all the carbon accounting tools currently available. The second section is a discussion, delving into a five-step carbon accounting framework and mapping the current tools to the steps of the framework. The third section concludes with the recommended application of the framework and relevant future research areas.

2. Literature Review

Boeing's market outlook has projected a continuous growth of the aerospace industry over the next decade. Their analysis claims that the industry is showing definite signs of recovery following the COVID19 pandemic. From a commercial air travel standpoint, the industry is on the path to recovery. Boeing's 20-year commercial forecast through to 2040, projects demand for more than 43,500 new airplanes valued at 7.2 trillion USD [7].

On the manufacturing side, OEMs like Airbus witnessed a 30% reduction in the overall production of commercial aircrafts due to the global pandemic [8]. The next four to five years however, will require a significant increase in production to meet growing global demand. Hence, there is an increased need to mitigate the potential environmental impact of such growth. This calls for a need to measure the GHG emissions throughout the aerospace value chain and to identify the potential drivers for change to counter this impact [9]. Thorough literature review of carbon accounting in aerospace manufacturing clearly indicates that whilst critical analysis of available accounting methods is evolving, the actual accounting methods used by enterprises still lack depth of study and formulation of unified practical frameworks [4]. This study attempts to investigate the various components of carbon accounting that are being deployed from an industry agnostic viewpoint.

2.1. Lifecyle Assessment

Life cycle assessment (LCA) (also known as life cycle analysis) is a systematic approach for evaluating the environmental impacts of a product, service or system, including the impact of the entire value chain associated with that product throughout various stages of its life, from cradle-to-gate, cradle-to-grave, or any other part of its life, depending upon the approach and scope. In manufacturing value chains, it includes assessment of environmental impact of raw material extraction, processing, distribution, and all affiliated services. This creates an overall environmental profile of the product [11].

LCA has been evolving during the last three decades. It initially emerged in the 1970s in the form of energy analysis, with value chain impact added in the 1980s and 1990s. In the early 2000s, the social impact of LCA was included and today it has become what is frequently referred to as comprehensive Life Cycle Sustainability Analysis (LCSA).

Multiple carbon footprint calculation mechanisms use LCA as the scoping approach to build frameworks that suit specific product categories and industry sectors or industry. This has happened regardless of the criticism that LCA approach faced regarding boundary definitions, insights generation and the need for pre-defined requirements and guidelines [12].

2.2. Emissions Scoping by Green House Gas Protocol (GHGP)

GHGP is the most frequently used method for carbon footprint calculations, preferred for its granularity across 15 different categories in the value chain [4]. It offers a set of standards designed to provide appropriate frameworks for measuring and reporting GHG emissions by different types of entities that are grouped in three broad "scopes":

- Scope 1 - Direct GHG emissions: Covers all the direct GHG emissions by a company. These are directly controlled by the organization like fuel combustion, company internal transportation or furnaces.

- Scope 2 - Electricity indirect GHG emissions: Covers indirect GHG emissions from the company's utilities like electricity, heat, cooling, or steam. These are a result of a company's activities outside its physical boundaries.

- Scope 3 - Other indirect GHG emissions: Covers other indirect emissions, such as the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity and electricity-related activities. This scope covers the entire supply chain activities beyond the organizational walls [13].

GHGP has been devised in partnership with the World Resources Institute (WRI) and the Business Council for Sustainable Development (WBCSD)[12].In 2016, the same partnership released a framework that is specific for logistics emissions, referred to as the Global Logistics Emissions Council (GLEC). These frameworks are recognized as independent standards by the UK government [14].

2.3. Product Category Rules

Product Category Rules (PCR) are a predefined set of rules, requirements, and guidelines specific to a product category. A group of products that fulfil a specific requirement are called a product category. PCR standardizes the information sharing process by product categorization. These set of rules allow for easier inter-industrial benchmarking by setting the scope of analysis and boundaries for impact measurement. PCR finds its application in Environmental Product Declaration (EPD) after being introduced in ISO 14025, where for all product categories basic procedures and requirements are listed out [15].

