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Comparative Life Cycle Assessment (LCA) in the Aerospace Industry Regarding Aviation Seat Frame Options

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Abstract: The aerospace industry is actively seeking sustainable solutions within the aviation sector to mitigate greenhouse gas (GHG) emissions driven by increasing population demands. This study presents the first environmental life cycle assessment (LCA) of economy-class seating frames, comparing conventional alloy steel with lightweight alternative materials, including magnesium alloy, aluminum alloy, and titanium. Seat frames account for an aircraft's total weight, making them a critical component for innovation toward more sustainable solutions. Using SolidWorks V3.1, economy-class seat frames were designed and evaluated through a cradle-to-grave assessment of a functional unit (FU) representing the interior of a single aircraft. The analysis was conducted using SimaPro V8.4.0 with the Ecoinvent V3.10 database. The total GHG emissions associated with seat frames composed of alloy steel, titanium, aluminum alloy, and magnesium alloy were 208 kt CO_2 equivalent (eq.), 120 kt CO_2 eq, 71.1 kt CO_2 eq, and 44.9 kt CO_2 eq per FU, respectively. This study identifies alloy steel and titanium to be the most sustainable seat frame materials relative to other considered materials for commercial aircrafts.

Keywords: aerospace aviation; environmental sustainability; environmental engineering; life cycle assessment; greenhouse gas emissions; seat frame

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1. Introduction

In 2024, the worldwide market for aircraft seating reached a valuation of USD 7.61 billion, with efforts underway to mitigate its contribution to the 4% share of the aviation sector in contributing to worldwide greenhouse gas emissions relative to other sectors [1,2]. The sustainable development goal of climate action can be fostered by reducing the weights of seats in an aircraft, which can significantly mitigate carbon emissions, environmental impacts, and fuel efficiency [3,4]. For example, seating accounts for a significant portion of an Airbus aircraft's weight and reducing the weight of the aircraft by 1 kg eliminates 0.94 kg of carbon emissions [5,6]. Lightweight seating can save airlines as much as 200,000,000 while meeting federal aviation administration standards for seating arrangements and advisory circular No. 700-014 [7,8]. Selecting the most sustainable material for aircrafts is crucial to make aviation more sustainable when addressing climate change [9]. The prominence of mitigating carbon emissions in the aviation industry is necessitated by the aviation sector, which generates circa 25% of carbon emissions in the world, rising from 2020 to 2025 [10]. There is an urgent need for more efficient, effective, and sustainable practices in the aviation industry.

This study aims to conduct a life cycle assessment of airplane seat frames made from different materials to show which option is the most sustainable for the aviation industry.

Currently, no studies exist to assess this topic in the aerospace industry. Common plane seat frames should be compliant with FAA seat frame specifications [11–13]. Aircraft seat frames are generally made from steel and aluminum for strength and weight optimization, with some designs incorporating a blend of both materials [14]. Titanium not only provides high performance levels for manufacturers, but also has a higher strength and density relative to aluminum, making this material suitable for aircraft parts and frames [15]. Magnesium seat frames are a viable option for planes due to their lightweight properties, offering benefits like increased payload capacity and fuel efficiency, making them suitable for high-volume production in the aerospace industry [16]. While the seat design is not itself FAA approved, it is incorporated within this paper to indicate the average environmental impact assessments for each of the various materials; specifically, aiming to influence more sustainable seat frame designs. The seat frame remains the same design for all materials: magnesium alloy, steel alloy, aluminum 1060 alloy, and titanium commercially pure R50400. Per chair, the weights are 5.12 kg, 23.22 kg, 8.14 kg, and 13.60 kg, respectively. Life cycle assessment (LCA) examines how various materials affect the environment throughout their entire life, prioritizing environmental impact over structural strength or design. Therefore, this research aims to evaluate the cradle-to-grave environmental impacts of different materials commonly used in airline seat frames, which remains a gap in the current research. Additionally, the most impactful system inputs will be examined to rank the standard seat design based on its sustainability in material use.

