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Assessing Social Impact for Sustainable Aircraft Design Through an SLCA Framework

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Abstract

The social dimension of sustainability is increasingly recognized as essential to the aviation sector, yet systematic assessment of social impacts across aircraft systems and their associated design and production processes remains limited. This study applies Social Life Cycle Assessment (SLCA) principles, guided by the UNEP/SETAC guidelines and the ISO 14075:2024 standard, to perform a country-based screening that identifies, quantifies, and analyzes hotspot impacts associated with materials production and manufacturing in the aviation sector. A tailored SLCA framework is developed to reflect the specific characteristics of the aviation sector and to identify relevant stakeholder groups, including workers, local communities, consumers, value chain actors, and society. Aviation-specific social indicators are defined in line with industry needs and regulatory expectations, enabling socially informed decision-making during early design stages. The methodology is demonstrated through a comparative assessment of two major commercial aircraft, examining social impacts across global supply chains, identifying social hotspots and country-specific risk drivers, and evaluating targeted improvement measures. In addition, alternative component production locations are assessed to explore supply-chain configurations with lower social risks. The results provide actionable insights for policymakers and industry stakeholders and support holistic sustainability assessments by explicitly integrating the social dimension into sustainable aircraft design.

Keywords: SLCA; social sustainability; aviation social impact; UNEP/SETAC; ISO 14075; 2024

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1. Introduction

In *The Social Effects of Aviation* (1946) [1], sociologist William Fielding Ogburn examined how aviation would reshape industries, change travel habits, and transform social structures. His insights into aviation's sweeping societal impact parallel today's pursuit of sustainability, where industries and behaviors must evolve to balance environmental, economic, and social priorities. Although the term sustainability is nowadays widely used, it is often loosely defined in practice, making it challenging to establish clear metrics or demonstrate the sustainability of products and processes. Sustainability is often described as a balance among environmental, economic, and social dimensions; however, in practice, it is predominantly interpreted as ecological sustainability. The interdependency of environmental, financial, performance, and social aspects is rarely considered holistically, despite their mutual influence. As a result, achieving true sustainability requires deliberate engagement with the trade-offs among all three dimensions [2].

In particular, within the social pillar of sustainability, Social Impact Assessment (SIA) or SLCA play a vital role across various sectors, and are go-to methods in mining industry [3], engineering project management [4], and in the assessment and comparison of technologies, such as those relating to water supply and fuel conversion in various countries [5]. SIA is also instrumental in evaluating the social impact of product-service systems [6] although scientific rigour is currently lacking in SLCA assessments [7]. Additionally, SIA is crucial for assessing the social impacts of large-scale transportation infrastructure, such as railways [8], as well as the general transport systems of specific countries [9].

SIA is increasingly relevant in the emerging air mobility sector. As drones and other advanced air mobility technologies gain traction, there is growing attention on evaluating their social impacts, including security concerns, social acceptance, regulatory issues, environmental effects, noise pollution, economic implications, job creation, and more [10–12].

To fully contextualize these emerging considerations, it is useful to relate them to the broader aviation domain, where SIA is highly dependent on the specific level being addressed. The assessment varies based on whether the focus is on the Air Transport System (ATS) as a whole, individual airports, aircraft, airlines, or other components of the system.

In relation to Air Traffic Systems (ATS), social impact has been closely linked to regional development and the wellbeing of citizens. A 1988 policy study by NASA sought to identify both beneficial and detrimental social impacts, examining these from the perspectives of economics, politics, human behaviour, urban and regional development, and the physical environment [13]. A 1994 study [14] identified the need for a comprehensive societal evaluation of air transport, suggesting policies that highlight ATS role in enhancing regional accessibility. Additionally, a review paper analyzing numerous studies on the social impact of ATS concluded that regional wellbeing is a crucial socio-economic factor, encompassing economic, social, and environmental dimensions [15]. The review also identified the key wellbeing indicators being studied and synthesized the results of prior research on this contemporary issue. Moreover, societal impact has also been linked to risk and safety issues in aviation, such as air accidents, accident rates, and fatality rates [16,17], as well as the measurement of societal risk within the field of civil aviation, with attention given to both ethical and analytical considerations [18].

In connection with airlines, social impact is frequently linked to the corporate social responsibility (CSR) initiatives of airlines, e.g., [19–22], focusing on their sustainability performance across governance, social, and environmental dimensions. CSR has increasingly become a strategic focus for both airlines and airports, emphasizing the need for transparent, standardized assessment methodologies that enable comparative analysis for all stakeholders.

The social impact of airports is among the most thoroughly examined aspects when assessing the social dimensions of aviation. Research in this area often emphasizes the implications of airport noise on human health, exploring both the direct physiological effects, such as sleep disruption and stress, and the broader community impact. In response to these concerns, many airports have introduced noise-related fees and other mitigation strategies aimed at reducing the adverse effects on nearby residents. Beyond noise, airports also contribute to regional sustainable development by fostering economic growth, particularly through job creation and infrastructure development. These dimensions of social impact, ranging from health and environmental concerns to economic benefits, and personal mobility, make airports a key focal point in aviation-related social impact assessments. Studies on these topics, which explore the multi-faceted role of airports in both local communities and broader sustainable development frameworks, can be found in [21–32].

In evaluating social impacts within aircraft systems, the UNEP/SETAC guidelines are widely recommended as a source of insights and high-level guidance for assessing social impacts across all life cycle phases of products, including aircraft and aircraft systems [33,34]. More recently, ISO 14075:2024 has provided an international standard for SLCA, offering a structured framework for evaluating social impacts throughout a product's life cycle and supply chain, enhancing comparability, transparency, and alignment with global sustainability goals [35]. UNEP/SETAC guidelines are also proposed in other sectors and for various products, demonstrating their broad applicability in addressing social impacts across diverse industries and contexts [36–40]. However, the majority of research on this topic has centred on the social impact of aviation biofuel supply chains, highlighting factors such as labor conditions, resource use, and community effects specific to biofuel production and distribution [33,41–46]. In contrast, relatively few studies examine social impacts directly at the aircraft level, focusing instead on cabin-related aspects like passenger comfort, cabin noise, air quality, ventilation systems, and the number of employees onboard, which contribute to both passenger experience and operational well-being [47–50].

In the context of aircraft systems, the existing literature overlooks three critical aspects. First, there is no systematic methodology for evaluating the social impacts of aircraft systems across their globally distributed supply chains, including the sourcing of raw materials and the manufacturing of components across multiple countries. Second, aviation-specific adaptations of Social Impact Assessment remain underdeveloped; in particular, the literature offers limited guidance on identifying the most relevant stakeholders and defining impact categories tailored to the unique characteristics of aircraft systems and their complex international supply networks. Third, social impact evaluations are often conducted as standalone sociological studies, with little discussion of how the identified social impacts can meaningfully inform or influence the early stages of aircraft system design. The afore-mentioned gaps highlight the need for a more integrated, aviation-focused approach to social sustainability assessment within aircraft development.

The current study aims to contribute on addressing these gaps by applying Social Life Cycle Assessment principles, guided by the UNEP/SETAC guidelines and ISO 14075:2024, on a country-based SIA screening. The objective of the present work is to evaluate social impacts across aircraft systems and their global supply chains, with the aim of informing decision-making in the early stages of design and providing practical guidelines for integrating social considerations into aircraft development. As a country-level screening, the study doesn't account for any organization-level adjustments, which may diverge significantly from the national legislation and policies under which they operate. Social impacts are influenced by the practices of manufacturers, suppliers, assemblers, and other actors involved in the production and supply of aircraft systems, as well as the social and political contexts of the countries where these activities occur. To ensure relevance to the aviation sector, the SLCA framework is adapted by identifying the social impact assessment metrics most pertinent to aircraft systems, along with the stakeholders affected by aircraft production and supply chain activities. The applicability of the proposed methodology is validated by its implementation in a comparative analysis of major commercial aircraft platforms, hereafter referred to as Aircraft A and Aircraft B. The current study advances the authors' earlier holistic sustainability assessment framework [51–53] by providing insights into the social dimension of sustainability and enabling the quantification of social impact. This provides the foundation for a future Social Impact Index to support multi-criteria decision-making in sustainable aircraft design. It also proposes using social impact as an early-stage design criterion, evaluated alongside other objectives to help proactively reduce social risks. The approach can be adapted to specific components or early design, depending on company data availability, designers expertise and knowledge in sustainable design approaches. This work represents a foundational step for subsequent activities within the EXAELIA project [54] where the proposed framework and insights will be used to assess the social impacts of novel aircraft configurations as part of a holistic sustainability assessment.

The paper is structured as follows: Following the Introduction (Section 1), Section 2 presents the methodology, providing overview of the SLCA screening, followed by the selection of stakeholders and impact categories, and an analysis of complementary routes for assessing social impacts in aircraft systems. Section 3 presents the use case used to demonstrate the proposed methodology. Section 4 reports and discusses the results, including a comparative assessment related to the case study, a country-level hotspot analysis, and an exploration of alternative production locations. Section 5 provides a broader discussion of the findings, while Section 6 concludes the paper and outlines directions for future research.

2. Methodology

The core essence of the proposed approach is to systematically identify and evaluate social hotspots within aircraft design, enabling engineers to better understand the broader social implications of their design choices. Social hotspots are flagged when a country's or supplier's social performance scores fall below a user-defined threshold, highlighting areas where social practices may be inadequate and improvements are needed. These hotspots pinpoint specific points in the supply chain where social risks are most pronounced. In essence, a higher number of identified hotspots indicates more severe social sustainability challenges for a country. The approach follows a structured methodology, as described in the following sections.

2.1. Social Life Cycle Assessment Approach

This screening adopts a SLCA approach to evaluate the social impacts of aircraft systems, following the UNEP/SETAC guidelines and ISO 14075:2024 standard. According to ISO 14075:2024, a Social Life Cycle Assessment is structured into four main phases: (1) Goal and Scope Definition, (2) Social Life Cycle Inventory Analysis (S-LCI), (3) Social Life Cycle Impact Assessment (S-LCIA), and (4) Interpretation (Figure 1). This study follows this standardized framework to ensure methodological consistency, transparency, and alignment with international best practices.

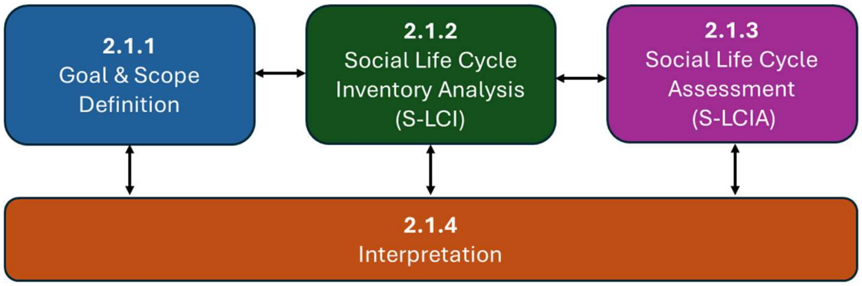

Figure 1. The SLCA Framework based on ISO 14075; 2024 [35].

