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Assessment of the sustainability of the implementation of circular economy principles in producing aircraft structures

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Abstract

Although composite materials have proven their worth for the construction of lighter aircrafts, their life-cycle impact is questionable, mainly due to difficulties associated with their end-of-life. In this frame, efforts to recover carbon fibers from CFRP waste and reuse them in aircraft-related applications represent a crucial task for the aviation industry. The present study aims to contribute towards assessing the sustainability of the implementation of circular economy principles in aviation, and consequently assessing the suitability of recycled components for aviation applications. In this frame, a hybrid multi-criteria decision making (MCDM) tool has been implemented to support recycled material selection in the aviation sector.

Keywords: holistic assessment, circular economy, sustainability, CFRP recycling, aviation

1. Introduction

Global warming and climate change represent great sustainability challenges for the aviation sector [1, 2]. An amount of approximately 920 million tons of CO_2 was emitted from worldwide aviation operations in 2019 only [3], while the long lifetime of aircrafts implies at least doubling of aviation-linked CO_2 emissions until 2050, unless significant changes are made [4]. Hence, it is of great importance to consider sustainable solutions and approaches when it comes to future aviation applications.

In this direction, weight reduction through utilization of low-density polymer-based composites to replace heavier materials, is a major goal for the aviation industry given that weight considerations in the aviation sector have different driving mechanisms compared to other transportation sectors [5, 6]. In this frame, carbon fiber reinforced plastics (CFRPs) are being widely used for lightweight aviation applications, towards fuel efficiency goals and consequently, towards lowering the environmental burden of aviation. However, the significant environmental and economic impact associated with the production of virgin carbon fibers as well as difficulties linked to their recycling, remain great challenges to be addressed [5, 7]. It is noteworthy that currently, nearly 98% of CFRP waste, end up in landfills [8]. Until today, recycled carbon fibers have not been used for mass production; only prototypes or demonstrators have been produced, involving secondary aviation applications (e.g. interior side-wall panels, aircraft seat arm rests, etc.) [9, 10].

To consider a recycled material utilization for the aviation sector, the financial and environmental viability of the recycled component need to be evaluated. For high-performance applications, it is also of major importance to include a technological quality feature in the phase of the evaluation, as the components under consideration are linked to specific manufacturing requirements and mechanical performance limits [11]. To add to the above, the adoption and implementation of circular economy (CE) principles when considering material selection is of great demand. To this end, multi-criteria decision making (MCDM) support tools are required to support decision makers towards CE goals and practices, especially when potentially contradicting aspects and criteria are present. MCDM represents a variety of techniques with the utter aim to determine a preference ordering among alternative options, whose performance has been scored against multiple criteria. MCDM have been widely used in diverse areas and fields as well as in the aviation sector, with the vast majority of their application referring to the airlines level for which service quality is the most considered specific objective [12].

Yet, to satisfy the design requirements, decision-making support is also necessary towards selecting the most appropriate design, material, component and manufacturing process in the design and development of a new product. Several MCDM methods may appear to be appropriate for a particular engineering-related application, hence, the decision maker faces the problem of selecting the most appropriate MCDM method among several available methods [13]. The MCDM methods can be compared along various dimensions, such as perceived simplicity, trustworthiness, and robustness. However, for a given engineering application, most attention lies on the proper selection of the relevant criteria and alternatives, instead on choosing the most appropriate multi-criteria decision-making method to be adopted [13].

The present study aims to contribute to the assessment of the sustainability of circular economy principles implementation in producing aircraft structures, and consequently to the assessment of the suitability of recycled components for use in high-performance aviation applications. To this end, a hybrid MCDM tool, is adapted to the needs of the current study, in order to aid decision makers and stakeholders identify and select a recycled CFRP component, among alternative ones, that best fit to their preferences and needs. The said tool combines a weighted sum method as the aggregation method, coupled with a widely used multi-criteria decision analysis (MCDA) methodology, i.e. the Analytic Hierarchy Process (AHP), for the determination of the considered criteria significance (weights), in order to reduce subjectivity of the weights determination. Preferences and specific needs are expressed through potentially conflicting criteria involving environmental, economic, and circularity aspects. More specifically, the tool integrates life-cycle ecologic and economic metrics as well as an appropriate CE indicator. The output of the tool is a quantitative Index, attributed to each one of the investigated components, obtaining eventually a ranking among the alternative components. The results are compared with those derived from the implementation of a well-established multi-criteria analysis tool from the literature, i.e. TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), in terms of the ranking order obtained and in terms of consistency with the decision makers preferences. The specific application-related strenghts and weaknesses of the two tools are also discussed.

