A SYSTEMATIC REVIEW OF CIRCULAR ECONOMY ADOPTION IN THE AVIATION INDUSTRY

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ABSTRACT

Aviation industry's impact on the natural and social environment is undeniable. The industry is moving forward with implementation of initiatives that address these issues in which this study is attempting to understand. It is meant to explore the levels of Circular Economy (CE) adoption within the industry and the areas needed to be given attention to. However, there is yet a study that addresses industry's level of CE implementation in a comprehensive manner. Through a systematic literature review, this study has found that the industry must broaden its scope of CE R&D and implementation to the many areas of the R-list framework. The study has finalized 21 literatures in its review and found uneven distribution of CE Rn initiatives throughout the list. A thematic analysis was conducted and 10 CE initiatives were identified. The initiatives are: Fuel Efficiency (FE), Electric Aircraft and Ground Vehicle (EAGV), Waste Management (WM), Energy Saving (ES), Water Management (WTM), Decision Making Model (DMM), Legislation and Taxation (LT), Multi-sided Platform (MSP), Sustainable Aviation Fuel (SAF), and Maintenance, Repair and Overhaul (MRO). From the findings, suggestions are made for the industry and its actors to establish CE units that plan, execute, review, and monitor progress of CE adoption within the industry.

KEYWORDS

Circular Economy; Aviation Industry; Initiative; R-list framework; Systematic Review

INTRODUCTION

Circular Economy (CE) implementation in the aviation industry has been becoming increasingly popular in the recent years. The establishment of international organizations in aviation waste management such as the International Aviation Waste Management Association (IAWMA) act as one of the many pieces of evidence that the industry is stepping up its effort in transitioning towards circularity [1].

The CE and Sustainable Development (SD) concept have been used interchangeably throughout many literatures and have at least 100 different definitions [2] that poses a major challenge to scholars and practitioners alike [3, 4]. The monitoring of its performances is difficult as there is no set of indicators that is generally accepted due to the variations [5]. Although both intend to seek balance in developments by taking social and natural environment into account, the CE concept employs a more practical approach than the other [6].

Generally, scholars agree that CE refers to an economic system that retains the values of extracted natural resources within a closed-loop economy [2, 7, 8]. Ekins in [8] suggested that our economies cannot be developed infinitely upon a finite resource. Intake of natural resources to create new products and technologies must be limited, and the resultant waste must be reduced substantially.

This is in opposition to the conventional Linear Economy (LE) concept, in which creation of new technologies and developments only consider its economic feasibility and viability [9]. The LE generally employs the take-make-break/dispose philosophy where extensive use of natural resources is exhibited due to abundance of natural resources, and comparatively lower cost than the cost of human labor. Typically, the consequences to such paradigm are neglect in reducing, reusing, and recycling, and hence results in more waste generation. Therefore, the aviation industry regards CE implementation as the percentage of the components' mass which can be reused or recycled after end-of-life (EoL) of the aircraft [7].

Kirchherr et al in [2] studied 114 different descriptions of CE and defines it generally as an economic system that prioritizes reducing, reusing, recycling and recovering materials across all levels of production, distribution and consumption, which are aimed at achieving sustainable growth that considers environmental quality, economic prosperity and social equity for present and future generations. For the aviation industry to become sustainable, a transition must be made from LE to CE, and this is the philosophy that this paper is adopting.

Most literature under review have yet to address the level of CE implementation in the aviation industry in a comprehensive manner. For example, Migdadi in [10] focused on 23 airlines' green strategies between 2013-2016 while Schafer et al. and Schwab et al. focused on electrification of mobility in the industry [11, 12]. A number of several others such as [13 - 18] studied about Sustainable Aviation Fuel (SAF).

Therefore, this study attempts at addressing the literature gap by reviewing the level of CE implementation in the global aviation industry, adapting a conceptual framework proposed by Potting et al. in [19] using the systematic literature review (SLR) method. It is meant to map initiatives and work related to adopting the CE throughout the aviation industry with the objective of providing a comprehensive view of the industry's level of circularity which could become a benchmark for future research and strategic investments.

Furthermore, the application of the SLR method to answer this objective enhances the study's transparency and reproducibility, thus furnishing decision-makers, entrepreneurs, and researchers alike with high quality information [20].

Methodology

Research Question

The research question (RQ) was designed in two phases. The first was by reading several literatures related to Circular Economy. Literatures such as [2] [21] were arbitrarily selected from Google Scholar and an objective as related by Kircherr et al. in [2] was formulated and elaborated in the Introduction section. This study, however, is formulated to evolve within the realms of adoption of CE in the aviation industry with similar intention to [2].

The second phase was developing an RQ related to research objective (RO) using PICo mnemonics as described by Lockwood et al. in [22]. PICo signifies Problem or Population (P), Interest (I), Context (Co) in which the purpose of this study is based on. In the context of this study, the following Global Airlines (P), Adoption of Circular Economy (I) and Initiative (Co) were used.

RQ: What are the initiatives related to the implementation of Circular Economy in global aviation industry?

Review Method and Protocol

The design of this SLR is guided by protocols laid by the Reporting Standards for Systematic Evidence Syntheses (ROSES) developed by Gusenbauer and Haddaway in [23]. Though there are many other SLR guidelines developed by various scholars, ROSES were chosen for this study as it is specifically designed for studies in environment management and suit the nuances and heterogeneity of the field of study [23].