2.1.1. Goal and Scope Definition

The goal of the study is to assess and compare the social impacts associated with aircraft systems across their global supply chains, focusing on two representative cases of commercial aircraft. The assessment aims to identify social risks and benefits throughout the supply network, linking them to suppliers. The system boundaries include all upstream processes from raw material extraction to component manufacturing and assembly -although in this study these processes are traced to a single supplier- excluding aircraft operation and end-of-life stages. The operational phase is omitted because aircraft operations-particularly on international routes- are not attributable to a single geographic or regulatory context. The end-of-life phase is also excluded due to the absence of a standardized dismantling, recycling, or disposal pathway in the aviation sector. Aircraft retirement practices vary widely depending on aircraft age, condition, market demand, and regional regulatory frameworks, making it difficult to define a representative and robust EoL scenario.

Stakeholders and impact categories were selected in accordance with the UNEP/SETAC SLCA guidelines, ensuring coverage of the most relevant social dimensions, including workers, local communities, society, and value chain actors. In accordance with ISO 14075:2024, the goal definition also specifies the intended audience and disclosure policy of the study. The intended audience includes researchers, aerospace industry stakeholders, sustainability professionals, and policy-makers concerned with the social performance of aircraft systems and supply chains. The results of this work are intended to be disclosed publicly to ensure transparency, support comparability, and promote broader application of SLCA principles within the aviation sector.

2.1.2. Social Life Cycle Inventory Analysis (S-LCI)

The social inventory phase involved compiling data on social performance indicators for suppliers, and production countries involved in aircraft systems. The Ansys Social Impact Audit Tool (SIAT, released version 04/2025) [55]used in this study includes a database comprising both quantitative and qualitative data for the relevant impact categories, offering standardized social

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metrics alongside region-specific datasets. These data include parameters such as labor practices, health and safety performance, gender equality, education, and community well-being, mapped to the locations of suppliers and material sources within the aircraft supply chain. The selection of impact categories is in line with the UNEP/SETAC SLCA guidelines, ensuring comprehensive coverage of key social dimensions across stakeholders, including workers, local communities, society, and value chain actors. Each selected impact category was then linked to relevant quantitative or qualitative metrics and corresponding data available in SIAT, which is populated with the data from Ansys EduPack Sustainability Database.

2.1.3. Social Life Cycle Impact Assessment (S-LCIA)

The Social Life-Cycle Assessment evaluates the social performance of a product across its life cycle by examining the interactions between stakeholders and the processes of material extraction, manufacturing, and use. Following the UNEP/SETAC guidelines, the analysis involves defining goals, system boundaries, functional units, and relevant impact categories, collecting social data at the national or supplier level, and conducting an impact assessment to identify potential social hotspots. These hotspots are flagged when the social performance scores of a country or supplier fall below a user-defined threshold, indicating areas where social practices may be inadequate and improvements are needed. To ensure comparability across different datasets and regions, all indicator values were normalized on a common scale from 1 to 100 (with the latter representing the best practice) [55], allowing consistent identification of underperforming suppliers or countries.

Based on the normalized results, social hotspots were identified using a threshold of 50%, meaning that any supplier or country with a performance score below this value was classified as a hotspot. These hotspots indicate specific points in the supply chain where social risks are most pronounced. Furthermore, the threshold value of 50% was adopted as an average baseline reference. Future work will undertake a more rigorous evaluation of threshold definition, with particular emphasis on identifying values that may be considered critical in terms of social impact. Sensitivity checks were performed using stricter thresholds of 40% and 30% to assess how the number of identified hotspots would change under more conservative criteria.

2.1.4. Interpretation

In the final phase, results from the S-LCIA were interpreted to identify the most significant social hotspots and performance drivers within the aircraft supply chains. The findings were evaluated for consistency, sensitivity, and alignment with the defined goal and scope. Recommendations were formulated to enhance the social sustainability of aircraft manufacturing through improved supplier selection and responsible sourcing strategies.

In accordance with ISO 14075:2024, the interpretation phase plays a critical role in the aircraft design and decision-making process, ensuring that results are communicated transparently and can inform both strategic and operational actions. This phase involves identifying the most significant issues that materially influence social performance outcomes, enabling prioritization of mitigation measures and targeted improvements across the supply chain. Furthermore, it integrates cross-comparisons between the two aircraft companies, providing insights into regional differences and supply chain dependencies that affect overall social performance, and guiding data-driven decisions to support sustainable aircraft design, and responsible sourcing.

2.2. Selection of Stakeholders and Impact Categories

For the comparative assessment of the two aircraft, stakeholder groups and impact categories were defined following UNEP/SETAC guidelines, with specific adaptations to ensure their relevance to commercial aviation systems (Table 1). Given the absence of aviation-specific SLCA frameworks, the most pertinent stakeholders and social impact categories were identified by assessing their potential exposure to, and influence from, activities across the aircraft supply chain, including raw material extraction, component manufacturing, and assembly. Table 1 presents the stakeholder groups and social impact categories considered in this study, along with their relevance to the aircraft supply chain and the associated life cycle phases, based on the author's expertise. Each impact category is linked to specific stages of aircraft production -from raw material extraction to component manufacturing and assembly- highlighting its significance for commercial aviation systems. This structured analysis ensures that the SLCA emphasizes the most relevant and actionable social impacts within the defined system boundaries. The stakeholder group "Consumers" was excluded from the analysis because commercial aircraft are business-to-business products, and end users do not directly interact with the manufacturing or supply processes within the system boundary. Additionally, the "Child Labor" impact category was excluded from detailed consideration due to the limited data availability provided by the SIAT tool database and the characteristics of the aerospace supply chain, which together indicate an extremely low probability of occurrence. These selections ensure that the SLCA screening focuses on the most meaningful and actionable social impacts relevant to the aviation context, enhancing the robustness and applicability of the assessment.

Table 1. Relevance of Stakeholders and Social Impact Categories in Aircraft Systems based on ISO 14075:2024 [56].

Stakeholder Group [56]		Impact Category [56]	Relevance for Aircraft Supply Chain	Life Cycle Phase
Workers	W.1	Freedom of Association & Collective Bargaining	Labor relations in aerospace material production, component manufacturing, and assembly operations	Raw Material & Manufacturing
	W.2	Fair Salary	Wage levels in aircraft component factories and raw material processing	Raw Material & Manufacturing
	W.3	Working Hours	Factory operations and assembly of aircraft parts under delivery schedules	Manufacturing
	W.4	Forced Labor	Risk in mining of raw materials (aluminum, titanium, rare earths) for aircraft	Raw Material
	W.5	Equal Opportunities / Discrimination	Equity and inclusion in aerospace factories and supplier workshops	Manufacturing
	W.6	Health & Safety	Occupational hazards in aircraft material extraction, component machining, composite curing, and assembly	Raw Material, Manufacturing
	W.7	Social Benefits / Social Security	Worker coverage for healthcare, pensions, and social protections in aviation suppliers	Manufacturing

Local Community	L.1	Access to Material Resources	Impacts on land, water, and energy near mining or production sites for aircraft materials	Raw Material & Manufacturing
	L.2	Access to Immaterial Resources	Skills, knowledge, or educational opportunities influenced by aerospace supply chain	Manufacturing
	L.3	Delocalization & Migration	Shifts in employment and economic opportunities from aerospace production relocation	Manufacturing
	L.4	Cultural Heritage	Rare impacts of aerospace material extraction or component production on heritage sites	Raw Material & Manufacturing
	L.5	Safe & Healthy Living Conditions	Environmental pollution from aerospace material extraction, component manufacturing, or assembly plants	Raw Material & Manufacturing
	L.6	Respect of Indigenous Rights	Material extraction for aircraft production affecting indigenous lands	Raw Material
	L.7	Community Engagement	Dialogue and consultation between aerospace companies and local stakeholders	Raw Material, Manufacturing
	L.8	Local Employment	Jobs created by aerospace material suppliers, component manufacturers, and assembly plants	Manufacturing & Assembly
	L.9	Secure Living Conditions	Safety and stability of communities affected by aerospace supply chain activities	Raw Material & Manufacturing
Society	S.1	Public Commitments to Sustainability	National and industry regulations affecting aircraft supply chain practices	Raw Material, Manufacturing
	S.2	Contribution to Economic Development	Economic value generated by aerospace material supply and aircraft manufacturing	Raw Material, Manufacturing
	S.3	Prevention & Mitigation of Armed Conflicts	Potential risks from sourcing aircraft materials from unstable regions	Raw Material

	S.4	Technology Development	Knowledge transfer and innovation through aerospace supplier networks	Manufacturing
	S.5	Control of Corruption	Governance and procurement transparency in global aerospace supply chain	Raw Material & Manufacturing
Other Value Chain Actors	O.1	Fair Competition	Supplier diversity and market concentration in aerospace supply chain	Manufacturing
	O.2	Promoting Social Responsibility	Codes of conduct, audits, and ethical sourcing within aerospace suppliers	Manufacturing
	O.3	Supplier Relationships	Long-term collaboration and monitoring with aircraft suppliers	Manufacturing
	O.4	Respect of Intellectual Property Rights	Protection of aircraft design, technical knowledge, and proprietary technology	Manufacturing

2.3. Analysis of the Complementary Routes for Social Impact Assessment in Aircraft Systems

The analysis follows three different, complementary routes/case studies to obtain a comprehensive investigation of the social impact of the two selected commercial aircraft (Figure 2). The **first analysis regards** a comparative assessment of the two aircraft, identifying social hotspots within their respective supply chains. The analysis was conducted using the Ansys Social Impact Audit Tool, applying multiple thresholds -50, 40, and 30- to examine how threshold selection affects the identification of social risks. The initial threshold of 50 was based on the average of the rescaled social performance data provided by SIAT, while the lower thresholds of 40 and 30 were subsequently applied to assess the sensitivity of the Social Impact Assessment results to more lenient definitions of hotspots. For each threshold scenario, the workflow was carried out as follows:

1. **Supplier and country identification**: Mapping the suppliers and manufacturing countries involved in the targeted structural subsystems production of both A and B aircraft.
2. **Hotspot extraction**: Retrieving hotspot values for each aircraft subsystem and its corresponding production country using SIAT.
3. **Tier 1 Suppliers aggregation**: Calculating the total hotspot value for each aircraft by summing the hotspot values across all subsystems. Particularly, each subsystem has been considered to have equal weight in terms of social impact relevance to the overall aircraft structure.
4. **Comparative analysis**: Comparing subsystem-level hotspot values between aircraft A and B to determine which aircraft exhibits lower potential social impacts in each supply chain segment.
5. **Scenario exploration**: For subsystems with alternative suppliers, all feasible supply chain configurations were generated and evaluated. These alternative configurations result in variation in total hotspot values; therefore, standard deviations are reported based solely on differences arising from alternative supplier selections, not from averaging across threshold scenarios.