2. Methodology

2.1 Assumptions and Basic Considerations

The methodology followed in the current study is applicable to any component of an aircraft. For the sake of the present investigation, it is assumed that the geometrical features of the component, with the sole exception of thickness, are not altered. The candidate components under investigation involve recycled two CFRP components with either randomly oriented or aligned fibers. The recycled components are compared with a woven CFRP containing virgin fibers. To be compliant with design requirements, the mechanical performance of the recycled components in terms of stiffness and strength must be identical to the virgin one. To this end, in order to compensate for the variation of the material properties among the different components considered, thickness (and consequently resulting mass) is treated as a variable which is adjusted so as to achieve equal stiffness; equal stiffness is considered an appropriate criterion for the comparison of different materials [14]. To calculate the expected mass ratio (Rm), an approximate formula [15-17] has been implemented:

$$R_m = \frac{m_{recycled}}{m_{virgin}} = \frac{p_{recycled}}{p_{virgin}} \left(\frac{E_{virgin}}{E_{recycled}}\right)^{\frac{1}{\lambda}} \tag{1}$$

where m and p are the mass and the density of the materials under comparison, E is the elastic modulus, and λ is a parameter which depends on design constraints and may vary between 1 and 3: $\lambda = 1$ is appropriate for components under tension and is selected as the relevant case herein, $\lambda = 2$ is for beams and columns under bending and compression in one plane, and $\lambda = 3$ is appropriate for plates and flat panels under bending and buckling conditions in two planes. Nevertheless, it must be mentioned that actual component designs require a thorough finite element analysis to identify the material design index which ensures that the design constraints set, have been met.

To be compatible with the objectives of a circular economy, both the environmental and economic impact of the considered materials have been assessed. The environmental and financial impact are also accounting for two different fuels considered in the present study; namely, kerosene and liquid hydrogen produced through a conventional method. Among the alternate fuels that are currently under research, hydrogen appears to be one of the most promising fuels for sustainable transportation, by providing clean, reliable and affordable energy [18, 19]. The said impact accounts for all life-cycle phases of the component, i.e. production and manufacturing, use phase, and recycling for the initial material recovery. Assessment of the environmental and economic impact is based on life-cycle data obtained from the most current and relevant literature as described below. More specifically, environmental impact was assessed in terms of the Greenhouse Gases (GHG) emitted from each of the life-cycle phases considered (production, manufacturing, use phase, and recycling). The GHG emissions are considered the most widely reported environmental impact metric across industry and academia [11]. The respective results are expressed as kgCO2eq per component mass or as per component mass per km when referring to the use phase. The economic impact of the investigated components has been related to the costs referring to either the process-related energy costs associated with the production, manufacturing, and recycling phases (expressed as € per component mass) or to the fuel cost (expressed as € per component mass per km) when assessing the impact of the use phase for the considered components. The non-household price of kWh in Germany has been considered [20] for the calculation of the process-related energy costs.

Life cycle assessment commences with the production of the primary material, i.e., carbon fibers (PAN), and epoxy resin [21–24]. For the manufacturing of the CFRP component, the autoclave molding process was chosen as the relevant manufacturing process of the virgin aeronautic component. Regarding the manufacturing of recycled CFRP components, compression molding was considered as the relevant manufacturing process [25]. The environmental and economic impact of the upgrade technologies of the recycled carbon fibers (e.g., alignment, sizing) was not taken into consideration due to a lack of relevant data in the literature. To assess the use phase impact of the components, said impact is directly linked to the weight of the component. Hence, CFRP components were considered as loads that must be carried by the aircraft during each flight [11]. GHG emissions and costs associated with the type of fuel implemented have been adapted from [19], in which a complete life cycle analysis of an aircraft running on different fuels was conducted including the production phase of the required aviation fuel. To assess the use phase impact of the components, the average lifetime distance of an Airbus A320 was calculated based on the number of flying hours for which it was designed, i.e., 60,000 flying hours over a 25-year lifespan, and its average economical cruising speed, i.e., 840 km/h [26,27]. Regarding the recycling of CFRPs, the fluidized bed process (FBP) has been considered in this study as being a promising recycling technique for CFRPs, capable of recovering carbon fibers with mechanical properties comparable to those of virgin ones [17]. FBP is currently at the pilot phase with a level 6 of technological readiness; on contrary, other promising recycling methods, such as solvolysis, are still at laboratory stage [28].