ROSES guides the research process by initially formulating an RQ as described in the Research Question section. Subsequently, a document search was planned and executed using the systematic search strategy approach. This approach is divided into four distinct phases of selection guided by inclusion and exclusion criteria namely: identification, screening, and eligibility. Following these processes is an appraisal of the articles' quality done by two experts as suggested by Charrois [24], with guidance from study by guidelines proposed by Kitchenham and Charters in [25].

As for the inclusion and exclusion criteria, maturity of studies was taken into consideration [20]. Only articles published between 2013 to 2023 were included. The type of articles to be included were expanded to grey literatures and book chapters, in addition to the typical peer reviewed articles [26] [27] due to the fact that CE in aviation is at its infancy. Additionally, only articles in English were accepted to avoid retrieval bias [28].

Four databases namely Science Direct, Emerald, Dimensions AI and Google Scholar were used with search strings described in Table 1. The databases were selected based on their accessibility to the authors. Subsequently, the identification process was conducted and found n

= 1454 articles with relevant titles. Then, the articles were further screened according to inclusion and exclusion criteria, narrowing it to a total of n = 1094. Article duplicates were removed and eventually only n = 34 made it to the quality appraisal (QA) stage (Refer Figure 1).

The following 6 criteria utilized during QA were adopted from [25]:

QA 1: Is the purpose of study clearly stated?
QA 2: Is the interest and the usefulness of work clearly presented?
QA 3: Is the study methodology clearly established?
QA 4: Are the concepts of the approach clearly defined?
QA 5: Is the work compared and measured with other similar work?
QA 6: Are the limitations of the work clearly mentioned?

Two authors were tasked to appraise the articles manually and independently where each question was given 1 mark for 'YES', 0 mark for 'NO' and 0.5 mark for 'PARTIAL'. Results were aggregated and discrepancies were discussed until a consensus was reached. Articles that scored above 50 percent were accepted for review.

After a full text review, 1 article [21] did not meet 50 percent of the QA criteria, 2 articles [29, 30] were found not related to the RO and RQ, and 10 articles [31-40] were inaccessible to the reviewers. Eventually, n = 21 articles were finalized and utilized for review.

Conceptual Framework

This study adapts a conceptual framework for mapping related initiatives in the aviation industry as proposed by Potting et al in [19]. The framework, hereafter called the R-list, has 10 distinct categories of CE level of implementation which establishes a priority of order based on waste treatment methods, aimed at reducing any industry's natural resources intake and waste production.

The highest circular initiatives can be found in the R0 to R2 category bracket of the R-list: R0 Refuse, R1 Rethink, R2 Reduce. According to the framework, initiatives within these categories exhibit smarter product use thus encouraging industry's circularity by consuming lesser natural resources and producing less waste. Initiatives within these categories are highly desirable as they prevent waste generation to achieve industry's circularity.

The second bracket, R3 to R7 contains initiatives inclined towards extending the lifespan of products and their parts: R3 Reuse, R4 Repair, R5 Refurbish, R6 Remanufacture, R7 Repurpose. It can be said that this bracket is the mid transition from the conventional take-make-break/dispose concept towards CE.

R8 to R9 are categories of initiatives with the lowest circularity where waste destined to landfills and incinerators are recovered with or without energy production. R8 describes recycling initiatives that involve processing materials to obtain new materials with the same or lower grade than its prior form. It is divided into two sub-categories called closed-loop recycling and open-loop recycling [41]. Though not in some cases, the closed-loop recycling is preferable [41] as it involves less logistics, hence lower carbon footprint [42]. R9 on the other hand, involves energy recovery from waste materials by means of incineration.

As a rule of thumb, the level of circularity in an industry increases as the number of Rn decreases. In the words of Potting et al in [19], the more circular the better it is for the environment. Table 2 describes this framework.

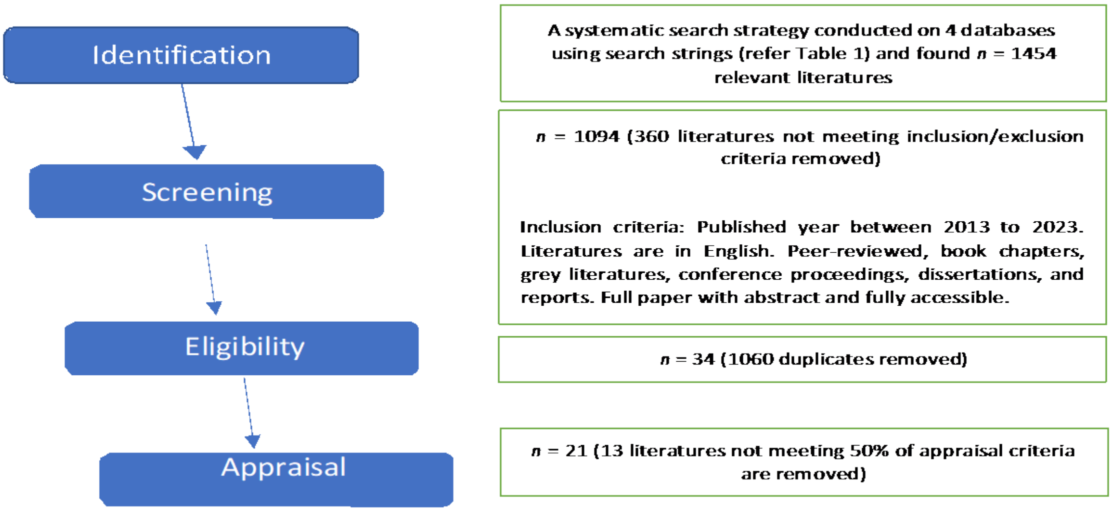

Figure 1: SLR literature selection Flow Diagram

Table 1: Databases and search strings used.

