LIFE CYCLE INVENTORIES FOR AVIATION:

Identifying sector-specific LCI shortcomings, translating fore- to background data, and enhancing dataset completeness for holistic aviation LCA analyses

Background data

Life Cycle Assessment (LCA) is a standardised tool for investigating the potential environmental impacts of a product or product system. It is a holistic tool comprised of four steps: 1. Goal and Scope Definition, 2. Life Cycle Inventory (LCI), 3. Life Cycle Impact Assessment (LCIA), and 4. Interpretation [1]. The LCI step in LCA, a critical but time-consuming stage, balances mass and energy by quantifying input and output flows within the system. It comprises the connection of numerous interlinked human activities, each with associated exchange flows. LCI models include a foreground system with specific, company-controlled data, and a background system with generic data from third-party databases. Figure 1 illustrates the the foreground data, which comprises engine and airframe (structure and components), and background data, with raw materials, resources, and utilities for an aircraft maintenance use-case.

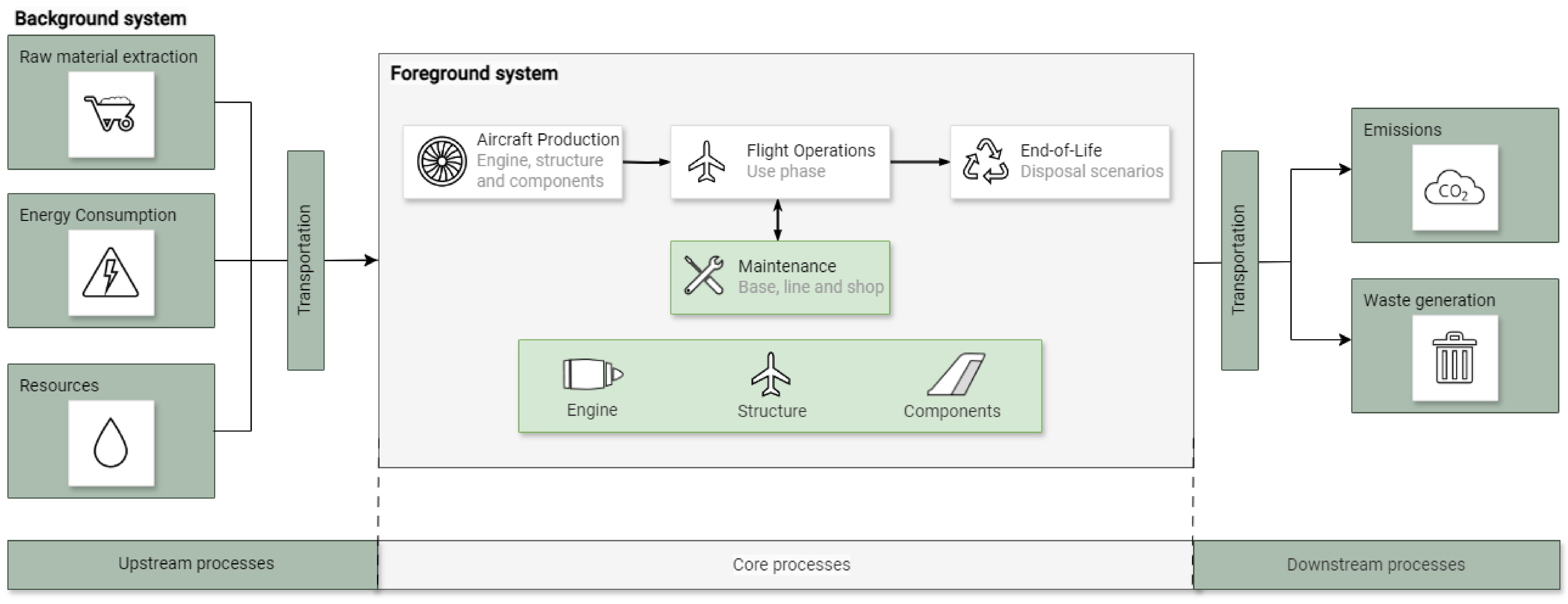

Figure 1: The aircraft life cycle data, comprised of core processes (production, maintenance, flight operations, and end-of-life) and up- and downstream processes (raw material extraction, energy and resource consumption, emissions and waste generation).