2.2 A holistic assessment tool towards material selection support

To assist recycled material selection for aviation applications, towards sustainability and circular economy objectives, a holistic assessment tool, previously implemented in [29] was adapted to the needs of the current study. The proposed tool is based on a combination of the Analytic Hierarchy Process (AHP) and a linear aggregation method, i.e. summation of normalized and weighted individual indicators, which is by far the most widespread linear aggregation method. The tool integrates environmental and economic metrics related to the material/component under stydy, as well as a suitable quality-related CEI which can be evaluated at the material/component level, and expressed through a specific property of the material. Based on the above definitions, the analytical relation takes the form:

$$P = K_{CEI} \cdot CEI_Q + K_C \cdot C + K_E \cdot E \tag{2}$$

where, E and C are the normalized terms refering to the environmental and economic impact of the component/material respectively. CEI_Q is the relevant normalized quality-related CEI, expressed through the specific stiffness of the investigated components. K_{CEI}, K_C, and K_E stand for dimensionless weight factors, reflecting the importance of each term to the overall Index value.

For obtaining the normalized indicators, the min-max method was implemented for rescaling the range of the individual indicators between 0 and 1. The general formula for the min-max technique is given as:

$$\mathrm{x}' = \frac{\mathrm{x} - \min(\mathrm{x})}{\max(\mathrm{x}) - \min(\mathrm{x})} \tag{3}$$

where x' is the normalized value, x is the original value, min(x) and max(x) are the minimum and maximum value of the dataset, respectively. For values which are not beneficial to the final output, namely environmental impact and costs, a reverted min-max scaling was applied.

To define the weight factors, the analytic hierarchy process (AHP) [30] was implemented. AHP is considered one of the most popular and widely employed multicriteria decision-making methodology [31]. The mentioned method is employed to rank a set of alternative solutions and select the 'best' option among this set of alternatives. The selection/ranking is made with respect to an overall goal, broken down into a set of chosen criteria. The main strength of AHP lies in the capability to combine it with a variety of other methodologies, for obtaining flexible, and tailored solution approaches. The definition of the weight factors (K_{CEI}, K_C, K_E) is subjective and reflects the priority criteria of the user and the specific application. The AHP analysis was implemented using the freeware 'SuperDecisions' [32]. The final output of the said tool is the summation of the weighted and normalized KPIs, i.e. a quantitative Index (P) which represents the trade-off between potentially contradicting aspects associated with circularity, environment and costs, accounting simultaneously for the type of fuel implemented. The latter calculations are performed via a spreadsheet (excel-based) model.

2.3 Comparison with TOPSIS

Following the implementation of the holistic tool to rank the different components investigated, a comparison was made with a widely used MCDA ranking tool from the literature, i.e. TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) [33]. TOPSIS is based on the concept that the selected alternative should have the shortest geometric distance from the positive ideal solution and the longest geometric distance from the negative ideal solution. It represents a method of compensatory aggregation comparing a set of alternatives by defining weights for each criterion, normalizing scores for each criterion and calculating the geometric distance between each alternative and the ideal alternative. The weights chosen for the TOPSIS technique, have been identical to the ones derived from the AHP analysis implemented for the holistic tool in order for the comparison to be made under a common base. The TOPSIS analysis was performed using an in-house spreadsheet model.