Database	Search String
Science Direct	TITLE-ABS-KEY (("Airlines" OR "international airlines") AND ("implementation" OR "aviation companies" OR "airline companies") AND ("circular economy" OR "closed-loop economy" OR "upcycling")) TITLE-ABS-KEY (("Airlines" OR "international airlines") AND ("implementation" OR "adoption" OR "integration") AND ("circular economy" OR "closed-loop economy" OR "upcycling"))
Emerald	(((aviation) OR (airlines)) AND ((circular economy) OR (closed- loop economy)) AND ((implementation) OR (adoption))) (aviation) AND (circular economy) AND (implementation)
Google Scholar	"aviation" "airlines" "Implementation" "circular economy" "circular design" "adoption" (("aviation industry" OR "airline service") AND ("closed-loop economy" OR "upcycling" OR "repurposing") AND ("adoption" OR "implementation"))
Dimensions.ai	aviation implementation 'circular economy'

Theme Identification

From the R-list, the first round of in-text review was conducted on finalized literatures with related initiatives identified and mapped against Rn in Table 3. For example, texts with the sentence that has word that directly describes the Rn such as "Repurposing of …" was mapped against R7 (Repurpose). Likewise, sentences that do not have Rn related word but describe an initiative that identifies with its respective Rn are mapped against that particular Rn. An example to this would be, "… is possible if MSW is utilized as feedstock for biofuel consumption" which corresponds to R2 (Reduce). The nature of the sentence itself is referring to one of the processes in SAF production that is meant to reduce utilization of fossil-fuel and CO2 emission as waste.

The findings were then further refined into those that answer this research's objective and question, as such text that do not relate to aviation industry's CE concept were excluded from forming this literature.

Based on the extracted data, a pattern of initiatives was clustered accordingly and a set of 10 subthemes were identified. The subthemes, which are also relevant initiatives, are: Fuel Efficiency (FE), Electric Aircraft and Ground Vehicle (EAGV), Waste Management (WM), Energy Saving (ES), Water Management (WTM), Decision Making Model (DMM), Legislation and Taxation (LT), Multi-sided Platform (MSP), Sustainable Aviation Fuel (SAF), and Maintenance, Repair and Overhaul (MRO).

Data Presentation – Evidence Map

An evidence map is described as a comprehensive exploration of a wide-ranging domain aimed at pinpointing areas where knowledge is lacking or future research requirements exist, and subsequently presenting the findings in a user-friendly manner, typically through visual representations like figures or graphs, or within and easily searchable database [43].

In the context of this study, evidence will be presented on a world map in the Results section and elaborated in text to give an overview of the geographic location of studies conducted related to topic in discussion throughout the globe. This representation will be discussed thoroughly in the Discussion section.

Data Presentation – Initiative mapping against R-list

Subsequently, initiatives extracted from the finalized literatures will be mapped against the R-list and presented in a tabular form and a mind map. The detailed description of the table and mind map are subsequently elaborated in text, and the discussion to this is provided in the Discussion section. This presents a comprehensive view of initiatives related to CE across the industry, and simultaneously provides an in depth understanding of current Rn pattern and level of CE strategies adopted.

RESULTS

Initiative mapping against R-list

A total of 21 finalized studies were mapped against the world map in Figure 2 and found studies were unevenly distributed throughout the 7 main continents: Europe, America, South America, Africa, Asia, India, and Australia.

The highest concentration of studies can be found in Europe. There were 9 studies of various CE topics conducted across the continent, namely Belgium (1) [8], Austria (1) [15], Greece (2) [7, 18], United Kingdom (1) [12], Finland (1) [44], Netherlands (2) [13, 14], Italy (1) [45]. Although de Jong in [13] was based in the Netherlands, the study conducted covered the bioenergy sectors in The United States (US), The European Union (EU) and Brazil.

The second highest concentration of studies was found in Asia. A total of 7 studies found: India (1) [3], Middle East (3) - Israel [17], Qatar [10], Turkey [46], Nepal (1) [47], Thailand (1) [48] and Singapore (1) [49]. The American continent holds third in place with 3 studies [11, 16, 50], while South Africa (1) [51] and Australia (1) [52] holds fourth in the rank.

Initiative across the literatures

From the R-list framework, a total of 10 main types of CE initiatives have been identified throughout the literatures (Refer Figure 3 and Table 3). They are labelled as FE, EAGV, WM, ES, WTM, DMM, LT, MSP, SAF, and MRO. These initiatives are the subthemes to the R_n. Given the complex nature of these initiatives, a particular initiative may be categorized in one or more of the R_n.