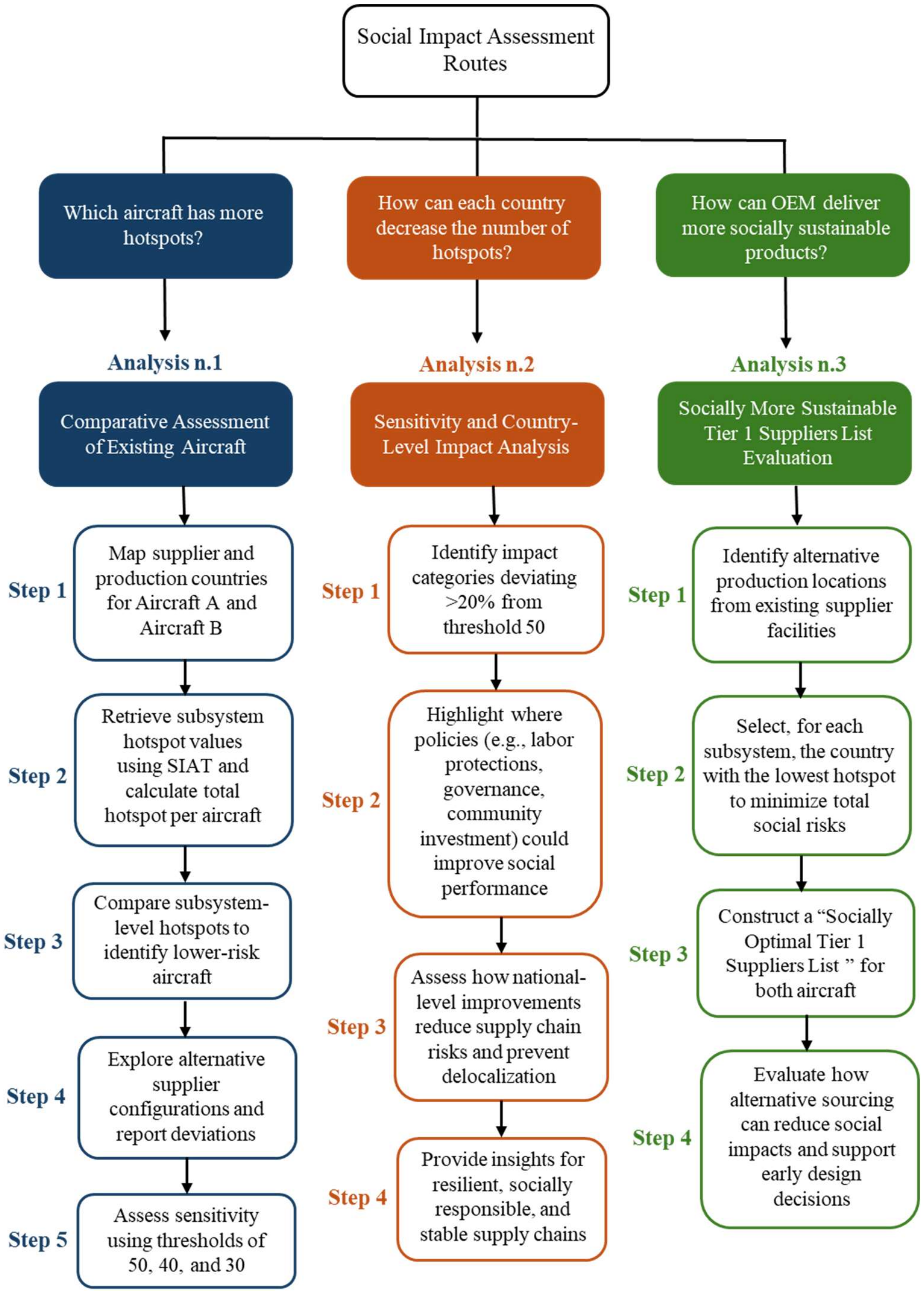


Figure 2. Overview of the three complementary analysis routes used to assess the social sustainability of the two commercial aircraft: (1) comparative assessment of supply chain hotspots, (2) inventory-based sensitivity analysis of impact categories, and (3) evaluation of alternative production locations to identify socially sustainable Tier 1 Suppliers.

The resulting total hotspot values and their associated deviations provide a clear basis for comparing the social performance of the two aircraft and assessing the influence of manufacturer choices on Tier 1 Suppliers social risks.

The **second analysis** involves an inventory-based sensitivity analysis to identify specific impact categories, with hotspot values exceeding a 20% decrease relative to the reference threshold of 50. This examination was designed to highlight categories in which targeted improvements -particularly those driven by governmental or institutional policies- could meaningfully enhance the social performance of production countries. By identifying where focused policy interventions (e.g., labor protections, governance reforms, community investment) had the potential to elevate category scores, the analysis provided insights into how national-level actions could improve a country's position within the aircraft Direct Suppliers List. Furthermore, the assessment demonstrated how such improvements could simultaneously reduce social risks across the supply network and help prevent the delocalization of subsystem production. In this way, the second objective illustrated the extent to which strengthening social conditions at the country level could support more resilient, socially responsible, and geographically stable supply chains for the aircraft systems examined.

The **third analysis** focuses on evaluating potential alternative production locations based on existing facilities operated by the suppliers within the aircraft manufacturers' global Approved Supplier List (ASL). The aim is to support early design decisions that could leverage lower-risk regions or take advantage of established operations demonstrating stronger social performance. This analysis enables a proactive assessment of how Tier 1 Suppliers restructuring -through alternative supplier-country choices- can mitigate social risks before design commitments are finalized. To operationalize this objective, a "Socially More Sustainable Tier 1 Suppliers List" was developed for both aircraft. In this configuration, the total number of social hotspots is minimized by selecting, for each subsystem supplier, the production country that exhibits the lowest hotspot value according to the SIAT data. This approach allows identification of the most socially favourable Direct Suppliers architecture that could theoretically be adopted without altering the technical functionality of the aircraft.

3. Case Study Description

To illustrate the approach proposed in this paper, a comparative case study is conducted on two major commercial aircraft platforms, hereafter referred to as Aircraft A and Aircraft B (Table 2). The three analyses provide actionable insights for integrating social considerations into aircraft design. The first analysis includes a comparative assessment of the two major commercial aircraft platforms, identifying social hotspots across life cycle stages, materials, and manufacturing practices. The second analysis examines country-specific hotspots to pinpoint areas that disproportionately drive negative social impacts and evaluates targeted improvement measures -such as enhancements in labor conditions, community infrastructure, or governance quality- to demonstrate how incremental changes can meaningfully improve overall social performance and prevent the delocalization of subsystem production. Finally, the third analysis explores alternative locations for component production to support early design decisions, leveraging lower-risk regions or operations with stronger social performance while guiding supply chain optimization.

Table 2. Key Characteristics of the Compared Aircraft.

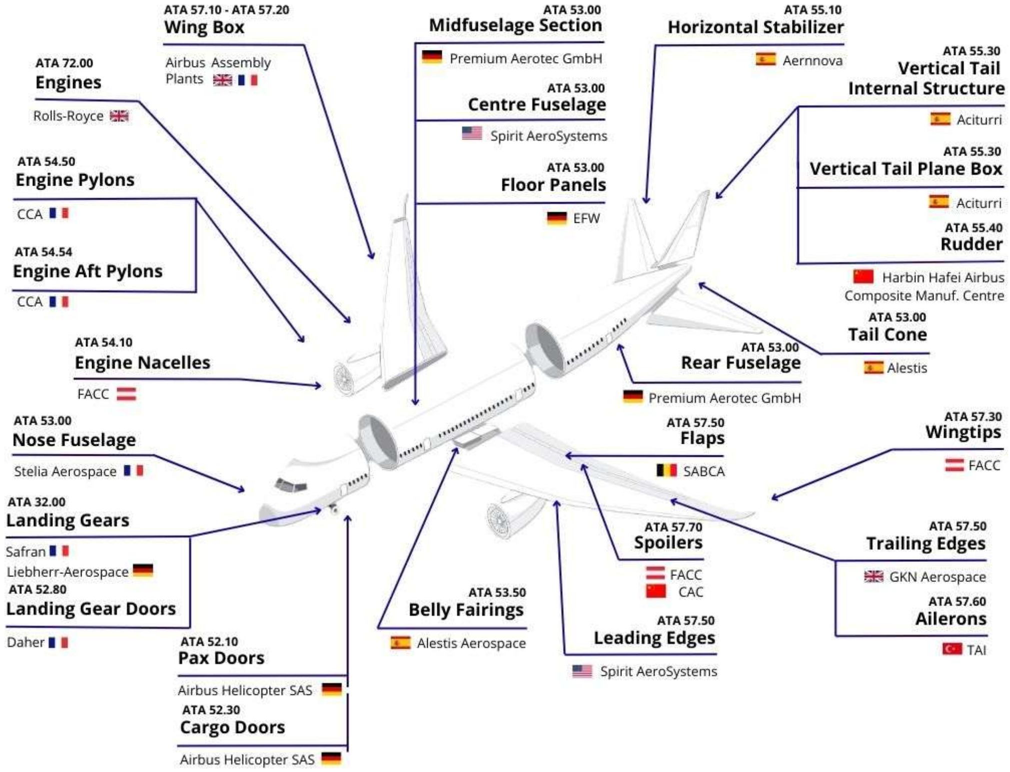
Characteristic	**Aircraft A**	**Aircraft B**
Capacity		
Max Passenger Seating	440 seats [57]	420 seats (exit limit) [58]
Typical 3 Class Configuration	332 – 352 seats [57]	294 – 345 seats [59–61]
Performance		
Range	15750 km [57]	14010 km [62]
Cruise Mach	0.85 [57]	0.85 [63]
Cruise Speed	1049.58 km/h [57]	1049.58 km/h [63]
Service Ceiling	13100 m [64]	13100 m [63]
Fuel Capacity	166488 lt (max) [57]	126372 lt [65]
Max Take-off Weight	283 t [57]	255 t [66]
Max Payload Weight	53.3 t [67]	53 t [68]

Operating Empty Weight	139 t [67]	129 t [69]
Engine Thrust	375 kN (Rolls-Royce XWB-84) [70]	236 kN – 347 kN (Rolls-Royce Trent 1000) [71]

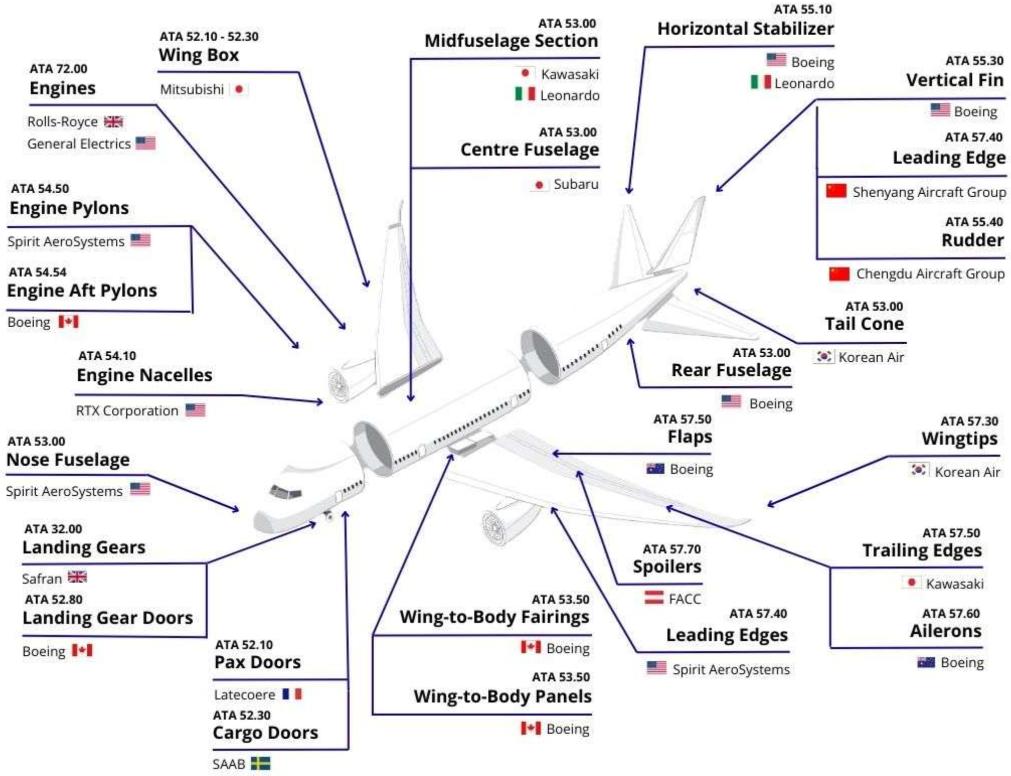
The assessment focuses on the comparative analysis of two wide-body aircraft: aircraft A and aircraft B. These aircraft were chosen because they serve comparable market segments, feature similar mission profiles, and are designed for equivalent long-haul operational ranges. Their technical specifications, performance capabilities, and overall configurations are therefore sufficiently aligned to enable a meaningful and balanced comparison of their respective involved manufacturers and suppliers. The key characteristics of the two aircraft are summarized in Table 2.