1.1. Literature Review

1.1.1. Aviation Seat Frames

In 2020, the magnesium alloy gained popularity due to its excellent physical and chemical properties, with China leading the scientific publication of papers in a global context [17]. High-strength and high-modulus magnesium alloys have been developed for superior applications within the aviation industry [17]. Despite their benefits, such as being lightweight and enhancing performance, these alloys have drawbacks, including limited corrosion resistance, reduced strength under high temperatures, and challenges in the casting process [18]. However, plane seat frames do not experience high temperatures, and the fuel cost savings from the lighter weight alloys implemented in commercial aviation frames exceed the savings from adjusting automobile materials [18]. Steel alloys are used in the frames of seats and plane frames [19]. Steel alloys are used in the frames of seats and plane frames [20,21]. For many emerging aviation designs, the titanium alloy has replaced the steels that were most used in the 1990s for landing gear structures [22]. Aluminum alloys have been known for their suitability within structural and functional materials, particularly in aircraft seat frames, where 55% weight reductions were achieved for the Boeing 787 Dreamliner [22]. Grade 1060 is the grade used as industrial pure aluminum and which has an optimal strength-to-weight ratio for aviation seats, remaining a key contributor to sustainable aviation [23]. Specifically, seat frames relatively struggle to hold heavy weight, so 1060 aluminum is an excellent option for seat frame selection. The material's strength, resistance to rust, and easy fabrication make it great for seats, contributing to better fuel efficiency and the lasting durability of the aircraft.

Commercially pure titanium grade 2 UNS R50400 is an extremely strong grade of titanium, making it one of the most suitable options for applications including aerospace [24]. Furthermore, passenger comfort has been studied in previous research, where the anthropometry of seat ergonomics was assessed. The study concluded that the optimal seat height and width are 11.98 inches and 16.9 inches, respectively [25]. Most seat frames are aluminum, and some manufacturers have shifted to carbon composite structures to reduce weight in aircraft cabins [26]. Scientists are actively developing lightweight, high-strength materials for the aircraft industry, such as high-strength titanium–aluminum and magnesium rare earth alloys [27,28]. However, the sole purpose of this study is to evaluate the environmental impacts of some of the basic materials used in seat frames. Future studies could expand on this work to consider more recent developments in alloy seat frame materials.

In this study, the weights of four plane seat frames are estimated in Solidworks V3.1 [29]. Figure 1 shows the economy class passenger chair designed for an average plane with weights of the magnesium alloy, steel alloy, aluminum 1060 alloy, and titanium commercially pure CP-Ti UNS R50400 (ss); per chair, the weights were 5.12 kg, 23.22 kg, 8.14 kg, and 13.60 kg, respectively. The seat frame dimensions were 15 inches, based off government guidelines and the following source, with an additional circa two inches from the cushion thickness giving optimal comfort [8,30–32]. No variations in the wall thicknesses of each seat frame were applied to remain consistent with the environmental assessment and to mitigate uncertainty. The armrests could be removably positioned and installed on the sides of the seat frame [33]. The armrests are excluded from the scope of this study because they may be repaired variably during the seat's lifespan. The seat design is based on the Airbus A320, with a seat width of 460 mm. In Figure 1, the width is 38 cm, and the cushion adds about 4 cm, making the total width 46 cm [34].

