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Complex fuzzy assessment of green flight activity investments for sustainable aviation industry

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ABSTRACT The aviation industry harms the environment mainly via the creation of carbon emissions. Hence, action needs to be taken to ensure the environmental sustainability of the aviation industry such as the recycling of waste products, effective waste management and the introduction of energy efficiency measures. However, at the same time, the implementation of improvements to remediate such problems leads to the creation of additional costs for aviation companies. Companies thus need to conduct comprehensive priority analyses regarding the optimum strategy for the sustainability of the aviation industry. However, there is a very limited number of studies in the literature that focused on which approach should be prioritized. Accordingly, this study aimed at the assessment of the viability of investing in so-called green flight measures in the aviation industry, for which a completely original decision-making model was created. Firstly, the various strategic priorities were weighted and the impact-relation directions between them illustrated aimed at the identification of potential influences by means of a multi stepwise weight assessment ratio analysis (M-SWARA) methodology that incorporates bipolar q-rung orthopair fuzzy sets (q-ROFSs) and golden cut. Secondly, the various flight activities are ranked, and the potential impacts of these activities determined in terms of the strategic priorities of a sustainable aviation industry employing q-ROF as the elimination and choice translating reality (ELECTRE) technique. All the calculations were also computed with intuitionistic fuzzy sets (IFSs) and Pythagorean fuzzy sets (PFSs) aimed at verifying the validity of the findings. The analysis concluded that while energy efficiency comprises the most important factor in terms of strategic priority investment for the circular economy-based aviation industry, emergency response makes up the most crucial activity in the industry. Operational efficiency must be prioritized to decrease the amount of fuel consumed, in connection with which flight routes should be planned according to current weather conditions, which would serve to shorten flight times and, thus, help to increase energy efficiency. Such an approach would make a positive contribution to minimizing carbon emissions aimed at ensuring the sustainability of the aviation industry.

INDEX TERMS energy efficiency, aviation industry, sustainability, fuzzy decision-making

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I. INTRODUCTION

The aviation sector plays a very significant role in the development of international trade. The efficiency of this sector exerts a positive impact on the economic development of countries since it allows for the transportation of products over very long distances in very short times. The sector is important in terms of facilitating exports, which contributes to countries maintaining positive current account balances. Additionally, the raw materials required for industrial production can easily be obtained from distant countries at relatively low costs using air transport [1], thus helping to ensure increases in production levels.

However, the activities of the aviation industry harm the environment. One of the most important reasons for the sector's carbon emissions concerns its preference for fossil fuels, which create a significant amount of air pollution. Moreover, operational activities at airports also create air pollution. In addition, the heating and cooling systems used at airports and airplane engine gases also cause to the environmental pollution. Importantly, airports also lead to significant noise pollution due to the take-off and landing of aircraft. All these issues inevitably decrease the quality of life of the population [2].

Thus, action needs to be taken to ensure the sustainability of the aviation industry. The recycling of products used in the sector is particularly important in terms of achieving this goal via the prevention of the unnecessary overuse of natural resources. In addition, it is necessary to ensure the effective disposal of the wastes generated by the operation of aircraft to avoid causing serious environmental problems. The efficient use of energy makes up a further crucial issue in this process [3]. The introduction of new technologies will serve to reduce the energy consumed by aircraft, thus helping to reduce the carbon emission burden.

It is not considered likely that the aviation industry will act to address all these issues at the same time. The main reason is the additional costs that will be incurred by the introduction of remedial measures. A significant increase in costs will lead both to a corresponding decrease in the profitability of airline companies. This situation has a negative impact on their competitive advantage. In summary, businesses need to identify the most important sustainability activities to use their resources and budgets in the most effective way possible. Companies thus need to conduct comprehensive priority analyses that lead to the determination of the optimum strategy for the sustainability of the aviation industry. This will allow the sector to attain its sustainability targets without incurring excessive costs.

Accordingly, this study assesses the approach to investment in green flight activities aimed at ensuring a sustainable aviation industry via the application of an original decision-making model. The first stage of the study involves the weighting of the various strategic priorities and the consideration of their impact-relation directions to determine potential influences. The analysis process takes into consideration multi stepwise weight assessment ratio analysis (M-SWARA) methodology with bipolar q-rung orthopair fuzzy sets (q-ROFSs) and golden cut. The following stage includes the ranking of flight activities and the determination of the potential impacts of these activities in terms of the strategic priorities of a sustainable aviation industry employing q-ROF as the elimination and choice translating reality (ELECTRE) technique. Finally, all the calculations are also computed with intuitionistic fuzzy sets (IFSs) and Pythagorean fuzzy sets (PFSs) aimed at verifying the validity of the findings.