From the analysis of the aircraft subsystems, a total number of 24 were distinguished and classified according to the ATA 100 Standard [72,73], covering the ATA chapters related to structural parts, such as Doors (ATA 52), Engines (ATA 72), Fuselage (ATA 53), Landing Gears (ATA 32), Nacelles/Pylons (ATA 54), Stabilizers (ATA 55), Wings (ATA 57). Other ATA chapters were excluded from the analysis, as the study targets specifically structural subsystems, which represent the primary focus of this case study.

For each subsystem, the principal manufacturing companies and the corresponding global production sites were identified. The obtained data (Figure 1) constitutes an adaptation of existing publicly available sources [74,75], updated to reflect the most recent and accurate information. This update was necessary due to factors such as supplier acquisitions, corporate decisions regarding the relocation or restructuring of production facilities, and changes in the global geopolitical landscape, all of which can significantly affect supply chain configurations and are therefore essential to capture in an SLCA context. Subsystems with more than one available supplier include an alternative option, which is reported under the label "Country 2."



(a)



(b)

Figure 3. Overview of the Aircraft Subsystems and corresponding Suppliers, for Aircraft A (a) and Aircraft B (b).

For each aircraft, the number of subsystems per country, and the related percentage, have been calculated (Table 3). Specifically, the percentage values represent the contribution of each country to the manufacturing of aircraft structural components. For the subsystems that result in having a second production country option, the subsystem has been attributed to both countries involved, resulting in equal weighting of both nations in terms of their influence on the Tier 1 supply chain.

Table 3. Overview of Aircraft Structural Subsystems per Country .

Aircraft A			**Aircraft B**		
Country	Subsystems	Percentage	Country	Subsystems	Percentage
Austria	3	11%	Australia	2	7%
Belgium	1	4%	Austria	1	3%
China	2	7%	Canada	3	11%
France	6	21%	China	2	7%
Germany	6	21%	France	1	4%
Spain	4	14%	Italy	2	7%
Turkey	1	4%	Japan	4	14%
United Kingdom	3	11%	South Korea	2	7%
United States	2	7%	Sweden	1	4%
			United Kingdom	2	7%

	United States	8	29%

4. Results and Discussion

4.1. Comparative Assessment of Aircraft A and Aircraft B

Following the development of the Tier 1 Suppliers list of both aircraft, the number of social hotspots per each subsystem and the total hotspot values are illustrated in Table 4. The results are presented in a heatmap, utilizing a colour scale that spans from green (representing the lowest and best hotspots value of the supply chain) to red (representing the higher and worse hotspots value). The obtained social hotspots values are 127 and 113, for Aircraft A and B respectively. Comparing the Tier 1 Suppliers' heatmaps and evaluating, per each subsystem, the social performance in terms of hotspots value, aircraft B shows a better aptitude to social impact management than A. Particularly, in 8 out of 24 subsystems, aircraft B has fewer hotspots. Vice versa, aircraft A shows better results in 6 out of 24 subsystems' categories. For the remaining 10 subsystems, both aircraft performed equally.

Table 4. Identification of the Social Hotspots per Subsystem's Supplier.

Threshold 50		**Aircraft A**		**Aircraft B**	
ATA_100 Standard	Subsystems	Country	Hotspots	Hotspots	Country
ATA 52.30	Doors (Cargo)	Germany	4	4	Sweden
ATA 52.10	Door (Passengers)	Germany	4	5	France
ATA 72.00	Engines	United Kingdom	5	4	United States
ATA 53.00	Front Fuselage Section	Germany	4	5	Japan
ATA 53.00	Nose Fuselage	France	5	4	United States
ATA 53.00	Centre Fuselage Section	Germany	4	5	Japan
ATA 53.00	Aft Fuselage Section	Germany	4	4	United States
ATA 57.10 – ATA 57.20	Wing Box	France	5	5	Japan
ATA 55.10	Horizontal Stabilizer	Spain	6	4	United States
ATA 32.00	Landing Gears	Germany	4	5	United Kingdom
ATA 52.80	Landing Gear Doors	France	5	6	Canada
ATA 55.30	Vertical Fin	Spain	6	4	United States
ATA 55.40	Rudder	China	11	11	China
ATA 57.30	Wing Tip	Austria	4	4	South Korea
ATA 53.00	Tail Cone	Spain	6	4	South Korea
ATA 57.50	Flaps	Belgium	4	3	Australia
ATA 57.40	Leading Edge	United States	4	4	United States
ATA 57.50	Fixed Trailing Edge	United Kingdom	5	5	Japan
ATA 54.50	Pylon Fairing Panels	France	5	4	United States
ATA 54.54	Aft Pylon Fairing	France	5	6	Canada
ATA 53.50	Belly Fairing	Spain	6	6	Canada
ATA 54.10	Engine Nacelles	Austria	4	4	United States

ATA 57.60	Ailerons	Turkey	13	3	Australia
ATA 57.70	Spoilers	Austria	4	4	Austria
Threshold 50		**Total Hotspots**	**127**	**113**	
Threshold 40		**Total Hotspots**	**81**	**74**	
Threshold 30		**Total Hotspots**	**51**	**30**	

By adjusting the threshold values to 40 and 30, different outcomes emerge. Across both supplier scenarios, aircraft B consistently exhibits fewer social hotspots, indicating that its manufacturing structure and associated corporate policies result in lower overall social impacts. However, when the threshold is set to 40, aircraft A performs better than in the other scenarios. As shown in Table A1, the aircraft A has lower hotspot values in 9 subsystem categories, whereas aircraft B scores better in only 6, with both aircraft showing equal values in the remaining 9 subsystems.

A further analysis has been conducted considering that some subsystems result in having more than one supplier and related production country (labelled as "Country 2"). Therefore, all the possible scenarios have been defined as a combination of the countries involved in the Tier 1 Suppliers of each aircraft. For both companies, 4 subsystems present the "Country 2" option. Thus, a total of 16 combinations have been implemented, varying one country per each composition. Consequently, the total hotspots number has been calculated per each possible Direct Suppliers architecture. The analysis has been carried out for threshold values of 50, 40, and 30. The average total hotspots value and related standard deviation (Table 5) have been used for the overall comparison.

Table 5. Average Hotspots Number of the corresponding Supplier's Combinations.

	Threshold 50	**Threshold 40**	**Threshold 30**
Aircraft A	131.00 ± 3.65	85.81 ± 3.75	52.63 ± 3.16
Aircraft B	117.50 ± 3.69	81.50 ± 4.35	33.56 ± 3.63

Based on the analysis of hotspots within their global Tier 1 Suppliers network, aircraft B exhibits better performance, reflected by a lower average number of hotspots when using threshold values of 50 and 30. However, at a threshold of 40, the two aircraft's results are comparable. Specifically, an evaluation of the average hotspot value and the related standard deviation suggest the aircraft are nearly aligned in the total number of hotspots across their respective Direct Suppliers list.

4.2. Country-Level Hotspots Analysis

For all countries involved in the aircraft Tier 1 Suppliers structure, the social impact categories, identified following the criterion in Chapter 2.3, are listed in Table 6. Social impact categories from the Ansys Granta EduPack Sustainability Database such as "Total Literacy" and "Wellbeing, Satisfaction with Life", both related to the "Local Community" stakeholder, have been identified in 7 out of 15 countries. Targeted enhancement restricted to these two categories is already yielding a lower number of hotspots and is likely to prevent the delocalization of subsystems' production. This highlights that significant desirable results can be realized swiftly, through efficient countries' policies.

Table 6. Identification of the Social Impact Categories per Country for prompt advancement.

Country	N. Hotspots	Cat.	Category Full Name	Value
Australia	0	-	-	-
Austria	2	S3-4	Total Literacy	40
		S3-5	Wellbeing, Satisfaction with Life	40
Belgium	2	S3-4	Total Literacy	41
		S3-5	Wellbeing, Satisfaction with Life	41
Canada	2	S3-4	Total Literacy	42
		S3-5	Wellbeing, Satisfaction with Life	42
China	2	S1-3	Minimum Wage	41
		S3-7	Voice & Accountability	43
France	3	S3-4	Total Literacy	43
		S3-5	Wellbeing, Satisfaction with Life	43
		S3-7	Voice & Accountability	45
Germany	2	S3-4	Total Literacy	46
		S3-5	Wellbeing, Satisfaction with Life	46
Italy	0	-	-	-
Japan	2	S3-4	Total Literacy	41
		S3-5	Wellbeing, Satisfaction with Life	41
South Korea	0	-	-	-
Spain	1	S3-8	Political Stability	49
Sweden	2	S3-4	Total Literacy	42
		S3-5	Wellbeing, Satisfaction with Life	42
Turkey	2	S1-2	Forced Labor & Slavery	44
		S1-6	Fatal Accident at Work	40
United Kingdom	0	-	-	-
United States	2	S1-4	Hours worked per week	49
		S3-2	Public Spend on Education, HDI (%GDP)	46

The outcomes presented in this section are related to the enhancement of all the above categories. Therefore, the improved Tier 1 Suppliers lists, for aircraft A and B respectively, are presented in Table 7. Aircraft A hotspots number is decreased from 127 to 82, equal to a 35% reduction, while aircraft B moves from 113 to 74 (35%).

Table 7. Comparison of the improved Tier 1 Suppliers List (I) and the Actual Scenario (A).