LCA practitioners commonly collect foreground data on selected activities relevant to a specific project, while the remaining activities (referred to as background data) are modeled using generic LCI databases [2]. The characteristics of LCI databases can vary depending on their intended use. Whether employed for a detailed LCA study or company-internal inventories, industry-specific analysis, or as a background LCI database, these databases exhibit differences in data quality, parametrisation, and aggregation levels of unit processes. The audience, be it experts, industry insiders, or general LCA users, plays a crucial role in shaping these variations.

Shortcomings

In aviation, LCA is a relatively new discipline, lacking sufficient knowledge for providing data in a format suitable to build datasets. The available information are often only provided in raw data format. In order to properly assess complex process chains, they need to extensively review the raw data gathered from suppliers and restructure such data. This is a highly resourceful and time-expensive process, often overlooked by industry partners who hold different understandings of aspects such as ecodesign and LCAs in general.

Study	Chester (2008)	Lopes (2010)	Dallara et al. (2013)	Jordão (2012)	Lewis (2013)	Howe et al. (2013)	Cox (2018)	Fabre et al. (2022)
Aircraft type	B737	A330	A330	A330, B777	A320, A330, A380	A320	SNB, LNB	A320
Manufacturing	●	●	●	●	●	●	●	●
Operations	●	●	●	●	●	●	●	●
Maintenance	●	◑	○	●	◑	○	◑	○
End-of-Life	○	●	◑	○	○	●	○	◑

● included; ◑ partially included; ○ not included

Table 1: LCA studies in aviation, in which small narrow body (SNB) and large narrow body (LNB).

Table 1 outlines the analysed LCA studies. The environmental assessment of aircraft is an emerging field, with most studies indicating that the operational phase has the greatest impact on the entire life cycle. The manufacturing and flight operations phases are the most thoroughly defined, whereas maintenance and end-of-life represent the greatest gaps in terms of life cycle coverage. Maintenance activities are either partially included by considering only airport infrastructure maintenance or not included at all [2]. End-of-life is intrinsically examined via simplifications in LCI background datasets or excluded from scope. Most studies use process-based LCA with ecoinvent as the LCI background database [3].

Improvements

Maintenance is a pivotal aspect in reducing emissions. The vehicle degradation tendency due to operations is avoided by timely and correct maintenance. Based on the identified challenges, the following will demonstrate how an improved dataset can simplify the conduct of an LCA via the example of maintenance activities of a conventional passenger aircraft [4]. Maintenance is a crucial component in an aircraft's life cycle, as it not only maintains the airworthiness of the aircraft but also holds the potential to continuously reduce ecological impact over its entire life cycle through targeted measures. Through the integration into the transport dataset, the activities are incorporated alongside other life cycle phases. This approach provides calculations based on different functional units as passenger-kilometer (PKM), flight cycle (FC), and flight hour (FH), and aircraft entire lifetime, which are then translated into impact categories during the LCIA phase. Figure 3 shows the cumulative LCI methodology aggregates environmental inputs and outputs across the entire life cycle of a product or process, i.e., in a cradle-to-gate approach.