The novelty of this study lies in the creation of specific priority strategies to ensure the sustainability of the aviation industry using a completely original and novel model, which builds upon the SWARA approach with several improvements. As a result, a new technique was created which we termed M-SWARA. The technique allows for the determination of impact relation directions between the various factors, which is not possible applying the classical SWARA method. Since the various criteria of the circular economy-based aviation industry frequently exert an impact on each other, it is important to form an understanding of the causal relationships between them. For instance, recycling of aircraft materials can have a positive influence on the energy efficiency. Similarly, reducing the consumption of raw materials can be very helpful for the effective management of the waste. Thus, the application of the M-SWARA approach is more appropriate than the use of the SWARA technique.

Decision-making problems have become so complex that classical techniques are often not able to solve them. Hence, there is an urgent need for the introduction of new applications, one of which involves the integration of decision-making techniques with fuzzy sets. However, again due to the increase in complexity, the need has arisen for new fuzzy numbers, in response to which IFSs and PFSs have been generated. The model employed in this study applies q-ROFSs since they consider a wider area than do IFSs and PFSs. Moreover, calculating the degrees appropriately plays a crucial role for the effectiveness of the evaluation. For this purpose, the golden ratio is employed in this model to enhance both the appropriateness and originality of the applied model.

In addition, the consideration of bipolar fuzzy sets provides several advantages, including the ability to be able to consider both positive sets and negative membership functions. This situation allows for the use of a detailed information set in the analysis process. Hence, it can be much easier to handle the uncertainty problem of the decision-making process more effectively. On the other hand, the main reason for selecting the ELECTRE technique is that it is possible to avoid the compensation between the criteria and the normalization process, the positive contribution of which concerns the use of original data without introducing distortions. Hence, the findings tend to have a higher degree of applicability. Finally, a further crucial advantage of the

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model described in this study concerns the ability to conduct comparative examinations using IFSs and PFSs, which facilitates the testing of the validity and reliability of the proposed model.

The following section of the paper provides information on references in the literature to sustainability in the aviation industry. The third section focuses on the methodology applied, which is followed by a section that serves for the presentation of the results of the analysis. The discussion and conclusions make up the final part of the study.

II. LITERATURE REVIEW

Energy efficiency is particularly important in terms of ensuring the sustainability of the aviation industry, i.e. the provision of the same flight intensity accompanied by significantly lower energy consumption [4]. Since most of the industry's energy consumption is via the use of fossil fuels, the most important issue concerns the production of carbon emissions. Therefore, ensuring energy efficiency will clearly contribute to the reduction of carbon emissions [5]. Thanks to technological progress, it is now possible for airplanes to operate with less energy consumption than previously. Therefore, the use of new technology aircraft contributes significantly to energy efficiency [6]. On the other hand, operational efficiency is also very important in terms of energy efficiency, for example the selection of the most suitable flight routes for aircraft results in the reduction of air traffic [7] and, consequently, the consumption of less energy during flights. Xu and Xu [8] attempted to determine the most important criteria with respect to enhancing energy efficiency in the logistics industry. They concluded that new aircraft technological improvements should be adopted to reduce the amount of energy consumed. Yilmaz [9] focused on the use of battery technologies and alternative fuels to ensure a sustainable aviation industry, concluding that energy efficiency should be addressed in terms of on-board service activities.

The use of renewable energy should also be taken into consideration in terms of ensuring sustainability in the aviation industry. The current preference for fossil fuels for the energy needs of the aviation industry [10], results in the creation of significant amounts of environmental pollution [11]. Thus, attention should be devoted to technological developments that enable the use of clean energy in aircraft [12]. In addition, the use of fossil fuel-based energy at airports [13] could be replaced to some extent by clean energy alternatives, thus further contributing to reducing carbon emissions. Barke et al. [14] conducted an assessment of the decarbonization process in the European air transport sector. They determined that to ensure economic and social effectiveness, clean energy alternatives should be adopted by the aviation industry, concerning which the cost effectiveness of the related investment should be investigated. Hu et al. [15] addressed the mitigation of the carbon emission problem in terms of the sustainability of the aviation industry; they concluded that the electricity needs of airlines should be met from renewable energy sources.

The recycling of materials is also very important in terms of ensuring aviation industry sustainability. Since natural resources are used in the production processes of the products used in the sector [16], the use of natural resources will be lowered if such products are recycled rather than replaced with new products [17], i.e. the introduction of recycling systems will result in the consumption of fewer natural resources [18]. Thus, it will serve to ensure that the aviation industry is more sensitive to environmental issues [19] and contribute to its sustainability. Ravishankar and Christopher [20] examined approaches to ensuring sustainability in the aviation industry. They concluded that materials should be recycled to attain this objective. Markatos and Pantelakis [21] assessed aviation sustainability based on circular economy principles and concluded that the recycling of materials plays a critical role in this context.