3. Results

3.1 Circular Economy Indicator Calculation

Circular indicators are useful for measuring circular economy progress. However, what should be considered as a circular indicator is a matter of debate, while the definition of circular indicators is ambiguous and might lead to misleading conclusions. Currently, most of the existent CE indicators focus on materials preservation [34]. Considering that quality of the recycled material is a decisive factor for achieving circularity, a CE metric is introduced linking circularity to a quality feature of the investigated material, i.e. its specific stiffness. For aircraft applications, that choice is well justified as the allowable design of an aircraft structure does not exceed the linear elastic region of the corresponding stress-strain curve which, in addition, in the case of CFRPs remains almost linear up to failure. In Table 1, the elastic modulus and the density of the investigated components, as taken from [25], are shown. Based on these inputs, the specific stiffness which is the relevant circular economy indicator for the current study, was calculated. The virgin component presents as expected, the higher specific stiffness, closely followed by the recycled component with a vf of 50% aligned fibers. The recycled component comprised of randomly oriented fibers showed by far the lower quality. The latter highlights the importance of upgrade tehcnologies (sizing, alignment, etc.) for the recycled fibers in order to compete with the virgin CFRP components.

Table 1: Properties of the investigated components

Component type	Elastic modulus (GPa)	Density (g/cm^3)	Specific Stiffness (GPa/(g/cm^3))
Virgin 50%	70	1.6	43.75
Recycled aligned 50%	60.8	1.5	40.53
Recycled random 40%	39.8	1.44	27.64

3.2 Environmental and Economic Impact Indicators Calculation

Based on the considerations of Section 2.1 and equation (2), the recycled components weights have been calculated with respect to the virgin component weight. Their respective environmental and economic impact are depicted in Tables 2 and 3, in which the impact of kerosene and hydrogen during the use phase has been also accounted for. In bold, the higher values associated with GHG emissions and costs, are shown. The results showed that the virgin CFPP component presents by far the greater GHG emissions and costs associated with the primary material production and the manufacturing of the component. This is owed to the high amount of energy required to produce virgin carbon fibers (PAN fibers) as well as to the energy intensity of the autoclave process to produce the component. The latter are also reflected on the high costs (Table 3) related to the mentioned processes. However, the above contributes only to a small percentage to the overall impact as the use phase dominates the life-cycle impact of the components in terms of GHG emissions and costs; over 99% of the environmental impact and costs are owed to the use phase when kerosene is used and over 97% when liquid hydrogen is used. Hence, the environmental and cost gains associated with the production phase of a recycled component instead of a virgin one, are not enough to compensate for its increased (compared to the virgin one) environmental and cost impact during the use phase of a kerosene-fueled aircraft. On the other hand, it is noteworthy that when liquid hydrogen is used as a fuel, the recycled component comprised of aligned fibers appears to be environmentally competitive compared to the virgin CFRP; although the environmental gains derived from the production phase cannot still compensate for the use phase impact, the total GHG emissions of the recycled component are almost 5% higher, compared to these of the virgin one. The latter is owed to the fact that the GHG emissions associated with the use phase of the components are almost 90% lower when hydrogen is considered as an aircraft fuel instead of kerosene. Yet, it should be noted that other factors such as the feasibility of the upgrade technologies of the fibers, the efficiency of the recycling processes and the capabilities of a remanufacturing methods to produce recycled components of high quality, as well as the availability of the recycled fibers, must be considered. On the contrary, the costs associated with the use of hydrogen are almost double compared to these of kerosene, owing to the currently high cost of liquid hydrogen.

From the results it becomes clear that the overall life-cycle impact, mainly dictated by the use phase impact, is directly related to the weight of the considered component. Therefore, the one presenting the lower weight, i.e. the virgin component, also demonstrates the lower total GHG emissions and costs. The worst by far environmental and economic impact belongs to the recycled component comprised of randomly oriented fibers. It is more than evident that such a low-quality component cannot be environmentally and cost competitive, especially when addressed to a high-performance application, and hence, upgrade technologies (sizing, alignment, etc.) are required.