2.4. International Reference Life Cycle Data System

The International Reference Life Cycle Data System (ILCD) is an enabler of product studies by providing a repository of credible life cycle data. This data is the foundation of the LCA approach that is the technical basis for all eco-design tools. This guide is intended for LCA practitioners and cross-sectoral experts who can make decisions about the sustainable management of products, resources, and waste. ILCD adds flexibility, consistency and addresses a large variety of questions related to quality assurance over ISO 14040 and 14044 standards. This is done by a series of technical documents that highlight best practices in LCA from a governance and business point of view. The development of the ILCD has been coordinated by the European Commission whom is responsible for the development of ILCD, along with various global functional experts[16].

2.5. Product Environment Footprint Category Rules (PEFCR) Guidance

PEFCRs are used for providing guidance on the potential environmental impact of all products' life cycles. These guidelines are very similar to type III environmental declarations in ISO 14025:2006 and fill a gap with regards to standardisation and consistency in assumptions, measurement and calculations. PEFCRs reduce the number of technical jargon and acronyms, aiding user friendliness. They focus primarily on the most relevant performance parameters in environmental impact, saving effort, time and cost. This is done by listing out the mandatory or most important processes along with default data for benchmarking. Mandatory process listing however is done per specific industry or company. This allows anyone without complete access to granular data, to carry out environmental analysis for a given product. PEFCR also acts as a supplement in the latest version of Product Environment Footprint (PEF) guide[17].

2.6. International Standards Organization (ISO) Standards

ISO 14000 is a family of standards affiliated with environmental management, providing practical voluntary set of tools for companies and organizations of all kinds in order to systematically control and reduce their environmental impact. All ISO standards are periodically reviewed every 5 years to ensure they continue to meet market expectations and keep up with advances in science, technology and management. ISO 14001is the most important component of the ISO 14000 family and provides the core framework in the design and implementation of effective environmental management systems (EMS) in organizations. ISO 14001 is also known as a generic management system standard, due to its breadth of application in all types of organisations[18]. Additionally, ISO 14004 offers best practices for good EMS, and specialized standards dealing with specific aspects of environmental management. The requirements of ISO 14001 are an integral part of the European Union's Eco-Management and Audit Scheme (EMAS).

ISO 14064 published in 2006, comprises of an integrated set of tools to a set standard for accounting of GHG. Part 1 ISO 14064-1:2006 provides specification with guidance at the organization level for quantification and reporting of GHG emissions and removals. Part 2 ISO 14064-2:2006 provides specification with guidance at project level for quantification, monitoring and reporting of GHG emissions reduction or removal enhancements. Part 3 ISO 14064-3:2006 provides specification with guidance for the validation and verification of GHG assertions [19].

2.7. Product Environment Footprint Method

The Product Environmental Footprint (PEF) is a multiple criteria-based measure of environmental performance. It is based on using an LCA approach coupled with PEFCRs standards and specific guidance. PEF information is used for the strategic purpose of reducing the environmental impact of end-to-end supply chain activities. PEF models the environmental impacts of material and energy flows of a

product throughout its life cycle together with GHG emissions and waste streams. This method is specific to each individual product and its associated supply-chain rather than organisation-wide [20].

2.8. Environmental Product Declaration (EPD)

Environmental Product Declaration (EPD) highlights manufacturers' focus on reduction of carbon footprint in the most transparent manner. It uses the LCA approach along with the ISO 14040 standards series and selecting an appropriate product category in PCR [21]. The additional step in this method is third party verification. It is principally centred on Business-to-Business (B2B) footprint calculation transactions rather than the entire value chain impact of a product. All the EPD reports under a product category are available in the International EPD system database [22].

2.9. Environmental Carbon Accounting (ECA)

In business terms, this method is referred to as corporate carbon footprint. This accounting method is a quick and cost-effective process used by enterprises for mapping, summarizing and reporting the entire end-to-end enterprise GHG inventories (including extended supply chain). Designed based on financial accounting principles, this approach uses the process of LCA along with appropriate financial process methodologies. ECA is an evolving concept as there is now a need for more detailed -yet scalable- solutions for carbon accounting. It uses a hybrid life cycle assessment approach and mandates a focus in identifying criticalities in the entire value chain [23].

2.10. Carbon Disclosure Rating

Carbon disclosure rating reports the environmental sustainability of a company as part of a voluntary reporting mechanism. This rating is predominantly for use by investors in their decision-making processes. Carbon Disclosure Project (CDP) is a UK-based non-profit organization that manages carbon disclosure ratings by working with individual companies [24]. In 2020, 6,800 companies participated in the CDP program by answering multi-layered questionnaires specific to their respective industries [19, 20].