Waste management makes up a further important factor that affects the sustainability of the aviation industry; the industry generates a significant amount of waste [22], which needs to be disposed of effectively. Otherwise, the aviation industry runs the risk of causing serious damage to the environment [23]. Every flight that takes off from our airports generates a substantial amount of waste [24]. The use of plastic products provides an important example of the waste creation process [25]. Companies thus need to take the necessary action to effectively dispose of the waste they generate. Sreenath et al. [26] assessed sustainability issues at airports focusing on Asian countries and concluded that waste should be disposed of as effectively as possible. Sebastian and Louis [27] conducted a study on waste management at airports, focusing particularly on the importance of plastic waste, which, if not disposed of in an effective manner results in irreversible damage to the environment.

The examination of similar studies reported in the literature suggests that the concept of sustainability has gained a strong foothold in the aviation sector, which understands its activities negatively affect the environment. While many studies reported in the literature stress the importance of this issue and have suggested a number of approaches and the action that should be taken, only a very limited number have attempted to suggest which approach should be prioritized. Companies are unable to introduce all the respective approaches at the same time due to budget constraints. In other words, companies must focus on the management of costs while introducing the necessary measures to ensure sustainability. Hence, a comprehensive priority analysis is required that results in specific suggestions as to the strategies that should be adopted by airline companies. This study describes the creation of a novel decision-making model that assigns weightings to the various strategic priority investment options of the circular economy-based aviation industry and that assists in identifying the critical strategies that should be followed.

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III. METHODOLOGY

This section of the study describes the techniques used in the assessment process.

A. Bipolar q-ROFs with golden cut

The degrees of membership and non-membership (DGM, DGN) of IFSs have been defined by Atanassov [28]. The sum of these degrees is awarded a value of between 0 and 1 as indicated in Equations (1) and (2), where (μ_I, n_I) refer to these degrees.

$$I = \{\langle \vartheta, \mu_I(\vartheta), n_I(\vartheta)\rangle / \vartheta \epsilon U\}, \quad (1)$$

$$0 \le \mu_I(\vartheta) + n_I(\vartheta) \le 1, \quad (2)$$

PFSs were generated by Yager [29] with the aim of covering a wider area to allow for the more effective handling of uncertainty. The sum of the squares of these degrees should be one or less according to the PFS conditions. Equations (3) and (4) illustrate the details of these sets.

$$P = \{\langle \vartheta, \mu_P(\vartheta), n_P(\vartheta)\rangle / \vartheta \epsilon U\}, \quad (3)$$

$$0 \le \left(\mu_P(\vartheta)\right)^2 + \left(n_P(\vartheta)\right)^2 \le 1, \quad (4)$$

Yager [30] generated q-ROFSs while integrating these two fuzzy sets, within the framework of which IFSs are represented by the first q level while the second part is represented by PFSs. The details are given in Equations (5) and (6).

$$Q = \{\langle \vartheta, \mu_Q(\vartheta), n_Q(\vartheta)\rangle / \vartheta \epsilon U\}, \quad (5)$$

$$0 \le \left(\mu_Q(\vartheta)\right)^q + \left(n_Q(\vartheta)\right)^q \le 1, \ q \ge 1, \quad (6)$$

The complexity of the decision-making process has increased significantly in recent years, which has acted to complicate the determination of the appropriate analysis results, thus resulting in the need for new fuzzy numbers [31-33]. Zhang [34] created bipolar fuzzy sets to remedy this situation by defining two different poles, i.e. a positive pole for the desired situation and a negative pole for undesirable situations. These poles thus act to enhance the quality of the evaluation by considering opposing issues [35,36]. The details are shown in Equation (7), where ${\mu_B}^+$ indicates the degree of satisfaction and ${\mu_B}^-$ shows the satisfaction.

$$B = \{\langle \vartheta, {\mu_B}^+(\vartheta), {\mu_B}^-(\vartheta)\rangle / \vartheta \epsilon U\}, \quad (7)$$

Equations (8)-(13) concern the integration of bipolar fuzzy sets with IFSs, PFSs and q-ROFSs.