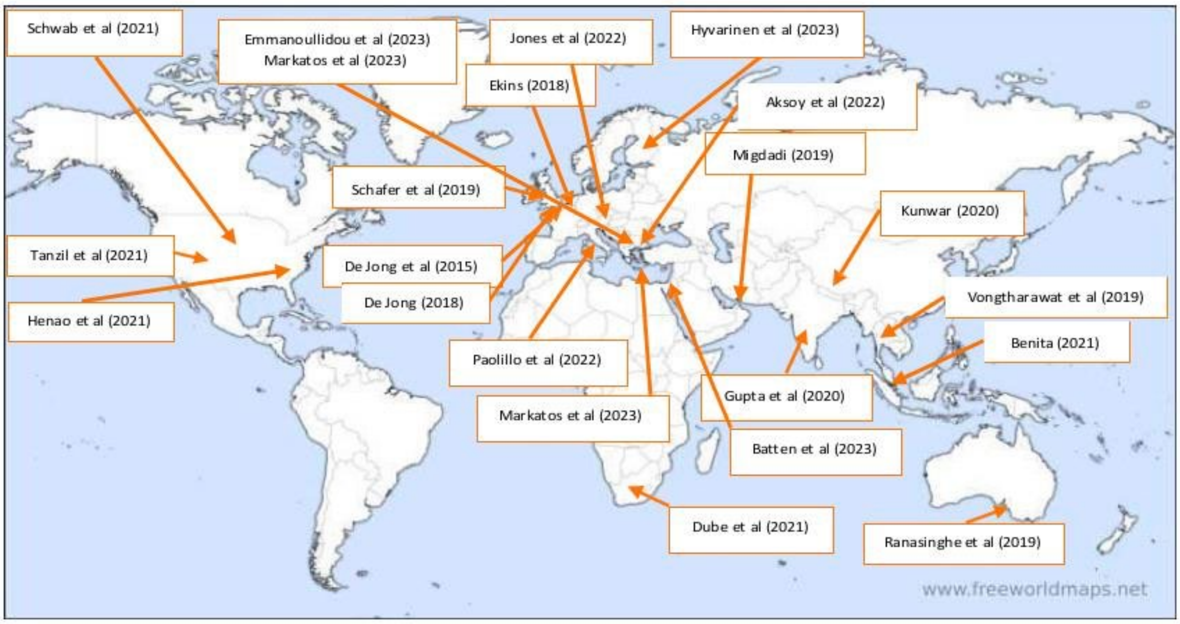

Figure 2: Location of studies related to CE implementation in aviation industry

Table 2: CE strategies adapted from Potting et al. (2017) in [19]

Circular Economy

Linear

	R*n*	Category	Description
Smarter product use and manufacture	R0	Refuse	Make a product unnecessary by either giving up its purpose or providing the same function using a completely different product
	R1	Rethink	Simplify product usage by sharing or introducing multi-purpose items
	R2	Reduce	Boost how products are made or used to save natural resources and work more efficiently
Extend lifespan of product and its parts	R3	Reuse	Discarded product that is in good condition and fulfills its original function is reused by another consumer
	R4	Repair	Fixing a broken product so it works as it should
	R5	Refurbish	Revitalize and modernize an antiquated product
	R6	Remanufacture	Employ components from discarded products in the fabrication of a novel product with equivalent functionality
	R7	Repurpose	Repurpose discarded products or their components for a new product with a different purpose
Useful application of materials	R8	Recycle	Process materials to attain either an equivalent or inferior quality grade
	R9	Recovery	Process materials by means of incineration with energy recovery

i. Fuel Efficiency (R2)

Generally, jet-fuel efficiency reduces fossil-fuel consumption and is categorized as R2. There are 3 elements of efficiency related to reduction of fuel consumption which are operational efficiency [3, 8, 10, 15, 46, 48], aircraft design [8, 44, 52] and engine design [8, 52]. coherently throughout the manuscript.

Prioritizing operational efficiency is essential to reduce fuel consumption. Flight routes should be strategically and accurately planned based on current weather conditions as this shortens flight durations [10, 46, 48]. Besides that, aircraft weight reductions, improved air traffic management, cruise speed reduction also helps in increasing energy efficiency [8, 46]. Some airlines encourage passengers to shut their cabin window shades prior disembarkation during hot summer day on ground to avoid heavy use of the Auxiliary Power Unit (APU) [48]. Vongtharawat et al. in [48] further added that there are airlines utilizing lightweight materials for all cabin service equipment and inflight e-journals (e-magazines), and in addition to those, they are also encouraged to pre- order duty-free items and inflight meals to further reduce aircraft's weight.

In terms of aircraft design, manufacturers have also managed to design lighter aircraft with the advancement in highly engineered materials such as fiber-reinforced polymers (FRP), or otherwise known as composite materials for aircrafts' primary structures such as the fuselage, cabin and wings [8, 44].

Ranasinghe et al. in [52] studied turbofan engines and found that engine efficiency [8] could be improved by modifications such as increasing engine bypass ratio, advancements in engine gearbox technology, utilizing lightweight material for the engine components and incorporating intelligent engine health management systems to extend engine life.

Migdadi in [10] highlighted fuel efficiency as highly adopted among airlines under his study. According to Gupta et al. in [3] Southwest Airlines has successfully lowered its fuel consumption, resulting in savings of 60 million barrels of fuel. This achievement underscores the significance of fuel efficiency as a primary metric guiding strategic investments in the aviation industry's transition to a CE model.

ii. Fuel Efficiency (R2)

Electric Aircrafts (EA) are essential in mitigating the industry's negative impact on the natural environment [7, 11, 13, 14, 49]. This is because EA do not use fossil fuel and lowers emission of dangerous Green-house Gasses (GHG) during its operation and as opposed to conventional aircrafts, EA do not produce contrails during its operation [12]. In this sense, EA is a mitigation effort for the industry to reduce dependency on fossil-based jet-fuel [11].

Schwab et al. in [11] further described three classes of EAs: More electric, hybrid electric and fully electric in which several prototypes have been produced such as the Eviation's Alice, Beta Technologies' Alia-250 and Lilium Jet. As of February 2020, there is 50 percent increment from April 2018 in electric aircraft projects which translates to approximately 170 EA projects. Wright/Easyjet is developing a 186-All-Electric aircraft which is estimated to be ready for testing in 2030. In addition to that, electrification of ground vehicles is also underway.