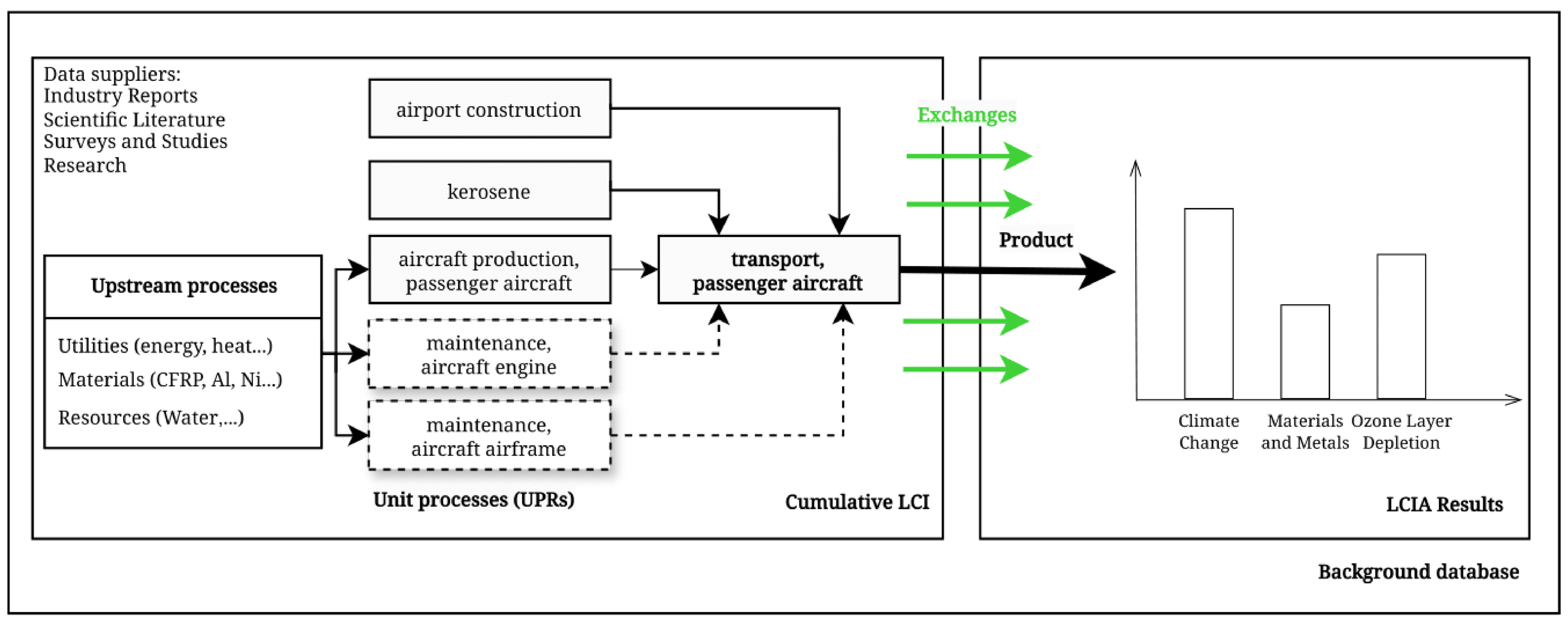

Figure 2: The proposed MRO dataset is categorized into airframe and engine maintenance.

Figure 4 illustrates the results for the climate change impact category per lifetime, PKM, FC, and FH for various flight distances. All maintenance checks are performed during an aircraft lifetime, but at different points in time. The frequency of such tasks is significantly influenced by the aircraft's utilization. The impact over the lifespan increases as the total lifetime distance rises. Despite having the smallest accumulated result, very short range flights had the highest environmental impact per FH due to shorter duration. Conversely, very long range networks exhibited the highest environmental contribution per flight cycle.