$$B_I = \left\{\langle \vartheta, {\mu_{B_I}}^+(\vartheta), {n_{B_I}}^+(\vartheta), {\mu_{B_I}}^-(\vartheta), {n_{B_I}}^-(\vartheta)\rangle / \vartheta \epsilon U\right\}, \quad (8)$$

$$B_P = \left\{\langle \vartheta, {\mu_{B_P}}^+(\vartheta), {n_{B_P}}^+(\vartheta), {\mu_{B_P}}^-(\vartheta), {n_{B_P}}^-(\vartheta)\rangle / \vartheta \epsilon U\right\}, \quad (9)$$

$$B_Q = \left\{\langle \vartheta, {\mu_{B_Q}}^+(\vartheta), {n_{B_Q}}^+(\vartheta), {\mu_{B_Q}}^-(\vartheta), {n_{B_Q}}^-(\vartheta)\rangle / \vartheta \epsilon U\right\}, \quad (10)$$

$$0 \le \left({\mu_{B_I}}^+(\vartheta)\right) + \left({n_{B_I}}^+(\vartheta)\right) \le 1, -1 \le \left({\mu_{B_I}}^-(\vartheta)\right) + \left({n_{B_I}}^-(\vartheta)\right) \le 0, \quad (11)$$

$$0 \le \left({\mu_{B_P}}^+(\vartheta)\right)^2 + \left({n_{B_P}}^+(\vartheta)\right)^2 \le 1, \ 0 \le \left({\mu_{B_P}}^-(\vartheta)\right)^2 + \left({n_{B_P}}^-(\vartheta)\right)^2 \le 1, \quad (12)$$

$$0 \le \left({\mu_{B_Q}}^+(\vartheta)\right)^q + \left({n_{B_Q}}^+(\vartheta)\right)^q \le 1, -1 \le \left({\mu_{B_Q}}^-(\vartheta)\right)^q + \left({n_{B_Q}}^-(\vartheta)\right)^q \le 0, \quad (13)$$

The operational laws of the bipolar q-ROFSs are given by the following equations

$$B_{Q1} = \left\{\langle \vartheta, {\mu_{B_{Q_1}}}^+(\vartheta), {n_{B_{Q_1}}}^+(\vartheta), {\mu_{B_{Q_1}}}^-(\vartheta), {n_{B_{Q_1}}}^-(\vartheta)\rangle / \vartheta \epsilon U\right\} \text{ and}$$

$$B_{Q2} = \left\{\langle \vartheta, {\mu_{B_{Q_2}}}^+(\vartheta), {n_{B_{Q_2}}}^+(\vartheta), {\mu_{B_{Q_2}}}^-(\vartheta), {n_{B_{Q_2}}}^-(\vartheta)\rangle / \vartheta \epsilon U\right\}$$

$$B_{Q1} \oplus B_{Q2} = \left(\left(({\mu_{B_{Q_1}}}^+)^q + ({\mu_{B_{Q_2}}}^+)^q - ({\mu_{B_{Q_1}}}^+)^q . ({\mu_{B_{Q_2}}}^+)^q\right)^{\frac{1}{q}}, ({n_{B_{Q_1}}}^+ . {n_{B_{Q_2}}}^+), -({\mu_{B_{Q_1}}}^- . {\mu_{B_{Q_2}}}^-), +\left(({n_{B_{Q_1}}}^-)^q + ({n_{B_{Q_2}}}^-)^q - ({n_{B_{Q_1}}}^-)^q . ({n_{B_{Q_2}}}^-)^q\right)^{\frac{1}{q}}\right), \quad (14)$$

$$B_{Q1} \otimes B_{Q2} = \left(\left({\mu_{B_{Q_1}}}^+ . {\mu_{B_{Q_2}}}^+\right), \left(\left({n_{B_{Q_1}}}^+\right)^q + \left({n_{B_{Q_2}}}^+\right)^q - \left({n_{B_{Q_1}}}^+\right)^q . \left({n_{B_{Q_2}}}^+\right)^q\right)^{\frac{1}{q}}, -\left(\left({\mu_{B_{Q_1}}}^-\right)^q + \left({\mu_{B_{Q_2}}}^-\right)^q - \left({\mu_{B_{Q_1}}}^-\right)^q . \left({\mu_{B_{Q_2}}}^-\right)^q\right)^{\frac{1}{q}}, -\left({n_{B_{Q_1}}}^- . {n_{B_{Q_2}}}^-\right)\right), \quad (15)$$

$$\lambda B_{Q1} = \left(\left(1 - \left(1 - \left({\mu_{B_{Q_1}}}^+\right)^q\right)^\lambda\right)^{1/q}, \left({n_{B_{Q_1}}}^+\right)^\lambda, -\left(-{\mu_{B_{Q_1}}}^-\right)^\lambda, -\left(1 - \left(1 - \left(-{n_{B_{Q_1}}}^-\right)^q\right)^\lambda\right)^{1/q}\right), \lambda > 0 \quad (16)$$

$${B_{Q1}}^\lambda = \left(\left({\mu_{B_{Q_1}}}^+\right)^\lambda, \left(1 - \left(1 - \left({n_{B_{Q_1}}}^+\right)^q\right)^\lambda\right)^{1/q}, -\left(1 - \left(1 - \left(-{\mu_{B_{Q_1}}}^-\right)^q\right)^\lambda\right)^{\frac{1}{q}}, -\left(-{n_{B_{Q_1}}}^-\right)^\lambda\right), \lambda > 0 \quad (17)$$