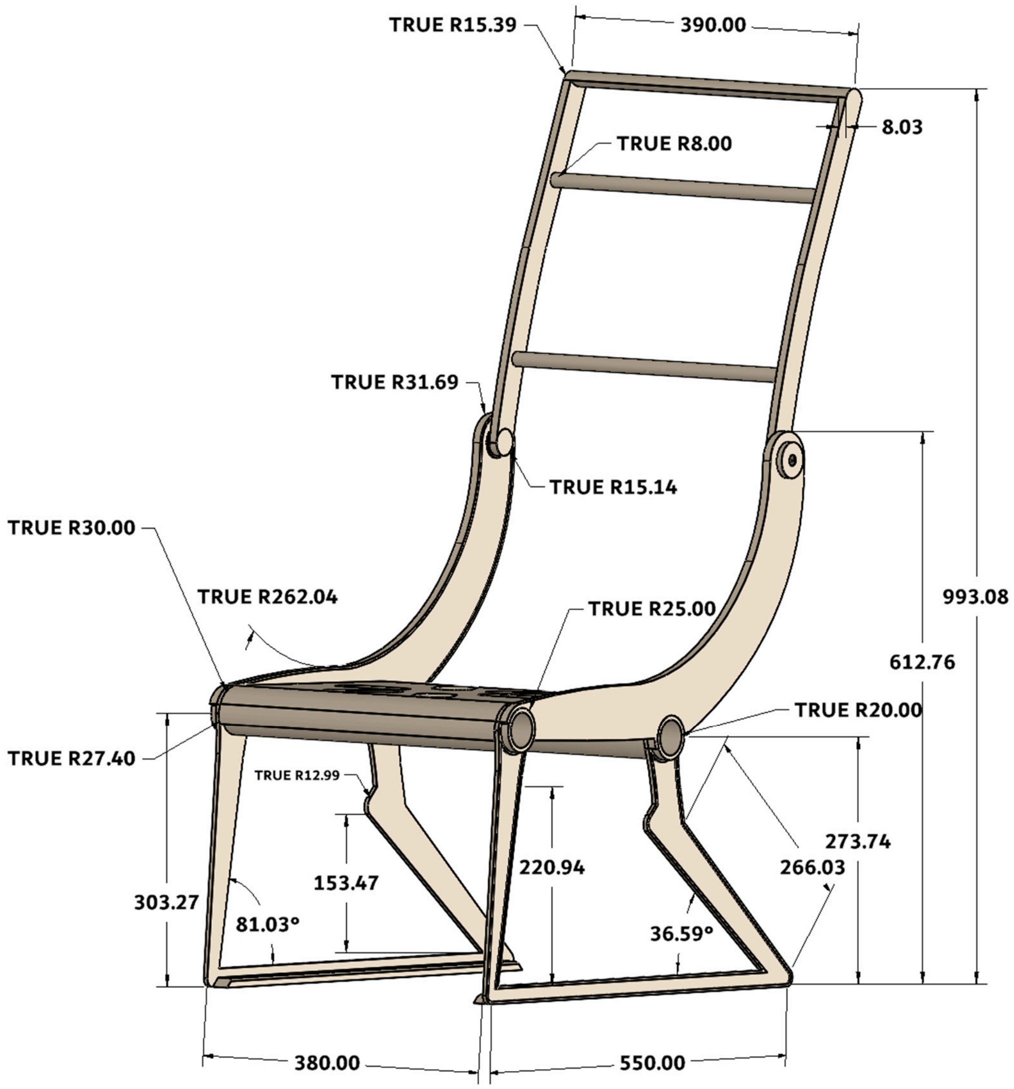

Figure 1. Proposed seat frame design for a commercial economy class arrangement; measurements in units of mm.

1.1.2. Aviation Life Cycle Assessments

Typically, most aviation LCAs rely on mitigating CO_2 emissions within the operation stage, improving the fuel, using novel technologies, and reducing airplane weights [35]. Raw material stages are included in the manufacturing of the seats for the interiors, being one of the modules of component processing [35]. An LCA of a two-seater commercial electric aircraft consisted of a functional unit (FU) of one hour of flight time over a cradle-to-grave period, with the final disposal of recycling applied [36]. ReCiPe 2016 evaluated the environmental stresses over five impact categories [36]. The airframe being 49% of the plane's mass was a leading contributor to all ReCiPe 2016 categories, chiefly constituted by 93% of the frame being carbon fibre [36]. A research gap is addressed for an environmental analysis considering the inclusion of scheduled maintenance activities, utilizing the example of an Airbus A320 aircraft in Germany, since it had large data sets available for the life cycle inventory (LCI) [37]. In this study, the Ecoinvent V3.9.1 database, life cycle cash flow environment tool, and open-source python-based framework Brightway2 were coupled with the FUs per flight hour and the available seat kilometres [37]. The possible software used to perform process-based aviation LCAs included SimaPro V8.0, LCA for experts (former GaBi), OpenLCA, Brightway2, and LCA-AD [38]. Low-quality metrics were the midpoints, which would be any metric below 40%, while mid-priority could be from 40 to 80%, and >80% was a high-priority metric [38]. High-priority aviation metrics include single scores, damage to human health, ecosystems, resource availability, and climate change [39]. On another note, the aviation industry can benefit from the circular economy by providing viable solutions to reuse waste frame materials [40]. Structural composition and waste management are key areas for achieving a circular economy through the implementation of innovative solutions [40]. For example, seat frames have been developed using closed-loop recycling and remanufacturing processes while considering lightweight, sustainable aircraft seat designs [4].

A holistic approach to LCA was conducted for a Fraunhofer ICT that had enhanced the plane's structural composite parts, like seating structures, to mitigate the environmental footprint during the development phase [41]. The most critical phase of operation comprised almost 100% of the total environmental stresses from cradle-to-grave for an aircraft [42]. Different aircraft configurations can be developed in the operational phase to reduce environmental impacts within a multidimensional LCA. Two dimensions were the conceptual specifications, consisting of the cabin or interior of an aircraft, and the methodological requirements from the LCA methods implemented [43]. A gate-to-gate scope was applied, closely focusing on the passenger seats, aircraft lavatories, gallery modules, and gallery equipment [43]. Two FUs per lifetime cabin and per passenger kilometre cabin were coupled with the ReCiPe 2016 method to evaluate the environmental impacts of the cabin alterations [43]. Climate change was the largest category with the highest midpoint impacts (47.36%) and the ecosystem had the largest endpoint impact share (54.7%) [43]. Negative impacts from the higher weight of the cabins were notable from the increasing fuel consumption, resulting in a relative 11% higher total environmental impact [43]. Greenhouse gas emission reduction targets are set by NASA, ICAO, and EU commissions and were closely worked towards in an LCA comparing the conventional reference aircraft and hybrid electric aircraft; utilizing MATLAB V9.1, the aerodynamic analysis programme Athena Vortex Lattice, and the aircraft design box coupled with an FU of the passenger kilometres within a cost analysis [44]. Aircraft panels were also analyzed in LCAs for the comparison of the environmental impacts resulting from conventional glass fibre reinforcement and sustainable panels [45]. Notably, over the life cycle of the sustainable panels in planes, their environmental outputs were offset by the benefits they posed relative to the conventional panels during the use phase [45]. Specifically, this study examined the sustainability of the different panels on an FU of one panel and a cradle-to-grave framework with ReCiPe V1.12 incorporated in SimaPro V8.0 [45]. Another LCA study derailed the significance of selecting more sustainable aviation fuels by coupling fleetwide AviTeam aviation burden modelling with LCA perspectives, encompassing the global warming potential and cumulative energy demand methods, using an FU of the seat km of a commercial passenger aircraft [46].