Table 2: GHG emissions of the investigated components

Component Type	**Weight**	**Primary Material Production (kgCO2eq-mass)**	**Component Manufacturing (kgCO2eq-mass)**	**Use phase**		**Recycling (kgCO2eq-mass)**
				Kerosene (kgCO2eq-mass-lifetime km)	**Liquid Hydrogen (kgCO2eq-mass-lifetime km)**	
Virgin 50%	1000	**20,440**	**103,000**	52,920,000	5,544,000	1,540
Recycled aligned 50%	1080	1,921	1,717	57,153,600	5,987,520	1,663
Recycled random 40%	**1580**	3,549	2,512	**83,613,600**	**8,759,520**	**2,433**

Table 3: Costs of the investigated components

Component Type	**Weight**	**Primary Material Production (€-mass)**	**Component Manufacturing (€-mass)**	**Use phase**		**Recycling (€-mass)**
				Kerosene (€-mass-lifetime km)	**Liquid Hydrogen (€-mass-lifetime km)**	
Virgin 50%	1000	**17,905**	**3,340**	4,032,000	7,056,000	499
Aligned 50%	1080	1,560	1,858	4,354,560	7,620,480	539
Random 40%	**1580**	2,882	2,718	**6,370,560**	**11,148,480**	**788**

3.3 Holistic tool Implementation for material selection and comparison with TOPSIS

The process described in Section 2.2 was followed in order to calculate the holistic Index for each of the investigated components and support recycled material selection. To derive the weights (importance) factors of Equation(2) through the AHP process, three different scenarios were considered in terms of importance variation. The paired comparisons were used to compare the alternatives with regard to the criteria defined and estimate the criteria weights, on a scale of 1 to 9, where 1 means that the criteria are of equal importance, while 9 means that the selected criterion is extremely more important compared to another criterion. The pairwise comparison matrices and the resulting weights, are shown in Table 4. The first scenario assumes an equal importance among circularity, environmental impact, and costs. The second scenario strongly prioritizes circularity over environmental impact and costs, while environmental impact is strongly prioritized over costs. Finally, the third scenario assumes that environmental impact is strongly prioritized over circularity and costs, while circularity is strongly prioritized over costs.

Table 4: Pairwise comparison matrices

Scenario 1				
	Circularity	Environmental Impact	Costs	Weight factor
Circularity	1	1	1	0.33
Environmental Impact	1	1	1	0.33
Costs	1	1	1	0.33
Scenario 2				
	Circularity	Environmental Impact	Costs	Weight factor
Circularity	1	5	5	0.69
Environmental Impact	1/5	1	5	0.23
Costs	1/5	1/5	1	0.08
Scenario 3				
	Circularity	Environmental Impact	Costs	Weight factor
Circularity	1	1/5	5	0.23
Environmental Impact	5	1	1/5	0.69
Costs	1/5	1/5	1	0.08

Following the weights definition, normalization of the environmental, economic, and circularity indicators is performed, and subsequently their aggegration into a single Index. The obtained Indices and the comparison among the investigated components, for the three scenarios described above, are shown in Figures 1-3. In the same figures, the holistic tool results are also compared against these obtained from the TOPSIS ranking tool.

From the comparison of the tools results, it becomes evident that for all 3 scenarios considered, the tools tend to agree on the first and last place of the ranking order, i.e. the ‘best’ component concerns the virgin one for which liquid hydrogen has been considered as the utilized fuel in the use phase, while the ‘worst’ concerns the recycled component comprised of randomly oriented fibers and for which kerosene has been considered as the utilized fuel. This is expected, as the virgin component for which hydrogen has been considered in the use phase is obviously ideal in terms of both quality and environmental impact; on the other hand, the randomly aligned recycled component for which kerosene has been considered in the use phase is obviously the worst alternative mainly due to its low quality and the high environmental impact of kerosene. Moreover, the recycled component comprised of aligned fibers, and for which hydrogen is considered, is attributed a high score for both tools (for all three scenarios); this score classifies this component as a good option for both the holistic tool and TOPSIS. However, the two tools appear to rank the rest of the intermediate components in a different order, especially for Scenarios 1 and 2.

Focusing on Scenario 1, where an equal weighting is considered, some discrepancies are observed between the two tools. The holistic tool gives a similar score to the ‘aligned hydrogen’ and the ‘virgin kerosene’ component which appears to be logical as it reflects the balanced trade-off between quality, environmental impact and costs when these criteria are considered of equal importance. On the other hand, the TOPSIS tool highly prioritizes the ‘aligned hydrogen’ component over the ‘virgin kerosene’ one; although an equal weighting of the criteria has been considered, the criterion of quality/circularity appears to be subestimated by the TOPSIS tool. Moreover, the TOPSIS tool assigns a quite high score for the ‘random hydrogen’ component which does not appear logical from the technological point of view, considering that the quality of ‘random hydrogen’ component is considerably downgraded compared to the virgin material.

