Estimating the CO_2 intensity of the space sector

Conflicting methodologies for estimating the CO_2 intensity of the space sector are beginning to emerge due to a lack of publicly available data, resulting in extensive variations in the credibility of reported results.

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Following a concurrent engineering study in 2009, the European Space Agency (ESA) identified Life Cycle Assessment (LCA) as the most appropriate method for measuring environmental impacts of space missions[1]. LCA is an internationally standardised methodology used for measuring the environmental impacts of products, processes or services over their entire lifespan. As part of their work on this topic, ESA produced a set of guidelines to act as a consolidated set of guiding principles for space LCA in 2016[2]. This facilitated a number of space LCA studies within industry which address the space, ground and launch segments of space missions. However, to date, confidentiality requirements have generally plagued space LCA, meaning that there has been a distinct lack of publicly available data on the carbon impact of the sector[3]. Writing in *Nature Astronomy*, Knödlseder et al.[4] presents the global carbon footprint of astronomical research infrastructures for the first time, highlighting that research infrastructures make the single largest contribution to the carbon footprint of an astronomer. To calculate this, the authors derived emission factors from available published literature and space LCA studies, using this information as part of an economic input-output (EIO) analysis to calculate the total carbon footprint. This approach goes against ESA guidance as the EIO method is not particularly well-suited to the space industry. However, as noted by the authors, due to the confidential nature of the required input activity data, an EIO analysis is currently the only feasible way to assess the combined carbon footprint of the world's space- and ground-based astronomical research infrastructures. For this reason, it is important to distinguish between existing methods for performing such analyses and their relevancy to calculating the carbon intensity of the space sector.

In this regard, three methods currently exist for performing LCAs – a process-based, an EIO, or hybrid analysis. The process-based method is most commonly used in LCA. It relies on physical activity data to develop a product tree derived from assessing all the known energy and environmental inputs of a particular process and calculating the direct emissions associated with the outputs of the process[5]. Inputs (materials and energy resources) and the outputs (emissions and wastes to the environment) are typically itemised within datasets and scaled to a reference value. In comparison, EIO methods would generally be used only in instances where environmental data is significantly lacking to a point whereby the missing piece of information cannot be scoped out of the study without severely

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impacting its result. The concept estimates the materials and energy resources required for, and the environmental emissions resulting from, activities in the economy. To do this, EIO methods use aggregate sector-level data to quantify the amount of environmental impact that can be directly attributed to each sector of the economy and how much each sector purchases from other sectors in producing its output[6]. As such, the linear attribution assumption between monetary and environmental flows provides only indicative results and cannot distinguish between products of different monetary value within a single sector[7]. Lastly, a hybrid analysis uses a combination of the previous two methods to form an integrated analysis. Combining the two gives the best of both worlds: the accuracy and transparency of a process-based analysis and the completeness of an EIO analysis[8]. Under the circumstances of incomplete environmental data, this can provide the most accurate estimation of the impacts caused by the product in question.

The application of each method within space LCA is not straightforward. Process-based methods require large volumes of input activity data to form an inventory. Conventional LCA databases typically consist of common, mass-produced products and processes which make them virtually incapable of accounting for the complexities of the space industry without appropriate adaptation. This is because space technologies have low production rates, long development cycles and use specialised materials and industrial processes which are subjected to significantly more research and testing than other products[2,9]. Comparatively, EIO analyses are a highly inaccurate method to account for calculating environmental impacts of space missions as it provides broad sector averages which are unrepresentative of the nuances of unique processes and products, especially for nonhomogeneous sectors. In this regard, the space industry does not fulfil the requirements of a completely free market due to state financing schemes and limited players. As a result, monetary flows are different than in other sectors since space components generally have an extremely high cost per weight and a large proportion of the cost of custom-made materials goes into research and development activities as opposed to manufacturing[2,9].

For these reasons, the ESA LCA guidelines[2] advise against the use of EIO analyses as this method tends to significantly overestimate the total environmental impact, whilst the use of the hybrid approach only fills existing data gaps in inaccurate ways. Therefore, to facilitate process-based analyses, new space LCA databases have recently been developed such as the Strathclyde Space Systems Database[9] and ESA LCA Database[10]. However, these databases do not presently include datasets on astronomical infrastructure, are still classed as under development, and are not yet widely available, with results disclosure being thus far slow[3,9]. As such, the uptake of process-based space LCA is still somewhat limited due to a lack of data and the small number of publicly accessible studies available.