Designing an aircraft for commercial use to be economically sustainable depends on the cost of existing plane fuel; according to the NASA report, the least expensive fuel to the type that is relatively the most expensive are LNG, LH2, JET-A, and SAF (100%), respectively [47]. In addition to LCA, other methodologies for environmental sustainability assessment in aviation exist, such as eco-efficiency analysis, environmental extended input–output analysis, and circular economy analysis [48–50]. However, there is a research gap in aviation studies that apply the LCA method in accordance with the ISO 14040 and ISO 14044 standards [51,52].

2. Methods

SimaPro V8.4.0 was used for the modelling of the life cycle assessment in sync with the ISO 14044: 2006 and ISO 14040:2006 standards [51–53]. The Ecoinvent V3.10 database was utilized within the software, with global unit processes selected to accommodate geographic data requirements for a global context analysis [54]. The impact method was implemented to evaluate the significant climate change contributor CO_2, based on the Intergovernmental Panel for Climate Change (IPCC) 2013, utilizing the timeframe of 100 years for climate change factors from the IPCC and yielding characterization scores [55]. Global warming potential (GWP) was chosen as the impact category because it is the most significant index concerning global climate change impact [56]. The factors only concern the direct (excluding methane) global warming potential of air emissions that avoid the indirect formation of dinitrogen monoxide and radiative forcing due to nitrogen emissions or other components in the lower stratosphere and upper troposphere [55].

2.1. Functional Unit

The Airbus A350-900 is a standard commercial aircraft passenger carrier that typically seats 280 passengers, with a maximum of 214 economy seats [57]. The scope of the study is a cradle-to-grave with an FU of one plane comprising 214 economy seat frames.

2.2. System Boundary

Figure 2 shows the complete life cycle system boundary on a cradle-to-grave basis. Importantly, the assembly of frame parts, specifically the labour and energy associated with this input, are out of this study's scope, followed by unexpected maintenance requirements relevant for the seat frames. The Ecoinvent V3.10 material inputs of alloy steel, aluminum alloy, magnesium alloy, and titanium were from the unit processes of alloy steel, Al alloy, Mg Alloy, and Titanium CP R50400. The transport, passengers, aircraft {RoW}, and Kerosene {RoW} were incorporated for the plane transport and fuel input.

2.3. Life Cycle Inventory (LCI)

Table 1 consists of the LCI for four altered metal frames that are typically used in airplane seat frames. The seat frame weights are reported using the SolidWorks V3.1 accurate mass calculator for defined materials. This LCI is the quantitative representation of the qualitative system boundary in Figure 2. The inventory is from an Airbus A350 with a lifespan of 30 years, and which endures an average economy class flight distance of 17,964 km, operating with a maximum of 20,000 flight cycles [58,59]. Typical Airbus A350-900 seats weigh 9 kg, and the fuel consumption of this model plane is 0.0339 L Kerosene/passenger/km [60,61]. The total fuel use represents a highly used commercial

Airbus A350-900 or the maximum conditions to approximate the maximum carbon footprint in this study's scope. The materials utilized are manufactured in HoneyWell, dispatched to Fleet Canada, and then to De Havilland. The seat cushions were excluded from the system frame because the variability in the materials for this element can increase uncertainty in the modelling. The seat frames are recycled every 6 years and are sent to recycling facilities in Quebec, Canada, such as Aerocycle and Dynajet Aviation, from the Toronto Pearson Airport. Currently, best practices are to recycle the components of an airplane; hence, the end-of-life option of recycling is selected for the seat frames [62]. Using all these assumptions, the data have been calculated in Table 1. The LCI consists of the following assumptions:

- The LCI does not account for unexpected seat frame repairs and labour, since this has variability leading to added uncertainty;
- Energy requirements are not measured for the assembly of parts of the frame;
- The LCI involves the economy class seating of an Airbus A350-900;
- The distances are approximated using Google Maps.