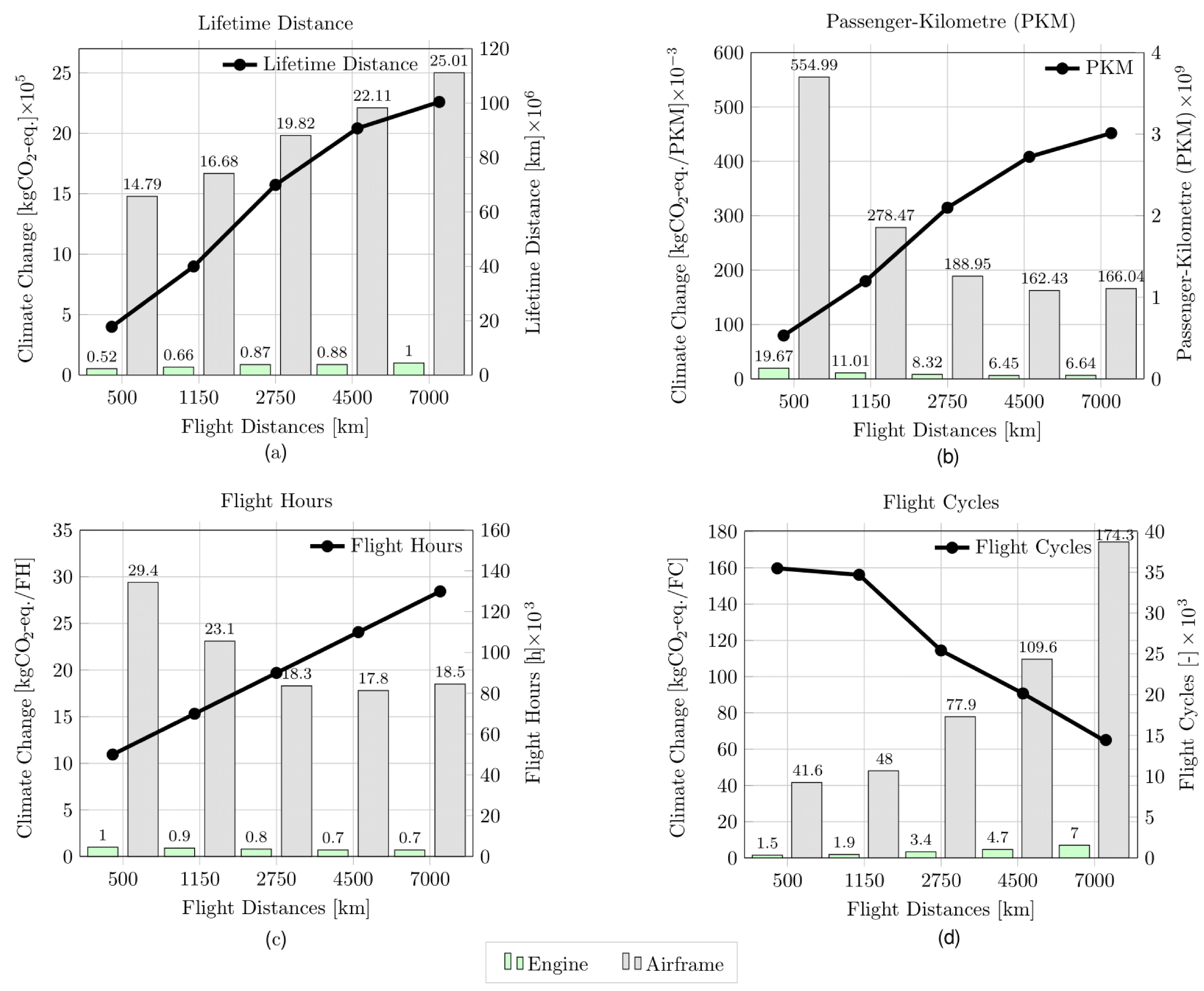

Figure 3: Climate change results [kgCO2-eq.] per (a) accumulated lifetime, (b) PKM, (c) FH, and (d) FC.

Data aggregation levels vary by use and audience. In aviation, flight distance matters for maintenance frequency and LCA accuracy. Sector-specific datasets by distance allow detailed analysis, while general LCA may prefer aggregated data. A recommended dataset represents medium-range aircraft maintenance in Germany.

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