The example of the aggregation is illustrated for two bipolar q-ROFSs ($q = 3$) as follows

$$B_{Q1=}\{0.45, 0.28, -0.43, -0.27\},$$
$$B_{Q2=}\{0.52, 0.32, -0.50, -0.31\}$$

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$$B_{Q1} \oplus B_{Q2}$$
$$= \Big(((0.45)^3 + (0.52)^3$$
$$- (0.45)^3.(0.52)^3)^{\frac{1}{3}}, (0.28.0.32), -(-0.43.-0.50), +((-0.27)^3$$
$$+ (-0.31)^3 - (-0.27)^3.(-0.31)^3)^{\frac{1}{3}}\Big)$$

$$B_{Q1} \oplus B_{Q2} = \{0.60, 0.09, -0.22, -0.37\}$$

Theorem 1. Suppose $B_Q = \{\mu_{B_Q}{}^+, n_{B_Q}{}^+, \mu_{B_Q}{}^-, n_{B_Q}{}^-\}$, $B_{Q1} = \{\mu_{B_{Q1}}{}^+, n_{B_{Q1}}{}^+, \mu_{B_{Q1}}{}^-, n_{B_{Q1}}{}^-\}$, and $B_{Q2} = \{\mu_{B_{Q2}}{}^+, n_{B_{Q2}}{}^+, \mu_{B_{Q2}}{}^-, n_{B_{Q2}}{}^-\}$ are the set of the bipolar q-ROFNs.

$$B_{Q1} \oplus B_{Q2} = B_{Q2} \oplus B_{Q1} \quad (18)$$
$$B_{Q1} \otimes B_{Q2} = B_{Q2} \otimes B_{Q1} \quad (19)$$
$$c(B_{Q1} \oplus B_{Q2}) = cB_{Q1} \oplus cB_{Q2} \quad (20)$$
$$c_1 B_Q \oplus c_2 B_Q = (c_1 + c_2) B_Q \quad (21)$$
$${B_Q}^{c_1} \otimes {B_Q}^{c_2} = {B_Q}^{c_1 + c_2} \quad (22)$$
$${B_{Q1}}^{c} \otimes {B_{Q2}}^{c} = (B_{Q1} \otimes B_{Q2})^c \quad (23)$$

Where $c, c_1, c_2 > 0$

Proof. The equations are proven as

$$B_{Q1} \oplus B_{Q2}$$
$$= \Big(((\mu_{B_{Q1}}{}^+)^q + (\mu_{B_{Q2}}{}^+)^q$$
$$- (\mu_{B_{Q1}}{}^+)^q.(\mu_{B_{Q2}}{}^+)^q)^{\frac{1}{q}}, (n_{B_{Q1}}{}^+.n_{B_{Q2}}{}^+), -(\mu_{B_{Q1}}{}^-.\mu_{B_{Q2}}{}^-), -((n_{B_{Q1}}{}^-)^q$$
$$+ (n_{B_{Q2}}{}^-)^q - (n_{B_{Q1}}{}^-)^q.(n_{B_{Q2}}{}^-)^q)^{\frac{1}{q}}\Big)$$
$$= \Big(((\mu_{B_{Q2}}{}^+)^q + (\mu_{B_{Q1}}{}^+)^q -$$
$$(\mu_{B_{Q2}}{}^+)^q.(\mu_{B_{Q1}}{}^+)^q)^{\frac{1}{q}}, (n_{B_{Q2}}{}^+.n_{B_{Q1}}{}^+), -(\mu_{B_{Q2}}{}^-.\mu_{B_{Q1}}{}^-), -((n_{B_{Q2}}{}^-)^q +$$
$$(n_{B_{Q1}}{}^-)^q - (n_{B_{Q2}}{}^-)^q.(n_{B_{Q1}}{}^-)^q)^{\frac{1}{q}}\Big)$$
$$= B_{Q1} \oplus B_{Q2}$$