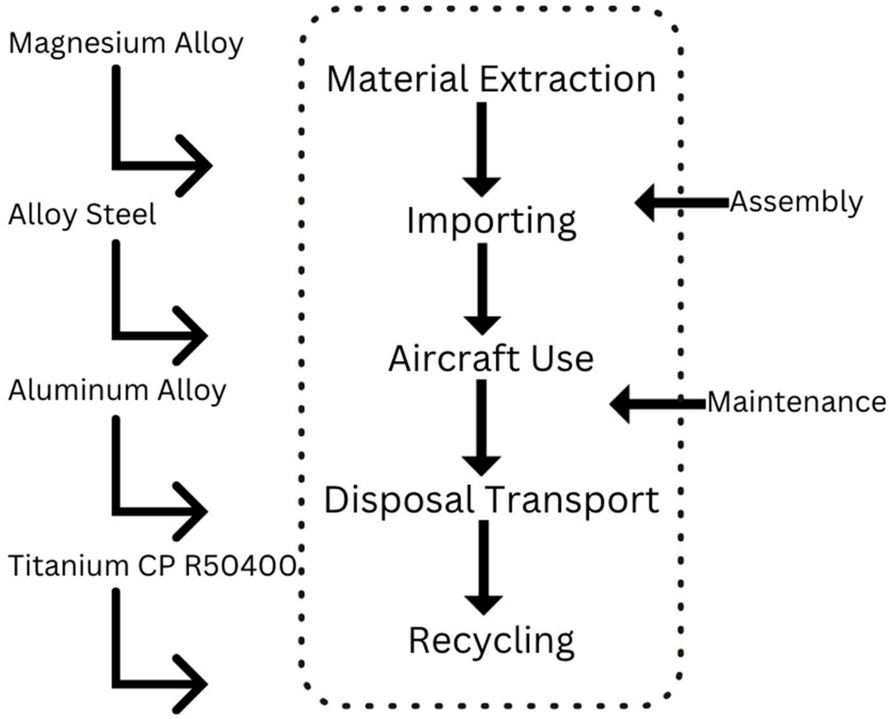

Figure 2. Preliminary system boundary of plane with seat frames from cradle-to-grave.

Table 1. LCI for the complete LC of one plane with specific seat frame materials of magnesium alloy, alloy steel, aluminum 1060 alloy, and titanium commercially pure R50400 materials from cradle-to-grave.

Per FU	Seat Frame Material			
Inventory Parameter	**Magnesium Alloy**	**Alloy Steel**	**Aluminum 1060 Alloy**	**Titanium (Commercially Pure R50400)**
Frame Weight (kg)	5478	24,845	8710	14,552
Importing (tkm)	19,273	87,406	30,641	51,194
Fuel Use (L)	1,482,770,596	6,724,596,335	2,367,373,564	3,938,609,395
Plane Use (tkm)	393,655,910	1,785,291,062	625,851,389	1,045,648,512
Disposal (tkm)	4448	20,174	7072	11,816
Recycling (kg)	5478	24,845	8710	14,552

3. Results

The mass of the frames was, from highest to lowest, in the order of alloy steel, titanium, aluminum alloy, and magnesium alloy, respectively; the global warming potential (GWP) LC emissions were also in this order. As depicted in Figure 3, alloy steel (24,845 kg), titanium (14,552 kg), aluminum alloy (8710 kg), and magnesium alloy (5478 kg) had total emissions of 53,298 kg CO_2 equivalent (eq.), 93,948 kg CO_2 eq, 137,764 kg CO_2 eq, and 285,465 kg CO_2 eq per FU, respectively.