As far as research and development (R&D) in this initiative is concerned, the Massachusetts Institute of Technology (MIT) was granted a grant of USD300,000 to conduct comparative assessments on electrification strategies by the Federal Aviation Administration (FAA) Aviation Sustainability Center or in short, ASCENT [11].

iii. Waste Management (R2 / R3 / R7 / R8 / R9)

Five sub-initiatives found under waste management: Aircraft Repurpose [51], and Inflight [48] and ground waste management, industrial waste management and hazardous waste management [10]. These managements include reduce, reuse, repurpose and recycle into its processes. A study by Migdadi among 23 airlines between 2013-2016, waste management is the least adopted among airlines as compared to fuel efficiency and energy saving [10].

According to Dube et al. in [51], during the COVID-19 pandemic, airlines were forced to put strict measures on their finances. Travel restrictions have called airlines to leverage on airfreight operations to mitigate negative financial impact where grounded passenger aircrafts were repurposed into freighter aircrafts.

Aside from that, Hyvarinen et al. in [44] also highlighted a collaboration between Finnair, Finnair Technical Operations and Kuusakowski Oy in efforts to recycle and reuse parts from its A319. Approximately, 49% of the aircraft was recycled, 38% of its components was reused and 7.4% was recovered as energy. Gupta et al. in [3] highlighted Southwest Airline's effort to repurpose nearly 80,000 pieces of aircraft leather seat coverings with the purpose of impacting the society and its natural environment positively.

Additionally, inflight waste recycling initiatives were also conducted in airlines where passengers were encouraged to assist cabin attendants to separate cabin waste onboard such as used cups, beverage cans, bottles and lids for recycling, in addition to reusing other inflight supplies such as paper cups, cutleries and headsets [48]. Airbus and Boeing have conducted research on aircraft recycling and found various pathways to give their aircraft a second life. Airbus found 85 percent rate of recyclability of its passenger aircraft components, while Boeing had implemented recycled materials on one of its 737 MAX's cabin sidewall [44].

Migdadi who studied 23 airlines between 2013-2016 in [10] further categorizes airlines' CE initiatives into inflight and ground waste recycling, industrial waste recycling, hazardous waste recycling, recycling and recovery of maintenance water, recycling and recovery of water for facilities and buildings, reducing the use of paper, inflight and ground repurposing, reusing inflight and ground waste, industrial waste repurposing, reusing of industrial waste and repurposing of hazardous waste.

Aksoy et al. in [46] pointed that aircraft materials recycling is critical in reducing consumption of raw materials. This has a direct impact on energy efficiency which is key to aviation industry's strategic investment. However, the aviation industry observes a small proportion of aircraft component recycling during the elimination phase of its service life.

iv. Energy Saving (R2)

As tabulated by Migdadi in [10], airlines adopted energy saving initiatives that are divided into a few categories which are, energy savings in facilities and buildings, accreditation of facilities and buildings, sustainable energy consumption for facilities and buildings, and upgrading and replacing of facilities. As compared to fuel efficiency, energy saving is moderately adopted.

v. Water management (R2)

Of all the 21 finalized literatures, only Migdadi briefly highlights on water management initiatives without in depth discussion in [10]. The water management initiatives were categorized as: Recycling and recovery of maintenance water, saving maintenance water, recycling, and recovery of water for facilities and buildings and saving water in facilities and buildings.

vi. Decision Making Model (R2 / R8)

In the context of CE, Markatos et al. in [7] suggested existing decision-making model do not address trade-offs between technological sustainability, economic competitiveness and costs and environmental sustainability in which the latter includes the CE concept. The example provided was conflicting CE values between usage of composite materials that reduces aircraft weight and fuel consumption, and its poor recyclability.

Therefore, a holistic approach to a Multicriteria Decision-Making Model (MCDM) that balances the social, environmental, and economic impact of an aircraft is needed. Markatos et al. proposed an integration of Analytic Hierarchy Process (AHP) and Weighted Sum Model (WSM) into MCDM to create a holistic model in comparing aircrafts' sustainability performances by comparing 4 different aircraft type. The resultant findings suggest a certain degree of uncertainty due to incomplete data on 2 aircrafts used in the study – the LH2 aircraft. LH2 aircraft is supposedly an aircraft powered by either blue or green hydrogen. Therefore, the development of this decision-making model is considered as preliminary.

Aksoy et al. in [46] on the other hand, attempts at creating a model that assists decision maker in deciding the prioritization of a CE strategy to be adopted, allowing for strategic investment planning. The model called Multi-stepwise Weight Assessment Ratio Analysis (M-SWARA) which is an innovation to the conventional SWARA, addresses costs repercussions that have been engulfing aviation companies.

vii. Legislation and Taxation (R2)

Legislation to encourage implementation of CE in the industry has never been more crucial than post COVID-19 pandemic. The pandemic has called public transport policies to adopt mobilities that are low in emission and pollution, thus decarbonizing the transportation sector [49].

Although there is yet any aviation legislation that address recycling of aircraft-related polymeric or polymeric composite waste materials [44], emissions from operations of aircrafts have received much attention from the European Union (EU) and the International Civil Aviation Organization (ICAO). These organizations have respectively enforced EU ETS and Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) where authorities have set a mechanism that taxes airlines' CO2 emissions [13, 51].