Regarding Scenario 2, where circularity/quality is highly prioritized over enrvironment and very highly prioritized over costs, the holistic tool ranks again the ‘aligned hydrogen’ component and the ‘virgin kerosene’ component as almost equivalent technological solutions. The latter appears logical as that reflects the trade-off between quality and environmental impact of the said components, i.e. the impact of the high quality of the ‘virgin kerosene’ component is mitigated by its high environmental impact, while the impact of the lower quality of the ‘aligned hydrogen’ component’ is mitigated by its high environmental friendliness. On the other hand, the TOPSIS tool, appears to overestimate the environmental friendliness of the ‘aligned hydrogen’ component as it highly prioritizes it over the ‘virgin kerosene’ one. That is something not expected, considering that for Scenario 2, quality/circularity is highly prioritized over the environmental impact. It is also noteworthy that the ‘random hydrogen’ component is assigned also for this Scenario a quite high score, which is somewhat unexpected by taking into account that the criterion of quality/circularity is highy prioritized over the others.

Focusing on the 3rd scenario where the environmental impact is strongly prioritized over circularity and costs, the two tools rank the candidate components in an identical way. It is evident that the holistic tool becomes sensitive to the fact that the environmental impact for this scenario is prioritized over the other criteria, and that is reflected on the highest scores assigned to the components for which hydrogen has been considered as the utilized fuel during the use phase. On the other hand, although TOPSIS also lead to the same reasonable ranking, the ranking order compared to the corresponding ranking of the first two scenarios is not altered, indicating that the TOPSIS appears to be insensitive to weights variations associated with the scenarios considered.

From the above, it becomes evident that although from the mathematical viewpoint, TOPSIS methodological approach is more sophisticated and more complex compared to that of the holistic tool, the obtained ranking is not necessarily satisfactory from the technological point of view. On the contrary, the methodological approach of the holistic tool appears to be more sensitive to the weights variation, while the obtained ranking appears to respect the users judgements as the results can be logically interpreted as well as be justified from the technological scope.

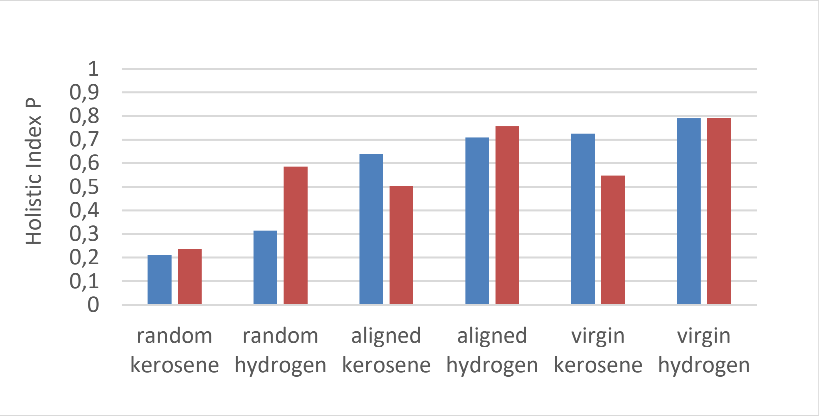

Figure 1: Ranking obtained from the holistic tool (blue color) and TOPSIS (red color) for Scenario 1

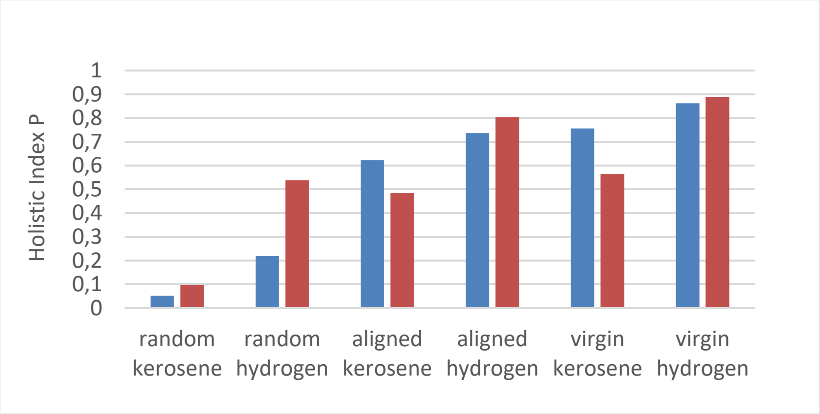

Figure 2: Ranking obtained from the holistic tool (blue color) and TOPSIS (red color) for Scenario 2