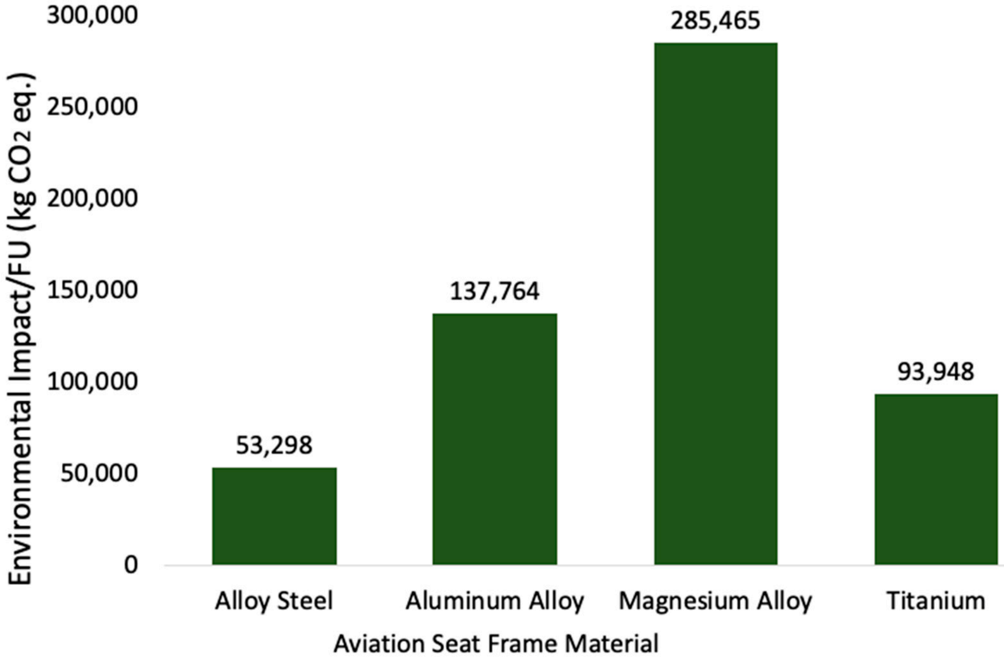

Figure 3. Cradle environmental impacts of the frame options for one plane seat of alloy steel, aluminum alloy, magnesium alloy, and titanium in kg CO_2 eq.

The hotspots were in the stages of plane use, cradle, and end-of-life for all scenarios per FU. The cradle stage GWPs (metric ton CO_2 eq) per FU for alloy steel, aluminum alloy, magnesium alloy, and titanium were 107, 276, 571, and 188, respectively, while the kerosene input for varying specified seat frames of magnesium, titanium, alloy steel, and aluminum alloy had GWP (metric tons CO_2 eq) impacts per FU of 894, 6306, 321,050, and 39,460, respectively. The impacts from plane use dominated that of the cradle or final disposal stages by a relative 99%. However, analyzing the cradle and grave stages relative to each material for the plane seats can reduce capital emissions, as shown in Figure 4.

Notably, the environmental impacts of magnesium alloy relative to alloy steel, aluminum alloy, and titanium are significantly high, suggesting the potential need to avoid incorporating magnesium alloy seats into the commercial aviation industry. Alloy steel and titanium seating frames should be selected to maximize the sustainability of airplane commercial seating frames in the aerospace industry. Further, on a cradle basis, selecting alloy steel over magnesium alloy mitigates 464,375 kg CO_2 eq FU^{-1}, and over the grave stage, 474,264 kg CO_2 eq FU^{-1}. The environmental impacts posed from importing and disposal transportation are relatively insignificant and are not reported as a separate entity, since the primary focus is on the material, fuel, and use life cycles. Cradle, grave, and material impacts are presented in Figures 3 and 4, respectively. Table 2 explicitly describes the environmental impacts of each stage of the system boundary. As noted, the use phase has the same environmental impact even with varying fuel consumption, differing from the original hypothesis.