On the other hand, regulations such as the US RFS2 and EU RED-I and EU RED-II creates a demand in renewable jet fuel as it incentivizes usage of biofuel [13]. Ekins in [8] suggested that legislations and taxations such as these are critical to address increased demand in air traffic and the pollution it entails. These regulations have pressured industry to reduce fossil fuel consumption.

viii. Multi-sided Platform (R1 / R2 / R7)

Kunwar in [47] qualitatively elaborated on the roles and relationship between multi-sided platforms (MSP) and tourism, in which the latter has direct relationships with the aviation industry in many ways. MSP's role in commercial aviation allows passengers to make direct flight bookings by connecting two or more independent groups. It operates as an intermediary between passengers and airlines, solving various issues related to the airline business, which in the context of study are conducted virtually. Virtual MSPs benefit the industry in ways that it reduces usage of paper in its daily operations such as production of e-tickets (flight bookings), check-in via mobile application, and pre-ordering of meals and duty-free goods prior boarding (flight processes) [48].

In the context of airport operations, Henao et al. in [50] MSPs enhances smart mobility and encourages ride sharing. App-enabled ride-hailing companies such as Uber and Lyft have been found to accommodate reduction in land use in airports across San Francisco, Portland, Denver and Kansas City.

This is due to reduced utilization of private vehicles into airports under study which translates to reduced parking space requirements, thus allowing airport authorities to consider other existing land uses by means of repurposing.

ix. Sustainable Aviation Fuel (SAF) (R2 / R3 / R7 / R8)

Developments in renewable jet fuel such as jet-biofuel, or popularly known as Sustainable Aviation Fuel (SAF) is catalyzed by regulatory policies such as EU ETS, CORSIA, US RFS2, EU RED-I and EU RED-II [8] [13] [51]. Scholars have studied various ranges of pathways: 5 pathways [16], 6 pathways [13] [14] and 8 pathways [18] in attempts to search for the most viable and feasible method in producing SAF. These studies include understanding the impact of SAF production on the environment and financial costs.

There are at least 200,000 flights flown with SAF up to April 2023 [18]. Batten et al. in [17] have conducted a Life Cycle Analysis (LCA) of corn feedstocks in repurposed corn dry grind facilities. The study investigated the corn-to-DMCO SAF pathway's potential in reducing GHG emission and concluded that repurposed corn dry grind facilities employing this pathway will meet current aviation industry's emission policy targets.

Similarly, Tanzil et al. in [16] concluded that repurposing of corn dry grind facilities is the most cost-effective solution to producing SAF in which the highest pathway being the Alcohol-to-Jet (ATJ). According to de Jong et al. in [14], production costs is key to SAF's large scale consumption, and therefore found that Hydro-processed Ester and Fatty Acid (HEFA) is the most cost-effective short-term solution to producing SAF commercially. This is followed by Hydro-Thermal Liquefaction (HTL) and pyrolysis pathways. Variations in feedstock prices and nascent nature of pathways technology were cited to be the obstacles for price parity with fossil-based jet fuel.

As feedstock prices remain as one of the obstacles in the commercialization of SAF [13, 18], Emmanouillidou et al. in [18] saw the potentials of having Municipal Solid Waste (MSW) such as waste cooking oil, food waste, forestry and agricultural residues, and plastics as feedstocks. Such feedstocks divert MSW from being dumped into landfills, thus mitigating incineration process that negatively impacts humans, the planet and its climate [18].

x. Maintenance, Repair and Overhaul (MRO) (R2 / R3 / R4 / R6 / R8)

In the aviation industry, remanufacture is known as overhaul in which the Original Equipment Manufacturer (OEM) will conduct aircraft parts disassembly, and subsequently inspected, measured, and cleaned before being reintroduced into service. This is typically done for engines, landing gears and many other components [44]. A CE effort such as this is critical for the OEM and MRO business as it helps reduce utilization of raw materials and energy, and emissions.

In contrast to the remanufacturing process, Hyvarinen et al. further studied the closed-loop recycling of a finger pinch shroud from Safran Seats US Z300 passenger seat as most aerospace materials are only destined for landfills or delivered to other industries. Though often understood as a remanufacturing initiative, a closed-loop recycling involves breaking down of part to its component level by means of melting, crushing, reprocessing, and remanufactured into a new part [44].

According to Hyvarinen et al. in [44] closed-loop recycling of polymeric aircraft parts has not been studied broadly. One of its challenges would be verifying and certifying the recycled parts to ensure their airworthiness to fulfill regulatory requirements such as the EASA's CS-25 Large Aeroplanes Certification specification. This is because data of the new parts such as its material properties, specifically its flammability is not available. In this case, the recycling and manufacturing operator must establish a process to identify the properties appropriately. Hyvarinen et al. suggested that the aviation industry may benchmark the process against the automative industry as it follows the EU directive on reducing waste from end-of life vehicles.

As this is a novel idea, Hyvarinen et al. further proposed a SWOT analysis on aircraft manufacturers or OEM, third-party manufacturers, and airlines' technical departments business models with regards to this type of aircraft parts recycling. The proposed analysis found that the aircraft manufacturers or OEM has the vantage point to conduct such initiative. This privilege is given to OEMs capability of conducting research and development (R&D) and the technical ability to execute such initiative. Furthermore, this initiative would be a great value proposition to them.

In terms of improving maintenance repair costs, inspection regularities and waste generation, Paolillo et al. in [45] suggested that an aircraft 's composite part could apply intrinsic self-healing epoxies because of the existing fundamental aspects for parts reprocess ability and recyclability which may revamp the composite manufacturing landscape. A combination of intrinsic self-healing epoxies inherent properties (great thermal stability, mechanical properties, adhesion to substrates and fibers, resistance to corrosion and moisture absorption), and physical and/or self-mending mechanisms presents composite materials with an extended service life and new functionalities. In addition to that, should recycling not be possible, the composite components can be reused by means of reshaping and welding, given the well-established adhesion properties of epoxies.