2.11. Carbon Performance

Carbon performance is the managerial lens to carbon emissions management. It enables managers to apply a standardized way in evaluating a company's performance with regards to physical impact of emissions and the associated financial impact both in the present and in the future. The 4 indicators that constitute a company's carbon performance are shown in Table 2. Carbon performance has different nuances for managers, financial analysts and policy makers. Managers use carbon performance to focus on carbon reduction strategies. Financial analysts and policy makers use carbon performance for evaluating investment strategies, liabilities and government policies [27].

Table 2: Indicators of Carbon Performance [26]

Indicator	Definition
Carbon Intensity	Relates carbon usage to business performance. Calculated as the firm's carbon usage for the year, divided by a financial metric (e.g., sales revenue) for the same time period.
Carbon Dependency	The change in a company's use of carbon (intensity) over a given time period, expressed as a percentage.
Carbon Exposure	Financial implications of carbon use for a given time period. Relates a company's carbon costs to another financial metric (e.g. sales).
Carbon Risk	The change in monetary carbon performance over a given time, expressed as a percentage.

2.12. Carbon Pricing

Carbon pricing (or CO_2 pricing) is the most renowned model for carbon management, to ensure that organizations reduce their overall GHG emissions. It highlights the economic problem associated with emissions, by putting a cost to the volume amount of emissions. Carbon price limits are set by carbon taxation or carbon emissions trading, which is a purchase allowance for emissions [28]. In 2021, at a global level, 21.7 % of GHG emissions were covered by carbon pricing. Carbon pricing is most popular in the EU and Canada. However, the biggest pollutants - India, Russia, Middle East and most US states, have not yet introduced carbon pricing.

3. Discussion

Complex manufacturing sectors such as aerospace, need to take aggressive action to reduce emissions by 2050. Although the sector is expected to grow significantly, there are challenges to its decarbonization efforts due to legacy infrastructure, manufacturing systems and hydrocarbon-based fuel technology. Decarbonization is a strategic priority especially for the commercial aviation industry in order to avoid any activity restrictions which could have a detrimental impact on international trade, jobs, and clean economic growth [24].

With these challenges in place, it is difficult to plot the starting point, scope, approach, and the right tool to ensure end-to-end accounting. To that end, we propose a carbon accounting framework as a 5- step process to ensure that there is no waste of resources and time on the path to decarbonization. Fig. 1 shows the proposed end-to-end carbon accounting framework. This framework can provide the much-needed standardisation in carbon accounting to ensure that all stakeholders across a complex value chain have consistency of approach in data collection, mapping and eventual reporting. The structured approach provided by the framework also ensures that end-to-end GHG emissions are taken into account by fixing the scope at the very beginning of the process. Clarity in scope, approach, and the overall process, increases the likelihood of overall efficiency of the carbon accounting method, especially for the aerospace industry as the number of stakeholders involved in its value chain are much higher compared to other sectors, with marginal to no scope for error.

Moreover, the framework can be mapped to the current available measurement tools in its different steps, thereby reducing the possibility of redundant effort and could focus the research agenda where there is a need for improved tools of evaluation.
The components of the framework are explained below:

Scope and Approach: 70% of emissions in aerospace manufacturing come from the associated supply chain. This calls for a need to ensure that all Scope 1, Scope 2 and Scope 3 of emissions, as elaborated earlier, are included in the calculations [29].This implies the need for more collaboration and standardisation of approach for all the stakeholders in the supply chain ecosystem. LCA seems to be the most relevant approach, however there is a need to down-select the specific method to be used in LCA. These are namely Process LCA, Economic input-output LCA and Hybrid LCA.

Standards and Guidelines: There are multiple guidelines and established standards that have been evolving over time based on geographical and industry-specific trends. These directives contribute to standardization and consistency in the process. Some carbon footprint calculation methods have recommended standards to be used and should therefore be cross referenced in accordance. For example, PEF method has recommended PEFCR.

Carbon Footprint Calculation: Post the setting of the scope, approach, and standards to use, for accurate foot-print calculation, there are multiple methods as explained above. In general, there are three steps to the calculation [5]:

- Identification of the relevant processes in the scope, collection of process related primary data and emission factors.
- Evaluation of the total emission based on the primary data and CO_2 emission factors.
- Allocation of the emission to a product category or material category.