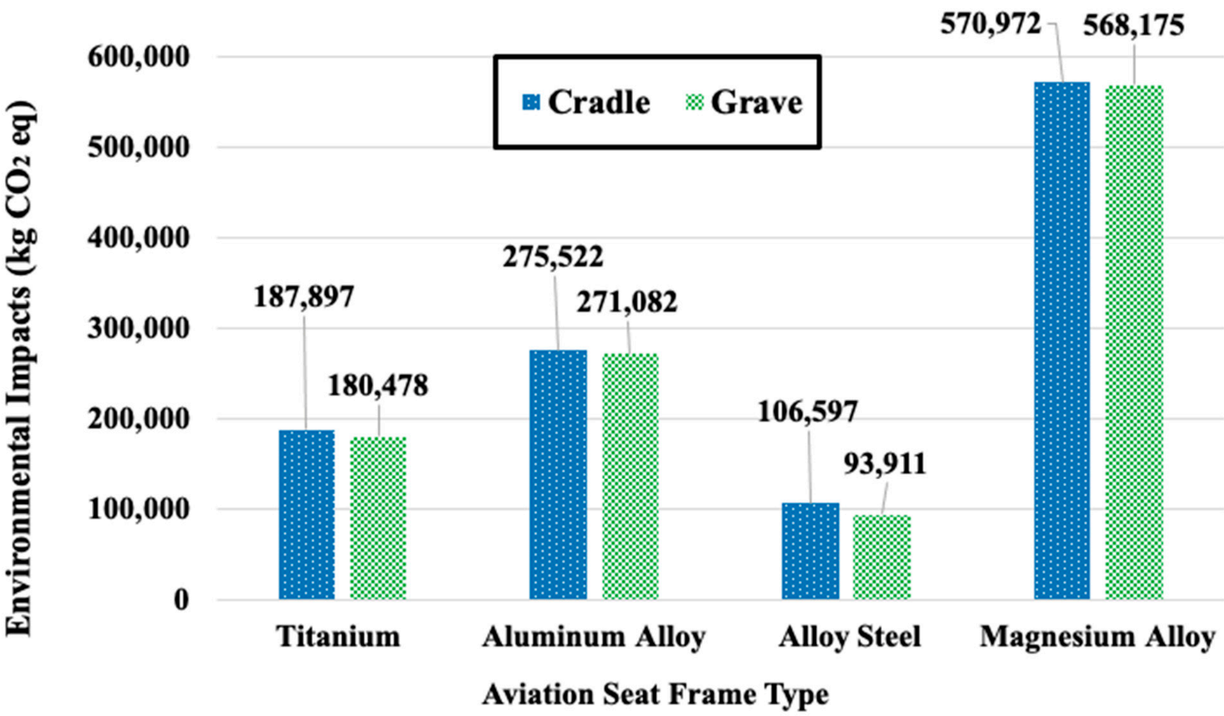

Figure 4. Cradle (blue) and grave (green) GWPs from titanium, aluminum alloy, alloy steel, and magnesium alloy for an FU of one plane's seating interior. The cradle is from material extraction and importing, and the grave is from the disposal transporting and recycling. The cradle and grave stages are separate for comparison purposes between different materials.

Table 2. IPCC GWP over 100 years of four different seat frames for cradle, use, and disposal (or grave) stages in kg CO_2 eq. per FU.

IPCC GWP 100a (kg CO_2 eq)	Cradle/1 kg	Use/1 tkm	Disposal/1 kg
Aluminum 1060 Alloy Seat Frame	15.82	0.11	1.89
Magnesium Alloy Seat Frame	52.11	0.12	15.56
Steel Alloy Seat Frame	2.15	0.11	51.86
Titanium CP R50400 Seat Frame	6.46	0.11	6.20

Sensitivity Analysis

In this sensitivity analysis, the variation in GWP was modelled for plane cycles from the base case of 20,000 to 7193 cycles in the use phase [63]. The magnesium alloy seat frame per FU had the least GWP with the least weight, hence its consideration to further maximize environmental emission reductions. The life cycle GWP was directly influenced by fuel consumption, varying with the plane cycles within the range of 8000 to 19,000 by increments of 1000. The GWP from the least to the highest life cycles showed that GWP increased linearly with an increase in plane use up to 57.81%, determined using Formula (1). The following assumptions of average flight distance (AFD), number of cycles (N_C, reference fuel consumption (Ref_F) in L Kerosene/passenger/km, number of seats in the plane (NSP), frame selected weight (W_F), and reference seat weight (W_R) formed the basis of this calculation.

$$\text{Fuel Consumption} = ((\text{AFD} \times N_C) \times (\text{Ref}_F \times \text{NSP})) \times \left(\frac{W_F}{W_R}\right) \quad (1)$$

4. Discussion

The importance of environmental assessments for aircraft cabin components, for which a current research gap exists, is valuable in completing cabin customization processes to ensure the satisfaction of the consumer market in the aviation industry [64]. LCAs are useful to gain initial environmental assessments to address the environmental implications of materials or fuels used in the aircrafts; aluminum, composites, and steel have all been considered for internal plane sheets and panels [65].

A study has assessed the maintenance activities based on the FU of an Airbus A320 aircraft over its 25-year lifespan, with a normalization of per flight hour and available seat kilometres, utilizing the Life Cycle Cash Flow Environment software, Brightway2, and the database of Ecoinvent V3.9.1 [37]. An ecological wing design was proposed in an LCA for an eco-demonstrator aircraft, designed per SAE standards over a 30-year lifespan [66]. This study was performed over a cradle-to-grave scope, using the Sustainable Minds 2013 software V4.0 and the Ecoinvent V 2.2 database [66].

It is no lie that the reduction in life cycle environmental emissions from the aviation industry is a significant challenge; efforts have been made to mitigate its burden on the environment using sustainable fuel, aircraft concepts, and propulsion system innovations [64]. A software has been developed in Germany to estimate the GWP in a state-of-the-art customization process integration [64]. Expanding aircraft economy class capacity could reduce flight cycles and mitigate carbon dioxide emissions, as indicated in this study's results. According to a report, the A320 aircraft seats weigh 1601 kg from a total cabin weight of 3919 kg, representing a reduction in the weight of seats by 20%, decreasing the total emissions from the life cycle of the cabin [62]. The seat frame designed in this study needs to be approved by the FAA, because approximately 80% of a products' environmental impacts are sought during this stage [62]. The International Civil Aviation Organization (ICAO) are primarily concerned with carbon footprints and high fuel consumption [67]. Having lighter weight seat frames reduces the fuel consumption and the total environmental impacts over their life cycle [67]. In this study, the fuel consumption was reduced with lighter frame options, but the environmental impact of the fuel consumption in the use phase was relatively the same across all alternatives. An Airbus A350 is a wide body aircraft which contributed 37% of the GWP emission rate relative to regional jet and narrow-body aircrafts from 2013 to 2019 according to the ICAO [67]. Even though narrow-body aircrafts are more efficient, wide-body aircrafts can be up to 55% more profitable and have 13% less environmental burden [68,69].