		Aircraft A			Aircraft B		
ATA 100 Standard	Subsystem	Country	I	A	Country	I	A
ATA 52.30	Doors (Cargo)	Germany	2	4	Sweden	2	4
ATA 52.10	Door (Passengers)	Germany	2	4	France	2	5

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ATA 72.00	Engines	United Kingdom	5	5	United States	2	4
ATA 53.00	Front Fuselage Section	Germany	2	4	Japan	3	5
ATA 53.00	Nose Fuselage	France	2	5	United States	2	4
ATA 53.00	Centre Fuselage Section	Germany	2	4	Japan	3	5
ATA 53.00	Aft Fuselage Section	Germany	2	4	United States	2	4
ATA 57.10 – ATA 57.20	Wing Box	France	2	5	Japan	3	5
ATA 55.10	Horizontal Stabilizer	Spain	5	6	United States	2	4
ATA 32.00	Landing Gears	Germany	2	4	United Kingdom	5	5
ATA 52.80	Landing Gear Doors	France	2	5	Canada	4	6
ATA 55.30	Vertical Fin	Spain	5	6	United States	2	4
ATA 55.40	Rudder	China	9	11	China	9	11
ATA 57.30	Wing Tip	Austria	2	4	South Korea	4	4
ATA 53.00	Tail Cone	Spain	5	6	South Korea	4	4
ATA 57.50	Flaps	Belgium	2	4	Australia	3	3
ATA 57.40	Leading Edge	United States	2	4	United States	2	4
ATA 57.50	Fixed Trailing Edge	United Kingdom	5	5	Japan	3	5
ATA 54.50	Pylon Fairing Panels	France	2	5	United States	2	4
ATA 54.54	Aft Pylon Fairing	France	2	5	Canada	4	6
ATA 53.50	Belly Fairing	Spain	5	6	Canada	4	6
ATA 54.10	Engine Nacelles	Austria	2	4	United States	2	4
ATA 57.60	Ailerons	Turkey	11	13	Australia	3	3
ATA 57.70	Spoilers	Austria	2	4	Austria	2	4
	Total Hotspots		**82**	**127**		**74**	**113**

Within the 24 subsystems, aircraft A performs better, in terms of hotspots number, in 8 subsystems. For 9 subsystems a draw result has been achieved. Due to the enhancement of the designated categories, not only the social impact of both Direct Suppliers list has been reduced, but it has also resulted in a diverse leading scenario in the hotspots comparison, with aircraft A performing better then aircraft B. Furthermore, these findings strongly prove that the overall social impact can be reduced, obviating the necessity of relocating subsystem manufacturing.

4.3. Alternative Production Locations

Alternative subsystem distributions, representing more socially favourable supply chains, were generated for the selected threshold values, as illustrated in Figure 4. The main objective of this analysis is the implementation of Tier 1 Suppliers' scenarios that minimize the number of social hotspots (including their depth) and guarantee the minimum social impact on the previous defined stakeholders' groups. The "Socially Tier 1 Suppliers List" has been implemented considering, for each subsystem, the alternative production sites available for the corresponding supplier. Afterwards, the country with the minimum number of hotspots have been picked as the optimal solution for the achievement of the established goal.

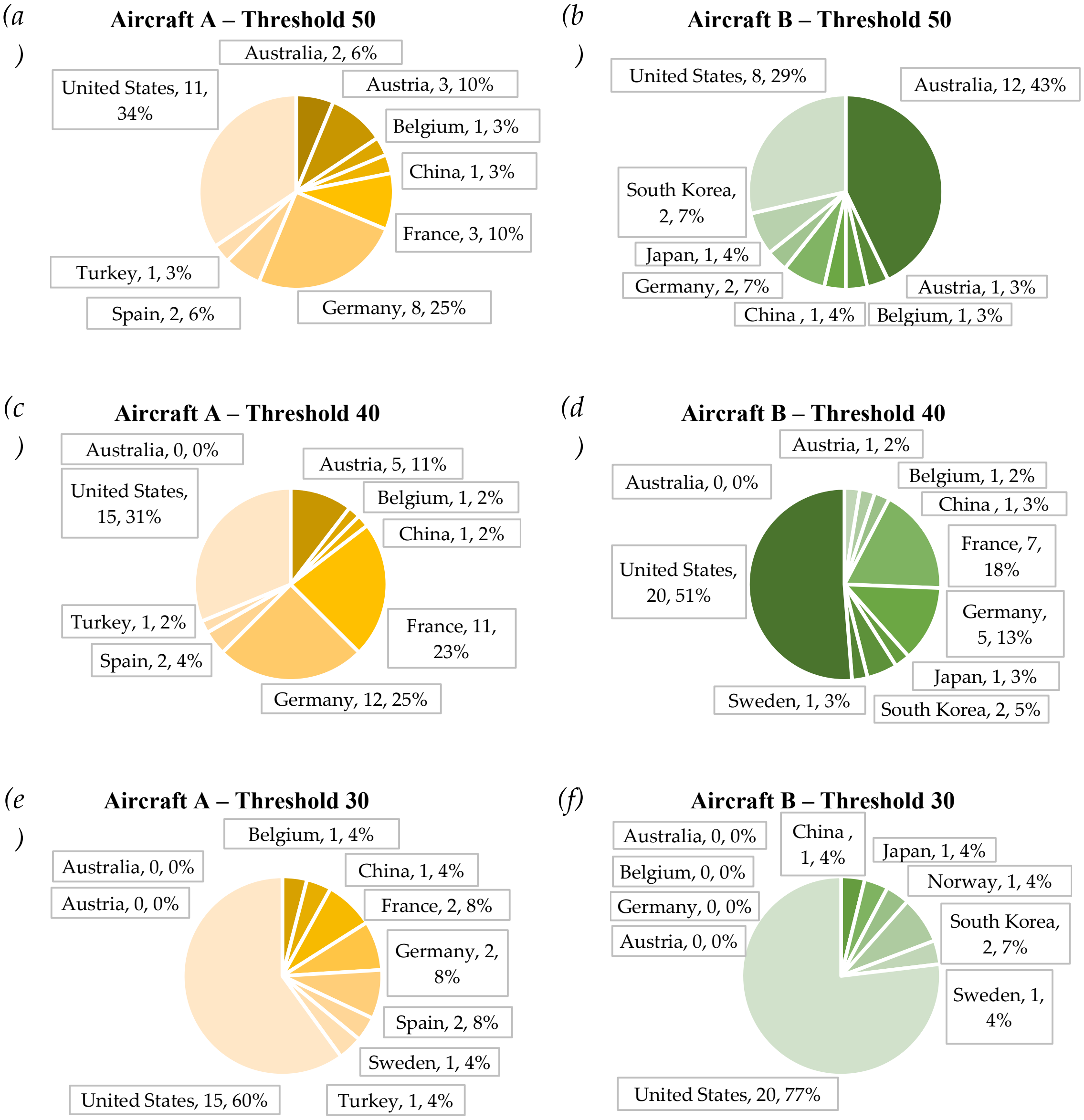

Figure 4. Overview of the implemented "Socially More Sustainable Tier 1 Suppliers List" for both aircraft in Threshold 50 (a)-(b), Threshold 40 (c)-(d), and Threshold 30 (e)-(d) Scenarios.

For both aircraft, the main supplier results being the United States, with the extreme scenario of 77% of the subsystems' manufacturing acquisition in threshold 30 scenario. On one hand, the socially more sustainable supply chain ensures the lowest number of hotspots and, consequently, the minimum social impact. On the other hand, it must be noticed that the obtained scenario is quite ideal and far from being possibly implemented in the corporate decisions, primarily exposing the companies to the loss of strategic suppliers' diversification and to all the related consequences. Advantages such as cost reduction, risk sharing, market access and political advantage (diplomatic and trade relations), access to specialized expertise and resources are highly negatively impacted.

The heatmap comparison between the actual suppliers' structure and the socially more sustainable Tier 1 suppliers list is presented in Table 8. Focusing on the scenario of threshold value equals 50, a reduction of 8% and 19% of the total hotspot values has been obtained, for aircraft A and B respectively. Comparing the hotspots number per each subsystem, aircraft B extremely strong lead in the comparison, with 14 subsystems showing lower number of hotspots than aircraft A. Only 8 subsystems result in an equal number of hotspots.

Table 8. Hotspots Comparison of the Actual Supply Scenario (A) and the Socially More Sustainable Tier 1 Suppliers List (S). (Country Abbreviations: ISO 3166 [76]).

Threshold 50	**Aircraft A**				**Aircraft B**			
Subsystem	Country	S	A	Country	Country	S	A	Country
Doors (Cargo)	AU	3	4	DE	US	4	4	SE
Door (Passengers)	AU	3	4	DE	BE/US	4	5	FR
Engines	DE/US	4	5	UK	AU	3	4	US
Front Fuselage Section	DE/US	4	4	DE	DE/US	4	5	JP
Nose Fuselage	DE/US	4	5	FR	US	4	4	US
Centre Fuselage Section	US	4	4	DE	JP	5	5	JP
Aft Fuselage Section	DE/US	4	4	DE	AU	3	4	US
Wing Box	DE/US	4	5	FR	DE/US	4	5	JP
Horizontal Stabilizer	US	4	6	ES	AU	3	4	US
Landing Gears	DE/US	4	4	DE	AU	3	5	UK
Landing Gear Doors	DE/US	4	5	FR	AU	3	6	CA
Vertical Fin	FR	5	6	ES	AU	3	4	US
Rudder	CN	11	11	CN	CN	11	11	CN
Wing Tip	AT/US	4	4	AT	KR	4	4	KR
Tail Cone	ES	6	6	ES	KR	4	4	KR
Flaps	BE	4	4	BE	AU	3	3	AU
Leading Edge	US	4	4	US	US	4	4	US
Fixed Trailing Edge	DE/US	4	5	UK	US	4	5	JP
Pylon Fairing Panels	FR	5	5	FR	AU	3	4	US
Aft Pylon Fairing	FR	5	5	FR	AU	3	6	CA
Belly Fairing	ES	6	6	ES	AU	3	6	CA
Engine Nacelles	AT/US	4	4	AT	AU	3	4	US
Ailerons	TR	13	13	TR	AU	3	3	AU
Spoilers	AT/US	4	4	AT	AT/US	4	4	AT
Threshold 50	**Total H.**	**117**	**127**		**Total H.**	**92**	**113**	
Threshold 40	**Total H.**	**69**	**81**		**Total H.**	**60**	**74**	
Threshold 30	**Total H.**	**29**	**51**		**Total H.**	**13**	**30**	

Analysing the Direct Suppliers lists for threshold value 40 (Appendix B), a reduction in the overall hotspot values of 46% and 47% respectively, has been obtained. Aircraft B leads in the comparison, while in the actual suppliers' scenario A demonstrates superior outcomes. For threshold 30, a reduction of 77% and 89% has been reached, moving from company B extreme lead to a more balanced comparison.

The development of the above scenarios leads to the unfavourable consequences of subsystems' delocalization to countries that better performed in terms of social impact. Table 9 presents aircraft A subsystems production loss per country, for threshold 50 scenario. European countries, such as

France, Germany, and United Kingdom, resulted in the higher number of subsystems' production delocalization. Thus, the obtained result highlights the core contribution of local policies in preventing the deindustrialization of specific areas and related repercussions on the stakeholders' groups, as well as impeding the loss of strategic leverage within the Tier 1 Suppliers list. Equivalent outcomes are achieved for aircraft B and in consideration of the diverse thresholds (Appendix B).

Table 9. Overview of the Subsystems Production Loss.

Aircraft A											
ATA_100	**Subsystems**	**Country**									
		AU	AT	BE	CN	FR	DE	ES	TR	UK	US
ATA 53.00	Centre Fuselage						x				
ATA 52.30	Doors (Cargo)						x				
ATA 52.10	Doors (Passenger)						x				
ATA 72.00	Engines									X	
ATA 57.50	Fixed Trailing Edge									X	
ATA 55.10	Horizontal Stabilizer							x			
ATA 52.80	Landing Gear Doors					x					
ATA 53.00	Nose Fuselage					x					
ATA 57.70	Spoilers				x						
ATA 55.30	Vertical Fin							x			
ATA 57.10 – ATA 57.20	Wing Box					x				X	
Subsystems Production Loss:					**1**	**3**	**3**	**2**		**3**	

For a comprehensive overview and identification of the shift in manufacturing capability, Appendix C display the subsystems' count per country for both the Actual and the socially more sustainable Tier 1 suppliers structures.