Thus, although the figures reported by Knödlseder et al.[4] provide fresh and vital insights into the carbon intensity of astronomical infrastructure and activities, it may be premature to blindly apply these findings as gospel truth since they are based on an EIO analysis. Instead, they should be seen as a preliminary ballpark estimate. Regardless, given the absence of more relevant process-based data, the reported results are an important insight and contribution to knowledge, which acts as a great starting point for more detailed analyses. However, perhaps more significantly, the paper also raises significant questions about how critical science can proceed when data is scarce. Should we do nothing and blame an absence of robust data or conduct first-order analyses irrespectively as a best available estimate intended for public disclosure? Evidently, there is a clear need for increased publication of process-based space LCA results as well as a greater transparency into the carbon intensity of the space sector as a whole, particularly due to the climate emergency. Without this, the gulf between operational practice and best practice is only going to deepen. To conclude, space LCA is currently at a crossroads – either it more openly shares data, methods and best practice, facilitating a genuine contribution to the global sustainability agenda, or risk seeing conflicting methodologies become more prevalent in practice, lowering credibility of results and interest in the approach.

Competing Interests

The author declares no competing interests.

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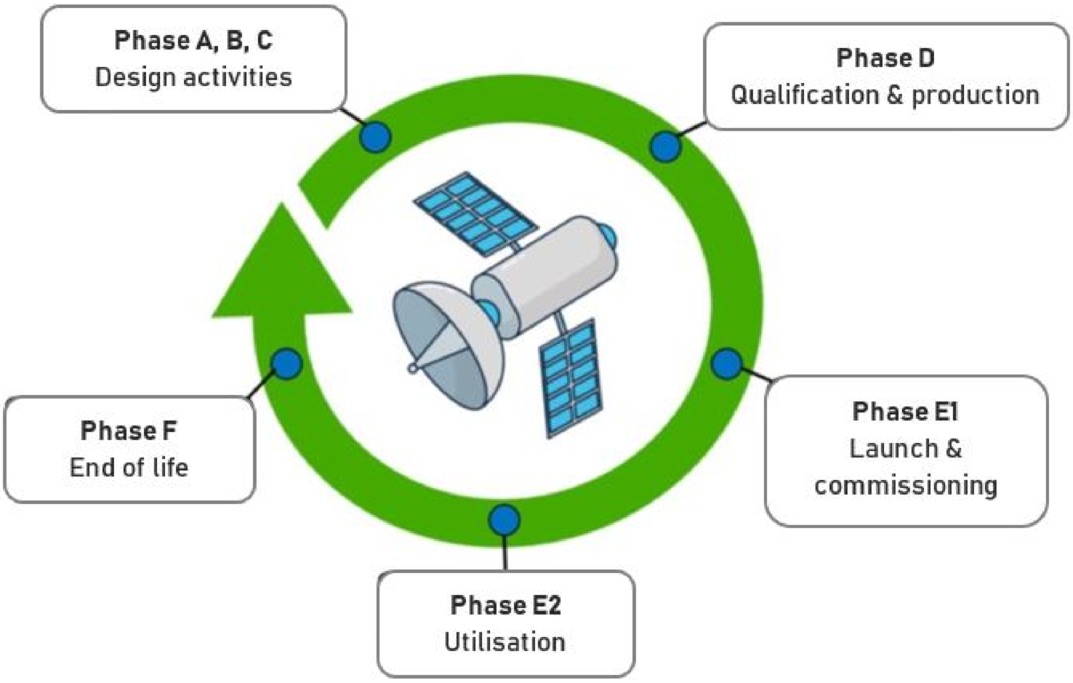
Basic life cycle stages of a space mission | A space mission can typically be broken down into phases to reflect different stages of its life cycle. Each mission phase encapsulates a range of different activities which all have some form of inherent environmental impact. Life Cycle Assessment (LCA) is a systematic methodology which can be used to scientifically quantify such impacts and to prioritise areas for action, considering the entire supply chain.


Phase A, B, C
Design activities
Phase D
Qualification & production
Phase E1
Launch &
commissioning
Phase E2
Utilisation
Phase F
End of life