THERE IS NO PLANET B: AN INITIAL ASSESSMENT FRAMEWORK TO CALCULATE THE ENVIRONMENTAL IMPACT OF THE INSIGHT MARS MISSION. C. A. Bill[1], B. A. Fernando[2], N. Schmerr[3], W. B. Banerdt[4]. [1]Department of Earth Sciences, University of Oxford, UK (Email: carys.bill@st-annes.ox.ac.uk); [2]Department of Physics, University of Oxford, UK; [3]Department of Geology, University of Maryland, MD, USA; [4]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA.

Motivation: The latest climate reports indicate that our civilization is rapidly approaching an environmental crisis [1]. To limit climate change to a 1.5◦C increase in global temperature, every aspect of society must begin to take responsibility. This includes those studying the Earth and other worlds - both of these research communities are positioned to know better than anyone "there is no Planet B" [2]. Thoughtful stewardship of our own planet is key.

Background: The environmental impact of scientific research activities is significant [3]. An example is astronomy, where recent studies have emerged emphasizing the large carbon footprint of the discipline (e.g. [4]). An individual astronomer has a work-related carbon footprint estimated to be up to ~13 times greater than the total footprint of an average citizen, largely owing to the amount of travel involved in scientific research [5].

The NASA InSight (*Interior Exploration using Seismic Investigations, Geodesy and Heat Transport*) Mission Team Meeting in November 2022 brought together planetary scientists from across the globe and different disciplinary backgrounds to discuss the findings of this mission to gather geophysical data on Mars [6]. Although such meetings are elementary for the progression of mission science, these activities have an as yet unquantified environmental impact. This appears to be the case universally across planetary missions - of 46 missions looked at, there is little to no publicly available data found regarding the real carbon cost of the mission, nor plans to mitigate those impacts.

Momentum to consider the environmental impact of science, and reduce its carbon footprint is, however, building. Movements such as the Astronomers for Climate [5], alongside increasing numbers of astronomical institutes and observatories publishing analysis of their footprint (e.g. [7, 8, 9]), and reduction strategies published by national organizations (e.g. [10, 11]) are encouraging. For over a decade, the European Space Agency (ESA) has been applying its Life-Cycle carbon footprint framework within its Clean Space Initiative [12], but data sharing is limited [13]. Therefore, whilst some mass and payload first order estimates have been calculated [13], the real carbon footprint of planetary missions remains largely unquantified.

Goals: Following end-of-mission for InSight, our goal is to identify and quantify the environmental impact of a specific planetary science mission across its lifetime. Improving our understanding of the key contributors to a mission's carbon footprint will highlight areas for potential reduction that could make missions more efficient carbon-wise. Taking responsibility and accounting for the environmental footprint of a planetary mission, is therefore likely to be critical in ensuring the sustainability and efficiency of subsequent missions.

By looking in detail at a specific mission, we also aim to improve on the uncertainty applied to the mass and payload carbon footprint estimates previously calculated for individual missions [13].

Scope: In this study, we will present the results of ongoing efforts to quantify the impact of a single planetary science mission, InSight.

To estimate the real environmental impact of a science mission, a logical and systematic approach is essential. Only marginal costs from the direct workings of the mission would be considered. As an example, we consider the carbon footprint of researchers when traveling to InSight team meetings, but not standard day-to-day activities such as commuting to and from their place of work.

Methodology: The Life Cycle Assessment (LCA) is currently identified as the most suitable methodology for application in the space sector and is the framework used by the ESA within its Clean Space Initiative [12]. Our initial work will focus on the footprint within Phase E (*Utilization*) of the goal and scope boundaries recognised in ESA's Handbook for large-scale space systems [14, 15]. Starting at the point of launch until the end of the mission would produce reasonable initial results and help make the problem tractable. Conceptualisation, design, manufacture and pre-launch transport, which will require access to more complex activity data, could be considered at a later time.

Within the wider context of LCA methodologies, our work looks to calculate and produce measured outputs of a particular mission's carbon footprint. To do this, we propose the following initial assessment framework:

1. Identify key contributors to carbon budget

2. Identify aspects with emission directly relating to the mission, and the major components under that aspect
3. Use a Fermi problem solving approach to identify & gather the activity and emission data required to calculate the component's carbon footprint
4. Multiply activity and emission data to calculate the CO_2 output
5. Scale the output according to the size of the mission, for example number of launches or number of attendees at a meeting
6. Assess the significance of the output - if significant add to total CO_2 budget

Within the scope outlined above, we identify the following key elements of the mission's carbon footprint, to include: 1): Launch, 2) Transport to/from team meetings, 3) operations and communications, 4) Science activities.

Discussion: Using a Fermi problem solving approach, as outlined in the proposed framework above, to quantify the carbon footprint of the InSight Mission, should facilitate an order of magnitude estimate for the actual emissions of the mission.

Previous work gives a first order mass and payload carbon footprint estimate of 34,700 tonnes and 99,980 tonnes CO_2 respectively for InSight [13]. However, this work, incorporating an Economic Input-Output Analysis and the Bilane Carbon methodology, has an adopted uncertainty of 80%. It was also limited by difficulty in obtaining mission specific data which is not publicly available. Data accessibility is often a limitation for implementing the ESA's LCA framework. Consequently, these emissions are likely to be lower limit estimates. Here we will focus on a specific space mission using specific activity data, which should produce more accurate estimates and smaller uncertainties for the mission's real carbon footprint.

For complete mission analysis using ESA's space -specific LCA framework, carbon footprint estimates are often dominated by the launcher which represents 99% of the mass [14]. To better represent the wider workings of the mission from the point of launch, our work will include detailed analysis of all the key elements we have identified.

The Covid-19 pandemic involved changes to the way of working during 2020 which will provide an interesting comparison when analyzing our results between the early and later stages of the mission; the InSight Mission launched in 2018 and continued to produce data until the end of 2022 [16].

Some of our initial results are surprising. We look forward to continuing this work to validate and expand these results.

Recommendations: We are open to new ideas and discussions regarding our study at LPSC. Meetings are a key aspect of the workings of a planetary mission and are also an ideal place to initiate discussions of this nature, as demonstrated by the inclusion of a special session to discuss climate change in the annual meeting of the Chilean Astronomical Society (SOCHIAS) last year [17]. However, previous studies show meetings have a large environmental footprint (e.g. [18]). Reduction strategies are being initiated (e.g.[11]) which both missions and planetary science conferences might care to adopt to ensure that these valuable opportunities for discussion and collaboration are sustainable.

Conclusions and outlook: Our estimate for the carbon footprint of the InSight Mission will reveal many opportunities to ensure the sustainability and efficiency of future space exploration.

Our goal is to make this research approach applicable to future missions, and that the practice of environmental impact monitoring is considered and tracked from mission conceptualization to end. Eventually expanding this line of research across all planetary missions would ensure that planetary science takes a step towards climate awareness and accountability as society faces the immense challenge of climate change.

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