Additive manufacturing, coupled with conventional casting and reduced-density materials, can reduce material wastage by nearly 90% and yield additional savings in cradle-to-gate environmental impacts [70,71]. Future LCAs could consider incorporating the manufacturing process of seat frames within the system boundary to understand the sustainability of manufacturing methods in an economically sustainable manner. Using a two-stage approach, topology optimization was employed economically to sustainably produce 32% lighter structural seat designs, with costs reduced by up to 24% [72]. This approach is recommended for inclusion in future LCA studies.

The electricity input using coal was a major environmental stressor, resulting from the treatment of coal to produce high-voltage electricity, the treatment of coal used in magnesium production, the treatment of coal gas in power plants, and coal mining operations. Natural gas in the electricity mixes further contributed to the environmental impact due to heat and power co-generation in conventional power plants. Recent research on sustainable development suggests phasing out coal and natural gas, recommending that the aviation industry transition to sustainable hydrogen energy [73–75]. Heat used in the life cycle of the seat frame components per functional unit (FU) was another key contributor to the high environmental impact. Heavy fuel oil produced in the refinery furnace, diesel-powered electrical generation, and its burning during the life cycle also added to the impacts. Sustainable aviation fuels, such as biofuels, should be explored to support the circular economy [76]. Lastly, the Pidgeon process during magnesium production was identified as a hotspot [77]. The Pidgeon process is known for causing high pollution, resource consumption, and energy requirements. A more sustainable alternative, the vacuum carbothermal reduction process, can reduce non-renewable resource use and energy consumption by up to 63% and 69%, respectively [77]. Key substances of significance include fossil-based carbon dioxide and dinitrogen monoxide. Dinitrogen monoxide is released during the thermal processes in magnesium production, resulting in high concentrations of thermal nitrogen monoxide [78]. Magnesium alloys should be avoided in seat frames to avoid unsustainable outcomes.

The sustainability goal of climate action is the central focus of this study. The aviation industry can make significant strides toward this objective by reducing seat frame weight alongside GWP reductions. Notably, as shown in Figure 3, the carbon footprint per FU could be mitigated by approximately 37% to 78%. However, despite being the heaviest frame material, alloy steel has the lowest GWP over the cradle-to-grave cycle compared to other options, followed by titanium, aluminum alloy, and magnesium alloy. To effectively meet the climate action sustainability goal, titanium and aluminum alloy emerge as the optimal choices, balancing both lightweight design and GWP mitigation. Compared to magnesium alloy seat frames, aluminum alloy and titanium alternatives reduce cradle-to-grave GWP by roughly 52% per FU and 68% per FU, respectively. These substantial GWP reductions should be a key consideration for the aviation industry in achieving its climate action objectives.

5. Conclusions

The results of this comparative life cycle assessment of alloy steel, titanium, aluminum alloy, and magnesium alloy in aviation seat frames showed that even though magnesium alloy is the lightest and has the lowest material extraction emissions, it has the highest life cycle GWP. In contrast, titanium exhibits lower overall GHG emissions for the material extraction, cradle, and grave stages, making it a more sustainable option than alloy steel. Material selection is crucial for reducing aviation's carbon footprint. Lighter, more efficient materials like titanium and aluminum alloy can significantly mitigate emissions. This study addresses a key research gap, offering policymakers, manufacturers, and airlines insights to enhance sustainability.

Some recommendations can be sought in future studies. Seat cushions should be included in the assessment, as they are a significant component of airplane interiors and contribute to the cumulative environmental score. Expanding the scope of the study to include assembly and maintenance requirements would provide a more comprehensive understanding of the environmental impacts associated with the entire life cycle of airplane components. They should be certified for each type of metal used, ensuring that they meet stringent environmental sustainability standards. This would help to enforce policies that target the mitigation of the environmental footprint due to aircraft manufacturing. The aviation industry should prioritize making the interiors of consumer planes more sustainable. By optimizing the sustainability of interior components, such as seats and other replaceable parts, the industry can reduce unnecessary emissions and enhance overall environmental performance.

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