As a final objective of the analysis, the socially more sustainable Tier 1 suppliers list, initially derived setting a threshold of 50, has been further refined by integrating the enhancements of the social categories detailed in Table 6. The achieved findings are presented in Table 10.

Table 10. Comparison of the Improved Socially More Sustainable Tier 1 Suppliers List (I) and the Socially More Sustainable Tier 1 Suppliers List (S).

		Aircraft A			**Aircraft B**		
ATA 100 Standard	Subsystem	Country	I	S	Country	I	S
ATA 52.30	Doors (Cargo)	Germany/France/US	2	3	Sweden/US	2	4
ATA 52.10	Door (Passengers)	Germany/France/US	2	3	France/US	2	4
ATA 72.00	Engines	Germany/US	2	4	Germany/US	2	3
ATA 53.00	Front Fuselage Section	Germany	2	4	Germany/France/US	2	4

ATA 53.00	Nose Fuselage	Germany/France/US	2	4	France/US	2	4
ATA 53.00	Centre Fuselage Section	Germany/France/US	2	4	Japan	3	5
ATA 53.00	Aft Fuselage Section	Germany	2	4	US	2	3
ATA 57.10 – ATA 57.20	Wing Box	Germany/France/US	2	4	Germany/US	2	4
ATA 55.10	Horizontal Stabilizer	US	2	4	Germany/France/US	2	3
ATA 32.00	Landing Gears	Germany/France/US	2	4	France/US	2	3
ATA 52.80	Landing Gear Doors	Germany/France/US	2	4	US	2	3
ATA 55.30	Vertical Fin	France/US	2	5	US	2	3
ATA 55.40	Rudder	China	9	11	China	9	11
ATA 57.30	Wing Tip	Austria/US	2	4	South Korea	4	4
ATA 53.00	Tail Cone	Spain	5	6	South Korea	4	4
ATA 57.50	Flaps	Belgium	2	4	US	2	3
ATA 57.40	Leading Edge	France/US	2	4	France/US	2	4
ATA 57.50	Fixed Trailing Edge	Norway	1	4	US	2	4
ATA 54.50	Pylon Fairing Panels	France/US	2	5	France/US	2	3
ATA 54.54	Aft Pylon Fairing	Germany/France/US	2	5	US	2	3
ATA 53.50	Belly Fairing	Spain	5	6	US	2	3
ATA 54.10	Engine Nacelles	Austria/US	2	4	Germany/France/US	2	3
ATA 57.60	Ailerons	Turkey	10	13	US	2	3
ATA 57.70	Spoilers	Austria/US	2	4	Austria/US	2	4

Total Hotspots	**68**	**117**	**60**	**92**

A reduction of 42% in aircraft A improved suppliers' architecture has been achieved, decreasing the hotspots number from 117 to 68. Aircraft B results in 35% reduction, from 92 to 60 number of hotspots. The enhancement of the categories presented in Table 6 results both in the reduction of hotspots number and in the decrement of the hotspots' values impact magnitude per Tier 1 Supplier list. The latter is calculated as the overall sum of the hotspot's values of the improved scenario, compared to the corresponding values of the socially more sustainable direct suppliers. The findings showcase an average reduction of 33% ± 24%. A diverse scenario has been obtained when the investigation and comparison of each subsystem's hotspot value have been conducted. In the socially more sustainable Tier 1 suppliers list, aircraft B leads the comparison showing better performances in 14 out of 24 subsystem (58%), while aircraft A social impact performance results better in only 8% of the subsystems. Contrarily, in the improved scenario, both aircraft results in a better performance in 3 out of 24 subsystems, with 18 cases of draw outcomes. These findings represent how governmental policies related to social categories enhancement, can directly influence the outcome of corporate decisions and, subsequently, affect the performance of the involved companies. Moreover, a limited effort in improving selected social impact categories lead to improved scenarios for both aircraft.

A comprehensive comparison of the subsystems' distribution per country is provided in Appendix D, where the Improved socially more sustainable Tier 1 suppliers list is compared to the previous implemented suppliers' architectures (Chapter 3.2).

5. Discussion

The comparative assessment of aircraft A and B Tier 1 Suppliers underscores the multifaceted nature of social sustainability in the aerospace sector. While company B generally exhibits stronger social performance across its global supply chain, subsystem-level analysis reveals that social risks are unevenly distributed. For example, focusing solely on aggregate hotspot reduction could obscure critical vulnerabilities that, if unaddressed, might lead to reputational, operational, or regulatory risks. The findings highlight the necessity of considering both the aggregate and subsystem-specific perspectives in corporate social responsibility strategies.

Exploration of socially more sustainable direct suppliers lists demonstrates the potential benefits of targeted interventions but also emphasizes the limitations of extreme optimization. Concentrating production in a limited number of countries can reduce social hotspots but may compromise supplier diversification, technological specialization, and supply architecture resilience. In the aerospace context, where geopolitical, logistical, and strategic considerations are critical, overly centralized supply chains could introduce operational fragility. Achieving social sustainability, therefore, requires balancing hotspot reduction with flexibility, diversification, and long-term strategic viability.

Country-level analysis further reinforces the importance of coordinated action between corporate policy and national initiatives. Improvements in targeted social categories—such as labor standards, education, and community well-being—can significantly reduce hotspots without necessitating radical restructuring of supply chains. This suggests that sustainable supply chain management benefits from alignment between corporate sourcing strategies and country-level social development policies, fostering local economic support while mitigating potential social risks, including those arising when component production is located in other countries.

While this SLCA screening provides valuable insights into social hotspots and sustainable supply chain strategies, several limitations should be acknowledged. First, the analysis is conducted at the country level rather than the site or facility level, meaning that local variations in labor practices, community engagement, or environmental performance within a given country cannot be fully captured. Individual manufacturers may also perform better socially than the country-level comparative scale suggests, limiting the applicability of these results. Unfortunately, aviation-specific hotspots and threshold values tailored to the sector are not currently available, requiring reliance on more general social performance data. Similarly, the granularity of upstream supplier information is limited, as complete visibility into all tier-n suppliers is rarely achievable in complex aerospace supply chains. Threshold-based assessments, while useful for comparative analysis, may oversimplify the spectrum of social risks and their interactions with technological, economic, and environmental factors. The socially more sustainable supply chain scenarios explored are hypothetical and do not account for real-world constraints such as contractual obligations, regulatory requirements, geopolitical risks, or strategic diversification goals. Finally, this screening does not suggest withdrawing from countries with the highest number of hotspots; rather, it highlights potential social risks that can guide targeted social investments or regulatory interventions in collaboration with authorities (e.g., capacity-building programs, improvements in health and safety standards, or other wellbeing initiatives identified through the assessment). Overall, these limitations indicate that the findings should be interpreted as indicative trends and guiding principles rather than precise operational prescriptions.

6. Conclusions and Future Work

The study applies Social Life Cycle Assessment (SLCA) principles, guided by UNEP/SETAC guidelines and the emerging ISO 14075:2024 standard, to assess and quantify the social impacts associated with material production and manufacturing in the aviation sector, using a screening approach to identify and evaluate relevant hotspots. A tailored SLCA framework with aviation-specific indicators is developed and demonstrated through a comparative assessment of two major commercial aircraft platforms.

More specifically, this study assessed company A and B Tier 1 Suppliers lists through three complementary analytical approaches: comparative evaluation of actual suppliers’ network, exploration of socially more sustainable direct suppliers’ scenarios, and improvement of Tier 1 Suppliers lists through targeted enhancements of specific social categories.

The comparative assessment of actual suppliers’ network revealed that company B generally exhibits fewer social hotspots than A, particularly at threshold values of 50 and 30. However, subsystem-level performance varies, and certain aircraft A subsystems perform better under specific conditions, highlighting that aggregate metrics alone may obscure localized social risks. This finding underscores the importance of detailed, subsystem-level analyses to capture critical vulnerabilities that could propagate operational, reputational, or social risks.

The socially more sustainable Tier 1 Supplier scenarios demonstrated that strategically reallocating subsystem production to countries with lower social risks can substantially reduce total hotspots, with reductions of up to 77–89% under the strictest threshold scenario (threshold = 30). Nevertheless, such scenarios are largely theoretical, as they compromise supplier diversification, technological specialization, and operational resilience. These findings emphasize the inherent trade-offs between minimizing social impacts and maintaining a robust, diversified supply chain, illustrating the complexity of integrating social sustainability into aerospace sourcing strategies within the broader context of holistic sustainability.

The improved supplier’s lists incorporating targeted social category enhancements -focused on labor standards, education, and community well-being- showed that moderate interventions can achieve substantial social improvements without major restructuring. Both aircraft reduced hotspots by roughly 35%, with aircraft A exhibiting relative improvements in multiple subsystems. This demonstrates that aligning corporate sourcing policies with social objectives can meaningfully reduce social impacts while preserving strategic operational and economic considerations.

From a sustainable aircraft-design perspective, these findings highlight the need for a truly holistic approach. Design decisions should simultaneously account for social, environmental, economic, and technological considerations, recognizing that subsystem choices, materials and components, and sourcing strategies have interconnected impacts. Subsystems with high social hotspot exposure could be redesigned for flexibility, enabling multiple sourcing options or alternative materials that reduce reliance on regions with elevated social risks. At the same time, environmental and circular economy principles -such as recyclability, resource efficiency [77]- must be integrated to minimize ecological footprint. Economic and operational feasibility cannot be overlooked, as excessive concentration of suppliers may reduce resilience and technological specialization. By combining social, environmental, and economic assessments within a framework that balances these trade-offs, aircraft designers can create systems that are technically solid, economically viable, socially responsible, environmentally sustainable, and aligned with circular economy objectives, ultimately supporting a resilient and ethical aerospace supply chain.

Importantly, this SIA screening advances a holistic framework for sustainable aircraft design and supply chain management, introducing quantifiable metrics that enhance the precision of social impact evaluation within complex aerospace supply chains. These metrics also help engineers interpret and apply social sustainability insights in their design efforts and support informed decision-making.

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Appendix A. Identification of the Social Hotspots.

The number of social hotspots per each subsystem and the total hotspots values have been identified for both aircraft A and B.

Table A1. Identification of the Social Hotspots per Subsystem's Supplier.