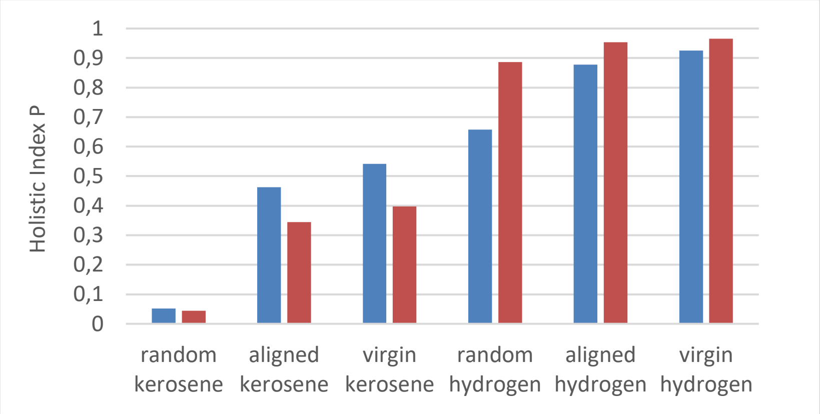

Figure 3: Ranking obtained from the holistic tool (blue color) and TOPSIS (red color) for Scenario 3

4. Conclusions

Implementation of circular economy principles in aviation is more and more required in order to achieve the goals and objectives of sustainable development. To this end, new approaches and tools are needed to assess sustainability and circularity in a concise and holistic manner and consequently support decision makers to take difficult choices, especially when contradicting aspects are included in their selection criteria.

In the current work, a MCDA tool previously implemented to support material selection in aviation, is adapted to support the selection of a recycled component in aviation and hence, assess the suitability of recycled components in the aviation industry. The said tool combines life-cycle metrics, including environmental, economic, and circularity aspects. Circularity is expressed through a quality feature of the investigated components. The tool is also capable of accounting for the type of fuel utilized during the use phase.

Assessment of the environmental and economic impact has shown that a recycled component of high quality seems to compete well with a virgin component in terms of environmental emissions and costs through its life cycle. Moreover, it has been highlighted that the use phase dominates the impact, and therefore the emissions and costs of production and manufacturing appear negligible when compared to the impact of the use phase. It has also been demonstrated that when accounting for an average lifetime distance of an aircraft, the use of hydrogen fuel is extremely beneficial, in terms of environmental emissions, compared to the use of kerosene. Yet, other aspects associated with the production, transportation and storage of liquid hydrogen have not been accounted for as they were not into the scope of the current study. On the other hand, the currently high costs of hydrogen may appear as a prohibiting factor for extensive use in aviation for the time being.

The results of the holistic tool analysis showed, for all scenarios considered, that the best performing component regards the one showing the highest quality, namely the virgin one, followed closely by the recycled CFRP aligned component. The worst performance belongs, for every scenario considered, to the random one, indicating that the circularity potential in aviation, and especially a closed-loop approach, makes sense only when upgrade has occurred and hence, quality is improved. Overall, the concept for both multi-criteria methodologies is simple and easy to understand and interpret, while computation is time-efficient and can be easily programmed into a spreadsheet. Both tools are based on compenastory methodologies, meaning that trade-offs between criteria are allowed, i.e. a poor result in one criterion can be negated by a better result associated with another criterio. However, the holistic tool seems to be more sensitive to weight variation and hence, respect the initial user needs based on the weights definition, while the differences among the considered components are more clearly distinguishable compared to TOPSIS. Moreover, the holistic tool leads to a ranking which is much more satisfactory from the technological point of view, compared to TOPSIS. Yet, it must be highlighted that both tools utilized are classified as decision support tools and therefore, the final choice eventually belongs to the user. Future work of the authors involves sensitivity and robustness analysis of the holistic tool with the utter aim to provide with an open-source, user-friendly, standardized and validated tool focused on aviation matters.

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