$$c(B_{Q1} \oplus B_{Q2})$$
$$= c\Big(((\mu_{B_{Q1}}{}^+)^q + (\mu_{B_{Q2}}{}^+)^q$$
$$- (\mu_{B_{Q1}}{}^+)^q.(\mu_{B_{Q2}}{}^+)^q)^{\frac{1}{q}}, (n_{B_{Q1}}{}^+.n_{B_{Q2}}{}^+), -(\mu_{B_{Q1}}{}^-.\mu_{B_{Q2}}{}^-), -((n_{B_{Q1}}{}^-)^q$$
$$+ (n_{B_{Q2}}{}^-)^q - (n_{B_{Q1}}{}^-)^q.(n_{B_{Q2}}{}^-)^q)^{\frac{1}{q}}\Big)$$
$$= \Big(\Big(1 - \Big(1 - \big((\mu_{B_{Q1}}{}^+)^q + (\mu_{B_{Q2}}{}^+)^q -$$
$$(\mu_{B_{Q1}}{}^+)^q.(\mu_{B_{Q2}}{}^+)^q\big)\Big)^c\Big)^{\frac{1}{q}}, (n_{B_{Q1}}{}^+.n_{B_{Q2}}{}^+)^c, -(\mu_{B_{Q1}}{}^-.\mu_{B_{Q2}}{}^-)^c, -\Big(1 -$$
$$\Big(1 - \big((n_{B_{Q1}}{}^-)^q + (n_{B_{Q2}}{}^-)^q - (n_{B_{Q1}}{}^-)^q.(n_{B_{Q2}}{}^-)^q\big)\Big)^c\Big)^{\frac{1}{q}}\Big)$$

$$cB_{Q1} = \Big(1 - (1 - (\mu_{B_{Q1}}{}^+)^q)^c\Big)^{\frac{1}{q}}, (n_{B_{Q1}}{}^+)^c, -(\mu_{B_{Q1}}{}^-)^c, -\Big(1$$
$$- (1 - (n_{B_{Q1}}{}^-)^q)^c\Big)^{\frac{1}{q}}$$

$$cB_{Q2} = \Big(1 - (1 - (\mu_{B_{Q2}}{}^+)^q)^c\Big)^{\frac{1}{q}}, (n_{B_{Q2}}{}^+)^c, -(\mu_{B_{Q2}}{}^-)^c, -\Big(1$$
$$- (1 - (n_{B_{Q2}}{}^-)^q)^c\Big)^{\frac{1}{q}}$$

$$cB_{Q1} \oplus cB_{Q2}$$
$$= \Big(\Big(\Big(1 - (1 - (\mu_{B_{Q1}}{}^+)^q)^c\Big)^{\frac{1}{q}}\Big)^q + \Big(\Big(1 - (1 - (\mu_{B_{Q2}}{}^+)^q)^c\Big)^{\frac{1}{q}}\Big)^q$$
$$- \Big(\Big(1 - (1 - (\mu_{B_{Q1}}{}^+)^q)^c\Big)^{\frac{1}{q}}\Big)^q \Big((1$$
$$- (1 - (\mu_{B_{Q2}}{}^+)^q)^c\Big)^{\frac{1}{q}}\Big)^q\Big)^{\frac{1}{q}}, (n_{B_{Q1}}{}^+.n_{B_{Q2}}{}^+)^c, -(\mu_{B_{Q1}}{}^-.\mu_{B_{Q2}}{}^-)^c, -\Big(\Big((1$$
$$- (1 - (n_{B_{Q1}}{}^-)^q)^c\Big)^{\frac{1}{q}}\Big)^q + \Big(\Big(1 - (1 - (n_{B_{Q2}}{}^-)^q)^c\Big)^{\frac{1}{q}}\Big)^q$$
$$- \Big(\Big(1 - (1 - (n_{B_{Q1}}{}^-)^q)^c\Big)^{\frac{1}{q}}\Big)^q \Big(\Big(1 - (1 - (n_{B_{Q2}}{}^-)^q)^c\Big)^{\frac{1}{q}}\Big)^q\Big)^{\frac{1}{q}}$$

$${B_Q}^{c_1} = (\mu_{B_Q}{}^+)^{c_1}, \Big(1 - (1 - (n_{B_Q}{}^+)^q)^{c_1}\Big)^{\frac{1}{q}},$$
$$-\Big(1 - (1 - (\mu_{B_Q}{}^-)^q)^{c_1}\Big)^{\frac{1}{q}}, -(n_{B_Q}{}^-)^{c_1}$$

$${B_Q}^{c_2} = (\mu_{B_Q}{}^+)^{c_2}, \Big(1 - (1 - (n_{B_Q}{}^+)^q)^{c_2}\Big)^{\frac{1}{q}},$$
$$-\Big(1 - (1 - (\mu_{B_Q}{}^-)^q)^{c_2}\Big)^{\frac{1}{q}}, -(n_{B_Q}{}^-)^{c_2}$$