Maintenance management such as these reduces aircraft's fossil fuel consumption, extends aircraft's life, thus reducing consumption of natural resources which simultaneously reduces waste generation [10].

Discussion

Although CE in aviation is a relatively new topic for discussion, the initiative across the industry has been found to be gaining traction in recent years. This study observes a pattern of two adoption levels within the industry which are research (R&D) and industry implementation levels. In rank from the highest to the lowest, most initiatives found within the two adoption levels are heavily focused in the R2 (20 literatures), and R8 (12 literatures) strategies. This is followed by R7 (10 literatures), R3 (5 literatures), R1 (2 literatures), R6 and R9 (1 literature respectively), and R0 and R5 (no literature found).

Literatures in R2 and R7 are discussing mainly on reduction of GHG emissions and fossil fuel consumption such as SAF and its development, improvements of operational efficiency, and electrification of the industry. CE decision making, digitalization, waste management, and management of water and energy receives minimum attention. Geographically, a concentration of studies and efforts in CE are observed from the EU region, followed by the US and the rest of the world which is believed to be because tighter regulations such as the EU RED-I and RED-II, and the US RFS2 are enforced in those regions.

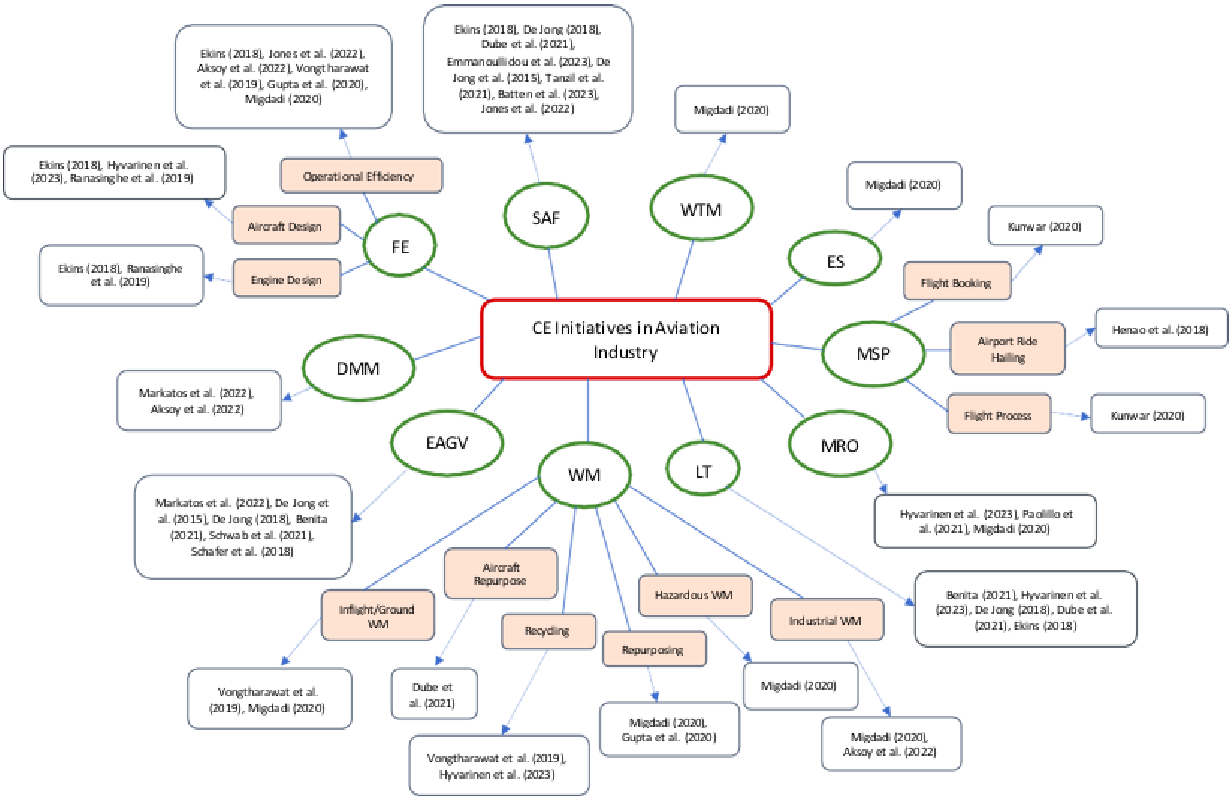

Figure 3: CE Initiatives in Aviation

Table 3: CE strategies across literatures versus R-list

Authors	Ref.	R0	R1	R2	R3	R4	R5	R6	R7	R8	R9
Ekins	[8]			√					√	√	
Dube et al.	[51]			√					√	√	
Jones et al.	[15]			√	√				√		
Gupta et al.	[3]			√					√		
Emmanouillidou et al.	[18]			√	√				√	√	
Batten et al.	[17]			√					√		
Henao et al.	[50]		√	√							
Migdadi	[10]			√	√	√			√	√	
Tanzil et al.	[16]			√					√	√	
Schafer et al.	[12]			√							
Hyvarinen et al.	[44]			√				√		√	√
Schwab et al.	[11]			√							
Ranasinghe et al.	[52]			√							
De Jong	[13]			√					√	√	
De Jong et al.	[14]			√					√	√	
Benita	[49]			√							
Vongtharawat et al.	[48]			√	√					√	
Paolillo et al.	[45]			√	√	√				√	
Markatos et al.	[7]			√						√	
Aksoy et al.	[46]			√						√	
Kunwar	[47]		√								

A number of documents such as the Regulation (EU) 2018/848, Directive (EU) 2018/849, Directive (EU) 2018/850, Directive (EU) 2018/851, Directive (EU) 2018/852 and 'A New Circular Economy Action Plan: For a Cleaner and More Competitive Europe" have motivated and guided CE transition in those regions, generally [5].