Carbon Management and Reporting: Carbon reporting and management facilitates the decision-
making process about carbon mitigation strategies to be adopted. Without the necessary reporting, carbon accounting will be incomplete. Accurate reporting is key to overall carbon management and sets the foundation for strategic discussions around environmental sustainability and the practical path to Net Zero GHG emissions.

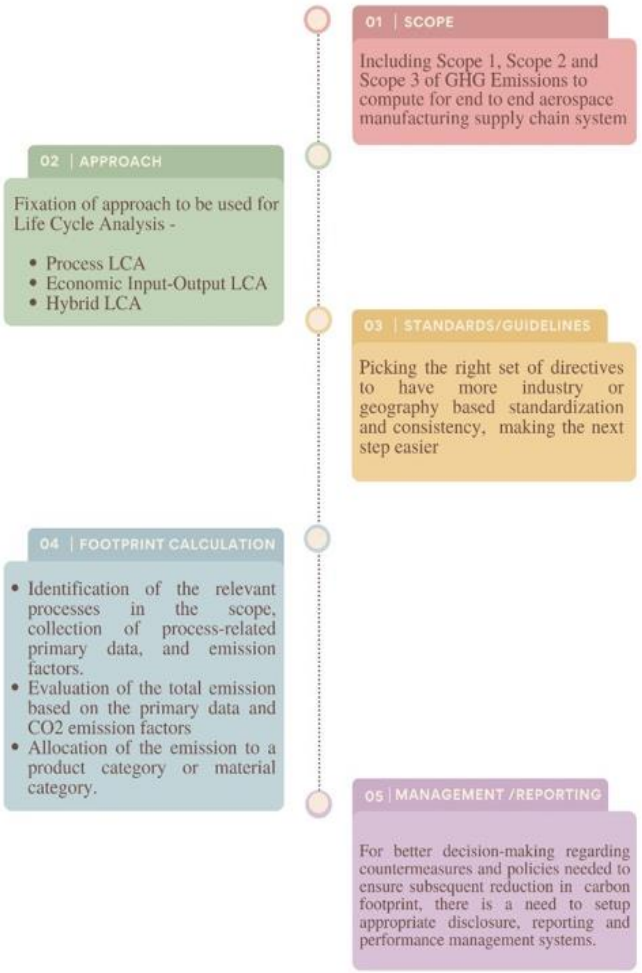

Figure 1 : Carbon Accounting Framework

In this study, we have attempted to align the various tools currently available under each step of the carbon accounting framework as shown in Table 3.

Table 3: Current tools mapped with framework

Component	Tools
Scope and Approach	GHG Emissions Scope 1, 2 & 3 Life Cycle Analysis - Process LCA - Economic Input-Output LCA - Hybrid LCA
Standards and Guidelines	- Product Category Rules - International Reference Life Cycle Data System - Product Environment Footprint Category Rule Guidance - ISO Standards
Carbon Footprint Calculation	-Greenhouse Gas Protocol - Product Environment Footprint Method - Environmental Product Declaration - Environmental Carbon Accounting
Carbon Management and Reporting	- Carbon Disclosure Rating - Carbon Pricing - Carbon Performance

4. Conclusion

The revenue models for complex manufacturing supply chains such as those in the aerospace sector, are at higher risk without addressing decarbonization, due to the imperative of climate change agreements. The aerospace sector is a strong component of the global economy and its associated trade. This also implies that it has a relatively high carbon footprint which needs to be mapped, calculated, managed, reported and systematically reduced. This study presents an end-to-end carbon accounting framework that can be used in the industry as a signpost to its decarbonization journey. It adds a much-needed structure to carbon accounting as in financial accounting, enabling organizations to systematically incorporate transparent carbon liabilities into their overall business plans, reporting and objectives. Similarly, such a carbon accounting framework could help to ensure that any accumulated carbon debt and its impact on aerospace manufacturing supply chains can be evaluated accurately and monetized correctly. Future research work can validate the framework's efficacy within aerospace manufacturing through several case studies of accounting for carbon emissions and accumulation in scope 1, 2 and 3. Additionally, there is a need to add certain extra dimensions via future research to ensure that the framework can be leveraged for the purpose it has been created. These dimensions include a scope 3 emissions responsibility matrix; carbon trading guidelines for end-to-end supply chains; reporting and disclosure platforms for the entire value chain and syndicated collaborative carbon management strategies in post measurement declarations.

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