$${B_Q}^{c_1} \otimes {B_Q}^{c_2} = (\mu_{B_Q}{}^+)^{c_1}(\mu_{B_Q}{}^+)^{c_2}, \Big(\Big(\Big(1 - (1 - (n_{B_Q}{}^+)^q)^{c_1}\Big)^{\frac{1}{q}}\Big)^q$$
$$+ \Big(\Big(1 - (1 - (n_{B_Q}{}^+)^q)^{c_2}\Big)^{\frac{1}{q}}\Big)^q$$
$$- \Big(\Big(1 - (1 - (n_{B_Q}{}^+)^q)^{c_1}\Big)^{\frac{1}{q}}\Big)^q \Big((1$$
$$- (1 - (n_{B_Q}{}^+)^q)^{c_2}\Big)^{\frac{1}{q}}\Big)^q\Big)^{\frac{1}{q}}$$
$$- \Big(\Big(\Big(1 - (1 - (\mu_{B_Q}{}^-)^q)^{c_1}\Big)^{\frac{1}{q}}\Big)^q$$
$$+ \Big(\Big(1 - (1 - (\mu_{B_Q}{}^-)^q)^{c_2}\Big)^{\frac{1}{q}}\Big)^q$$
$$- \Big(\Big(1 - (1 - (\mu_{B_Q}{}^-)^q)^{c_1}\Big)^{\frac{1}{q}}\Big)^q \Big((1$$
$$- (1 - (\mu_{B_Q}{}^-)^q)^{c_2}\Big)^{\frac{1}{q}}\Big)^q\Big)^{\frac{1}{q}}, -(n_{B_Q}{}^-)^{c_1}(n_{B_Q}{}^-)^{c_2}$$

$${B_Q}^{c_1+c_2} = (\mu_{B_Q}{}^+)^{c_1+c_2}, \Big(1 - (1 - (n_{B_Q}{}^+)^q)^{c_1+c_2}\Big)^{\frac{1}{q}}, -\Big(1$$
$$- (1 - (\mu_{B_Q}{}^-)^q)^{c_1+c_2}\Big)^{\frac{1}{q}}, -(n_{B_Q}{}^-)^{c_1+c_2}$$

The defuzzification process is performed with the score functions ($S(\vartheta)_{B_I}$, $S(\vartheta)_{B_P}$, $S(\vartheta)_{B_Q}$) as in Equations (24)-(26).

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$$S(\vartheta)_{B_I} = \left(\left(\mu_{B_I}{}^{+}(\vartheta)\right) - \left(n_{B_I}{}^{+}(\vartheta)\right)\right) - \left(\left(\mu_{B_I}{}^{-}(\vartheta)\right) - \left(n_{B_I}{}^{-}(\vartheta)\right)\right), \quad (24)$$

$$S(\vartheta)_{B_P} = \left(\left(\mu_{B_P}{}^{+}(\vartheta)\right)^2 - \left(n_{B_P}{}^{+}(\vartheta)\right)^2\right) + \left(\left(\mu_{B_P}{}^{-}(\vartheta)\right)^2 - \left(n_{B_P}{}^{-}(\vartheta)\right)^2\right), \quad (25)$$

$$S(\vartheta)_{B_Q} = \left(\left(\mu_{B_Q}{}^{+}(\vartheta)\right)^q - \left(n_{B_Q}{}^{+}(\vartheta)\right)^q\right) - \left(\left(\mu_{B_Q}{}^{-}(\vartheta)\right)^q - \left(n_{B_Q}{}^{-}(\vartheta)\right)^q\right), \quad (26)$$

The proposed model computes the degrees with the help of golden cut (φ), for the purpose of which a and b provide information on large and small quantities [37]. The details are shown in Equations (27)-(29).

$$\varphi = \frac{a}{b}, \quad (27)$$

$$\varphi = \frac{1+\sqrt{5}}{2} = 1.618, \quad (28)$$

$$\varphi = \frac{\mu_{G_{B_Q}}}{n_{G_{B_Q}}}, \quad (29)$$

Equations (30)-(32) illustrate the adaptation of golden cut to the bipolar q-ROFSs.

$$G_{B_Q} = \left\{\langle \vartheta, \mu_{G_{B_Q}}{}^{+}(\vartheta), n_{G_{B_Q}}{}^{+}(\vartheta), \mu_{G_{B_Q}}{}^{-}(\vartheta), n_{G_{B_Q}}{}^{-}(\vartheta)\rangle / \vartheta \epsilon U\right\}, \quad (30)$$

$$0 \le \left(\mu_{G_{B_Q}}{}^{+}(\vartheta)\right)^q + \left(n_{G_{B_Q}}{}^{+}(\vartheta)\right)^q \le 1, -1 \le \left(\mu_{G_{B_Q}}{}^{-}(\vartheta)\right)^q + \left(n_{G_{B_Q}}{}^{-}(\vartheta)\right)^q \le 0, \quad (31)$$

$$0 \le \left(\mu_{G_{B_Q}}{}^{+}(\vartheta)\right)^{2q} + \left(n_{G_{B_Q}}{}^{+}(\vartheta)\right)^{2q} \le 1, \quad 0 \le \left(\mu_{G_{B_Q}}{}^{-}(\vartheta)\right)^{2q} + \left(n_{G_{B_Q}}{}^{-}(\vartheta)\right)^{2q} \le 1 \quad q \ge 1, \quad (32)$$