In the global aviation industry, the International Air Transport Association's (IATA) net 50 percent CO2 emission reduction by 2050 [10] [16], and ICAO's CORSIA's market-based-measures (MBM) are pressuring airlines to be more aware and responsible of their emission from their daily flight operations.

European airlines have the highest adopting green strategies because of EU's commitment (EU ETS) as reported in [10]. Due to these motivations, airlines and aircraft manufacturers alike are pressured to execute measures in reducing their consumption of natural resources.

The impact of COVID-19 pandemic has also pressured the industry to transition towards circularity as operating costs from fossil-fuel use is becoming substantial, which is another motivation that have catalyzed by the COVID-19 pandemic as cited in literatures such as [51].

Fund allocations for R&D in CE also play a pivotal role. Contributions from the global aviation authorities such as the FAA are encouraging research activities by means of funding to achieve this objective. Although there are legislations and taxations addressing GHG emissions from the industry's fossil fuel use, there is currently no known controlling measures that address other type of resources' intake. Perhaps, these motivations justify the uneven distribution of literature focus throughout the R- list strategies.

As with any development, CE in aviation is presented with many challenges. For example, challenges such as the recycling of composite materials that are widely used throughout the aircraft manufacturing sector. Composite materials have poor recyclability performance, and the production of these materials require significant energy and increases emissions [44]. Given the high potential of waste generation from this type of consumption, more support such as incentives, should be channelled to encourage rapid development in this area. In addition, activities in maintaining aircraft and their parts for as long as possible should be given more attention. As of 2015, the global aircraft retirement age is averaged at 26 years [53]. By extending the lives of aircraft, the industry could escalate the CE transition and reduce the intake of natural resources further.

Current studies focusing on digitalization of processes in the industry such as the use of MSP for airline bookings and such are lacking. Within the 21 finalized literatures, there is no literature that provides a complete life-cycle analysis (LCA) of digital platforms that enable those processes. This is critically important to consider as the impact of e-waste on the natural and social environment is significant. O'Neill in [54] estimated the global e-waste generation was worth 55 billion Euros in 2016, and this value is expected to increase over time due to increased demand and extensive use in many areas. Therefore, the industry's contribution with regards to digitalization must be considered.

Like the impact of digitalization, the production and consumption to the electrification of the industry must also be given equal attention. There is yet any study of a complete LCA of the production of EAGV. This literature suggests a holistic study in the realms of the impact of electrification for a better comparison between repurposing of existing technologies and future technologies. LCA of virgin and recycled materials could be conducted for future studies [44].

Though clean water is abundance and not a major impact of air transport [55], the industry must consider viewing a policy in this area. Limited number of literatures addressing this area is a sign on lack of industry's attention towards the issue. Industry consumes water in many areas of operation such as in-flight catering and potable water, airport fire and rescue services, aircraft manufacturing and maintenance. Water uplift management in commercial aircraft must also be considered as they contribute much to the aircraft's all up weight which eventually contributes to its fuel consumption performance.

Development in CE decision making processes requires attention too. A holistic decision-making model for policy and decision makers are at its early stages of development [7]. Currently, known work on sustainable decision-making models are focused in the areas of aircraft procurement and seat selection such as in [7, 56] that prioritizes on economic benefits and passenger comfort. There is yet a comprehensive model that considers the complete environmental and social impact of raw materials extraction for components production. Similarly, there is yet a model that compares the footprint between creating new technologies and redeveloping older technologies.

CONCLUSION

Addressing the industry's circularity has never been more critical than today, given the industry's growth and the amount of waste it generated along the way. There are many challenges and opportunities addressed by scholars throughout, and this can be overcome with the help of concerned aviation authorities such as implementation of policies and targeted fund allocations for R&D.

This study has found the levels of CE adoption in the industry is at its early stages. It provides a comprehensive view of CE initiatives across industry and addressing existing literature gaps. Most of the initiatives found are focused only on areas that are given much attention by the aviation authorities such as SAF, fuel efficiency and electrification of the industry.

The global aviation industry may use the EU and US as benchmarks in the implementation of the R-list and other CE strategies. The R-list framework could also be utilized by actors to map related CE initiatives to understand the CE adoptions within their respective organizations. In a nutshell, systemic approach to ensuring smooth and rapid transition to CE in the aviation industry is needed. A holistic monitoring and enforcement of efforts mentioned in this literature must be established.

Establishment of states' and industry actors' Aviation Authority Sustainability or Circular Economy unit is necessary to ensure industry's smooth transition into a complete circularity. The purpose of such establishment is to plan, execute, review, and monitor CE developments within the industry and its sectors and sub-sectors.

This analysis serves as a starting point for the industry to review its CE-related policies and approaches, which eventually will contribute to balanced resources distribution and support that encourages the industry's transition from LE to CE. Future work may include wider range of databases such as Web of Science and Scopus, and the use of wild cards within the search strings for a wider literature search.

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