Threshold 40		Aircraft A		Aircraft B	
ATA_100 Standard	Subsystems	Country	Hotspots	Hotspots	Country
ATA 52.30	Doors (Cargo)	Germany	2	2	Sweden
ATA 52.10	Door (Passengers)	Germany	2	2	France
ATA 72.00	Engines	United Kingdom	5	2	United States
ATA 53.00	Front Fuselage Section	Germany	2	3	Japan
ATA 53.00	Nose Fuselage	France	2	2	United States
ATA 53.00	Centre Fuselage Section	Germany	2	3	Japan
ATA 53.00	Aft Fuselage Section	Germany	2	2	United States
ATA 57.10 – ATA 57.20	Wing Box	France	2	3	Japan
ATA 55.10	Horizontal Stabilizer	Spain	5	2	United States

ATA 32.00	Landing Gears	Germany	2	5	United Kingdom
ATA 52.80	Landing Gear Doors	France	2	4	Canada
ATA 55.30	Vertical Fin	Spain	5	2	United States
ATA 55.40	Rudder	China	9	9	China
ATA 57.30	Wing Tip	Austria	2	4	South Korea
ATA 53.00	Tail Cone	Spain	5	4	South Korea
ATA 57.50	Flaps	Belgium	2	3	Australia
ATA 57.40	Leading Edge	United States	2	2	United States
ATA 57.50	Fixed Trailing Edge	United Kingdom	5	3	Japan
ATA 54.50	Pylon Fairing Panels	France	2	2	United States
ATA 54.54	Aft Pylon Fairing	France	2	4	Canada
ATA 53.50	Belly Fairing	Spain	5	4	Canada
ATA 54.10	Engine Nacelles	Austria	2	2	United States
ATA 57.60	Ailerons	Turkey	10	3	Australia
ATA 57.70	Spoilers	Austria	2	2	Austria
		Total Hotspots	**81**	**74**	

Threshold 30		**Aircraft A**		**Aircraft B**	
ATA_100 Standard	Subsystems	Country	Hotspots	Hotspots	Country
ATA 52.30	Doors (Cargo)	Germany	2	0	Sweden
ATA 52.10	Door (Passengers)	Germany	2	1	France
ATA 72.00	Engines	United Kingdom	1	0	United States
ATA 53.00	Front Fuselage Section	Germany	2	2	Japan
ATA 53.00	Nose Fuselage	France	1	0	United States
ATA 53.00	Centre Fuselage Section	Germany	2	2	Japan
ATA 53.00	Aft Fuselage Section	Germany	2	0	United States
ATA 57.10 – ATA 57.20	Wing Box	France	1	2	Japan
ATA 55.10	Horizontal Stabilizer	Spain	3	0	United States
ATA 32.00	Landing Gears	Germany	2	1	United Kingdom
ATA 52.80	Landing Gear Doors	France	1	2	Canada
ATA 55.30	Vertical Fin	Spain	3	0	United States
ATA 55.40	Rudder	China	7	7	China
ATA 57.30	Wing Tip	Austria	1	2	South Korea
ATA 53.00	Tail Cone	Spain	3	2	South Korea
ATA 57.50	Flaps	Belgium	1	1	Australia
ATA 57.40	Leading Edge	United States	0	0	United States

ATA 57.50	Fixed Trailing Edge	United Kingdom	1	2	Japan
ATA 54.50	Pylon Fairing Panels	France	1	0	United States
ATA 54.54	Aft Pylon Fairing	France	1	2	Canada
ATA 53.50	Belly Fairing	Spain	3	2	Canada
ATA 54.10	Engine Nacelles	Austria	1	0	United States
ATA 57.60	Ailerons	Turkey	9	1	Australia
ATA 57.70	Spoilers	Austria	1	1	Austria
		Total Hotspots	**51**	**30**	

Appendix B. Implementation of the Socially More Sustainable Tier 1 Suppliers List

Heatmaps' comparison of the actual scenario and the socially more sustainable for threshold 40 and 30.

Table A2. Hotspots Comparison of the Actual Supply Scenario (A) and the Socially More Sustainable Tier 1 Suppliers List (S). (Country Abbreviations: ISO 3166 [76]).

Threshold 40	**Aircraft A**				**Aircraft B**			
Subsystem	Country	S	A	Country	Country	S	A	Country
Doors (Cargo)	AT/US7FR/DE	2	2	DE	SE/US	2	2	SE
Door (Passengers)	AT/US7FR/DE	2	2	DE	FR/BE/US	2	2	FR
Engines	DE/US	2	2	UK	DE/US	2	2	US
Front Fuselage Section	DE	2	3	DE	FR/DE/US	2	3	JP
Nose Fuselage	FR/DE/US	2	2	FR	FR/US	2	2	US
Centre Fuselage Section	FR/US	2	3	DE	JP	3	3	JP
Aft Fuselage Section	DE	2	2	DE	US	2	2	US
Wing Box	FR/DE/US	2	3	FR	DE/US	2	3	JP
Horizontal Stabilizer	US	2	2	ES	FR/DE/US	2	2	US
Landing Gears	FR/DE/US	2	5	DE	FR/US	2	5	UK
Landing Gear Doors	FR/DE/US	2	4	FR	US	2	4	CA
Vertical Fin	FR	2	2	ES	US	2	2	US
Rudder	CN	9	9	CN	CN	9	9	CN
Wing Tip	AT/US	2	4	AT	KR	4	4	KR
Tail Cone	ES	5	4	ES	KR	4	4	KR
Flaps	BE	2	3	BE	US	2	3	AU
Leading Edge	FR/US	2	2	US	FR/US	2	2	US
Fixed Trailing Edge	DE/US	2	3	UK	US	2	3	JP
Pylon Fairing Panels	FR	2	2	FR	US	2	2	US
Aft Pylon Fairing	FR/DE/US	2	4	FR	US	2	4	CA
Belly Fairing	ES	5	4	ES	US	2	4	CA
Engine Nacelles	AT/US	2	2	AT	FR/DE/US	2	2	US
Ailerons	TR	10	3	TR	US	2	3	AU
Spoilers	AT/US	2	2	AT	AT/US	2	2	AT

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Total Hotspots		69	74			60	74	
Threshold 30								
Doors (Cargo)	US	0	2	DE	SE/US/NO	0	0	SE
Door (Passengers)	US	0	2	DE	US	0	1	FR
Engines	US	0	1	UK	US	0	0	US
Front Fuselage Section	DE	2	2	DE	US	0	2	JP
Nose Fuselage	US	0	1	FR	US	0	0	US
Centre Fuselage Section	US	0	2	DE	JP	2	2	JP
Aft Fuselage Section	DE	2	2	DE	US	0	0	US
Wing Box	US	0	1	FR	US	0	2	JP
Horizontal Stabilizer	US	0	3	ES	US	0	0	US
Landing Gears	US	0	2	DE	US	0	1	UK
Landing Gear Doors	US	0	1	FR	US	0	2	CA
Vertical Fin	FR	1	3	ES	US	0	0	US
Rudder	CN	7	7	CN	CN	7	7	CN
Wing Tip	US	0	1	AT	KR	2	2	KR
Tail Cone	ES	3	3	ES	KR	2	2	KR
Flaps	BE	1	1	BE	US	0	1	AU
Leading Edge	US	0	0	US	US	0	0	US
Fixed Trailing Edge	SE/US	0	1	UK	US	0	2	JP
Pylon Fairing Panels	FR	1	1	FR	US	0	0	US
Aft Pylon Fairing	US	0	1	FR	US	0	2	CA
Belly Fairing	ES	3	3	ES	US	0	2	CA
Engine Nacelles	US	0	1	AT	US	0	0	US
Ailerons	TR	9	9	TR	US	0	1	AU
Spoilers	US	0	1	AT	US	0	1	AT
Total Hotspots		29	51			13	30	

Appendix C. Overview of the Subsystems Production Acquisition or Loss per Country

This comparison allows for the identification and tracking of which subsystems are gained or lost by the involved countries within each suppliers' lists. Figure A1 illustrates the results related to threshold 50. It is evident that some countries, such as United States for the aircraft A case and Australia for aircraft B scenario, enhanced their manufacturing capacity with 9 and 10 more subsystems respectively. Conversely, countries such as the United Kingdom, Italy, and France lost all subsystem production and are therefore excluded from the Tier 1 suppliers, as they no longer meet the threshold requirements, resulting in a reduction in the number of hotspots.

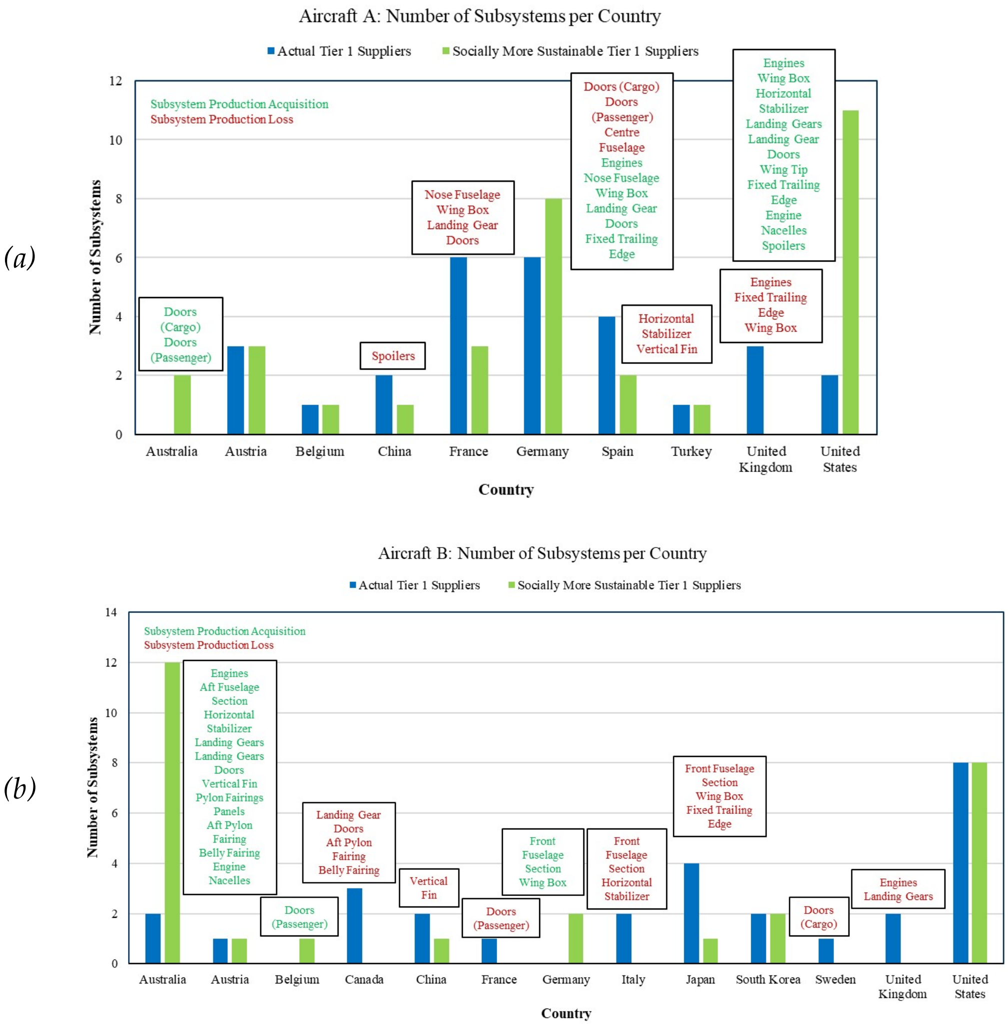
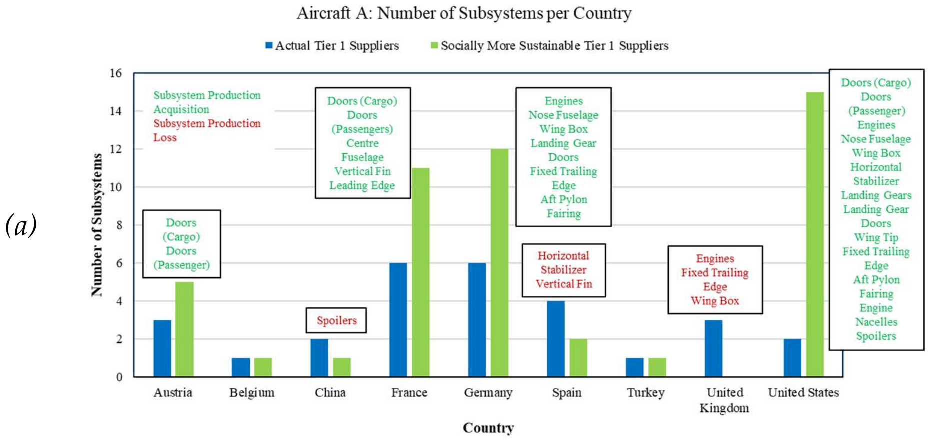


Figure A1. Comparison of Subsystems' Distribution for (a) Aircraft A and (b) Aircraft B, in Threshold 50 Scenario.

For a threshold of 40, United States is the major supplier of both companies, with 13 more aircraft A subsystems acquisitions and 12 B's. It must also be noticed that European countries, particularly France and Germany, increase their manufacturing capacity, leading to a more balanced overall outcome in terms of subsystems acquisitions.



(b)

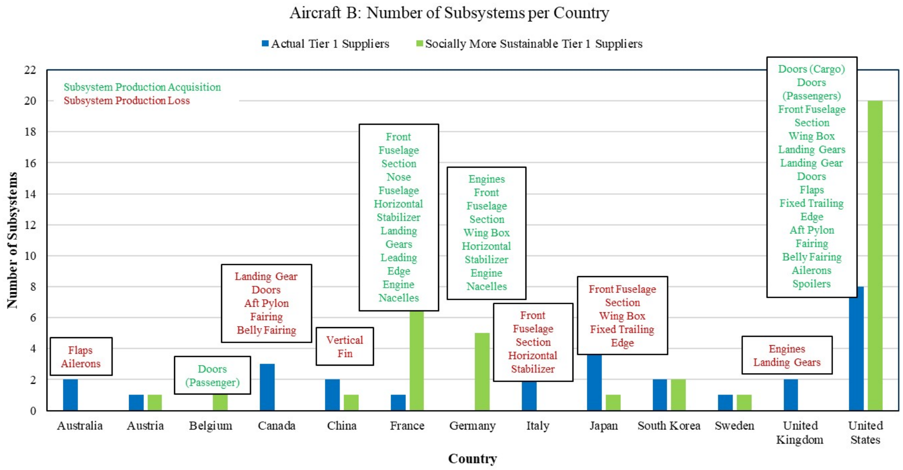
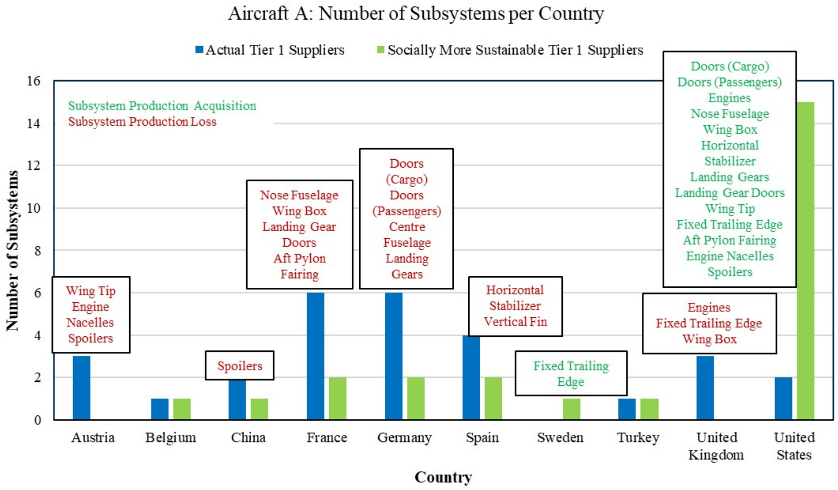


Figure A2. Comparison of Subsystems' Distribution for (a) Aircraft A and (b) Aircraft B, in Threshold 40 Scenario.

Threshold 30 can be considered as an extreme scenario. For both aircraft, United States results in being the only country to enhance the subsystem production capacity, whereas all the other countries within the actual supply scenario lost a number of subsystems or are excluded from the suppliers' list. Focusing on the socially more sustainable Tier 1 Suppliers list of aircraft B, out of 12 countries involved in it, 6 are excluded from the supply chain in the socially more sustainable scenario. A reduction in the number of supplier countries of 50% is indeed a non-realistic goal to be achieved by the companies, due to the consequences resulting from the low diversification of suppliers and relative production sites countries.

(a)



(b)

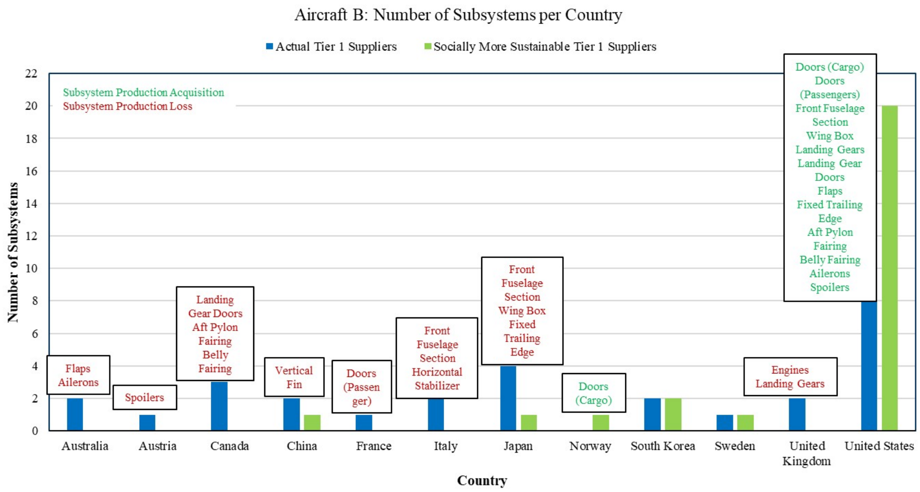


Figure A3. Comparison of Subsystems' Distribution for (a) Aircraft A and (b) Aircraft B, in Threshold 30 Scenario.

Although, hypothetically, the socially more sustainable Tier 1 Suppliers list achieves the goal of minimizing the social impact, it is important to recognize that its implementation might lead to negative consequences for the companies involved. Furthermore, the resulting local deindustrialization creates significant drawbacks, affecting stakeholder groups like Workers and Local Community.

Appendix D. Comprehensive Overview of the Subsystems Production Acquisition or Loss per Country

The analysis has been conducted to compare the subsystems' distribution per country, already discussed in Chapter 3.2 and illustrated in Figure 6, and the improved socially more sustainable scenario. The identification and tracking of the subsystems have been implemented to highlight the diverse outcomes and related consequences. The results related to aircraft A are presented in Figure A4. The implementation of the improved socially more sustainable scenario, primarily leads to partially preventing the delocalization of subsystems' production to countries outside the European Union, facilitating the acquisition of subsystems by EU countries, such as France and Germany. The United States is confirmed being the main supplier, responsible of the manufacturing of 16 subsystems, followed by France and Germany, with 11 subsystems each. The latter outcome is highly optimistic, as it presents the possibility for specific countries to move from a critical scenario of subsystems' loss into a favourable state of subsystems' production acquisition.

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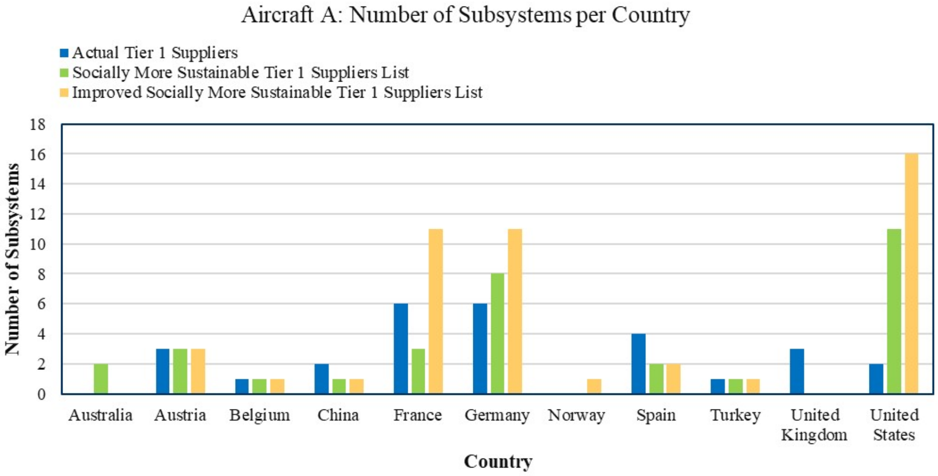

Figure A4. Comparison of the Number of Subsystems in the implemented Direct Suppliers Lists.

Figure A5 represents the comparison results for aircraft B. In the framework of the improved socially more sustainable Tier 1 suppliers lists, the overall scenario results in a wide variation of subsystems' distribution within the countries of the suppliers' network. Australia moves from obtaining 12 subsystems in the socially more sustainable scenario, to gain 2 subsystems in the improved more sustainable Tier 1 Suppliers architecture. Whereas the United States counts 20 subsystems in the improved scenario, potentially the 83% of the subsystems' production. This outcome is far from being possible pursuing by the companies' policies, where different strategic aspects are taken into consideration to implement a more comprehensive analysis of the supply chain development.

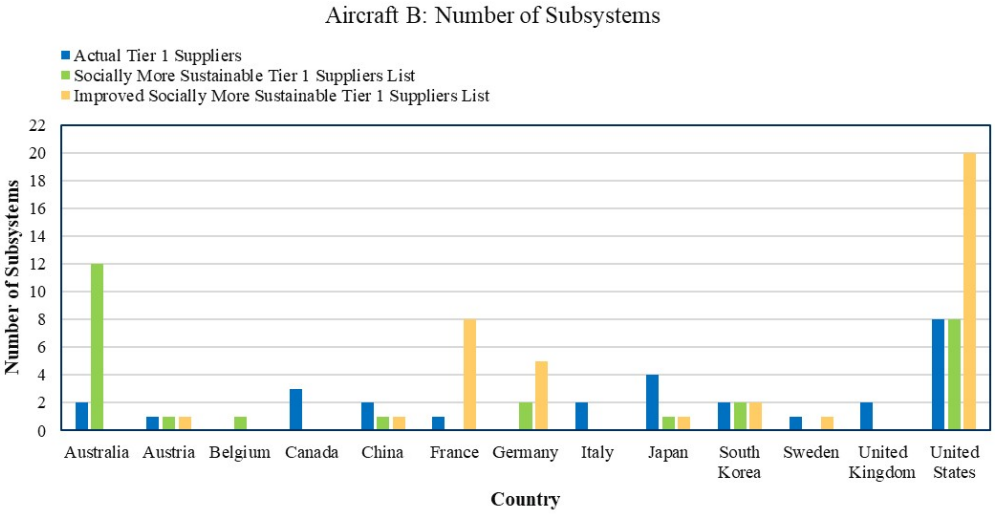

Figure A5. Comparison of the Number of Subsystems in the implemented Direct Suppliers Lists.

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