B. M-SWARA with bipolar q-ROFSs

Keršuliene et al. [38] introduced the SWARA technique aimed at determining the weightings of various factors. It was created as an expert-oriented technique via which it is possible to make only a limited number of comparisons by considering priorities defined by experts. The model proposed in this study, however, employs a new technique that we termed M-SWARA that involved the introduction of several improvements to the classical model. The new method allows for the identification of causal relationships [39,40]. After obtaining evaluations from a team of experts, a bipolar q-ROFS relation matrix is created as shown in Equation (33).

$$Q_k = \begin{bmatrix} 0 & Q_{12} & \cdots & \cdots & Q_{1n} \\ Q_{21} & 0 & \cdots & \cdots & Q_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ Q_{n1} & Q_{n2} & \cdots & \cdots & 0 \end{bmatrix}, \quad (33)$$

The next stage involves the computation of bipolar q-ROFSs and the calculation of score functions. Equations (34)-(36) are then used to define the significant values, where k_j represents the coefficient value, q_j refers to the recalculated weighting, s_j identifies the comparative importance rate and w_j shows the weightings of the criteria.

$$k_j = \begin{cases} 1 & j = 1 \\ s_j + 1 & j > 1 \end{cases}, \quad (34)$$

$$q_j = \begin{cases} 1 & j = 1 \\ \frac{q_{j-1}}{k_j} & j > 1 \end{cases}, \quad (35)$$

$$If\ s_{j-1} = s_j,\ q_{j-1} = q_j; If\ s_j = 0,\ k_{j-1} = k_j$$

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_k}, \quad (36)$$

This is followed by the identification of stable values involving the transposition of the matrix and its limitation by considering the power of 2_{t+1}. The threshold values in this matrix are defined to compute causal degrees. This matrix is also used to calculate the weightings.

C. ELECTRE with bipolar q-ROFSs

The ELECTRE methodology was introduced by Benayoun et al. [41] for the purpose of ranking various alternatives. The methodology takes into consideration binary superiority comparisons. Several differing versions of the ELECTRE technique have been reported in the literature. Our model integrates this method with bipolar q-ROFSs. Firstly, evaluations are collected from the team of experts, which result in the creation of a bipolar q-ROF decision matrix as shown in Equation (37).

$$X_k = \begin{bmatrix} 0 & X_{12} & \cdots & \cdots & X_{1m} \\ X_{21} & 0 & \cdots & \cdots & X_{2m} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ X_{n1} & X_{n2} & \cdots & \cdots & 0 \end{bmatrix}, \quad (37)$$

The next stage involves the generation of the bipolar q-ROFSs, which is followed by the definition of score function values, which are also normalized via the following stage as shown in Equation (38).

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}}, \quad (38)$$

Equation (39) is then employed to compute the weighted values.

$$v_{ij} = w_{ij} \times r_{ij}, \quad (39)$$

The concordance and discordance interval matrixes (C and D) are generated by Equations (40)-(45).

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$$C=\begin{bmatrix} - & c_{12} & \cdots & \cdots & c_{1n} \\ c_{21} & - & \cdots & \cdots & c_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ c_{n1} & c_{n2} & \cdots & \cdots & - \end{bmatrix}, \quad (40)$$

$$D=\begin{bmatrix} - & d_{12} & \cdots & \cdots & d_{1n} \\ d_{21} & - & \cdots & \cdots & d_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ d_{n1} & d_{n2} & \cdots & \cdots & - \end{bmatrix}, \quad (41)$$

$$c_{ab} = \{j | v_{aj} \geq v_{bj}\}, \quad (42)$$

$$d_{ab} = \{j | v_{aj} < v_{bj}\}, \quad (43)$$

$$c_{ab} = \sum_{j \in c_{ab}} w_j, \quad (44)$$

$$d_{ab} = \frac{max_{j \in d_{ab}} |v_{aj} - v_{bj}|}{max_j |v_{mj} - v_{nj}|}, \quad (45)$$

The next stage explains the creation of the concordance *E*, discordance *F* and aggregated *G* index matrices as shown in Equations (46)-(53),

$$E=\begin{bmatrix} - & e_{12} & \cdots & \cdots & e_{1n} \\ e_{21} & - & \cdots & \cdots & e_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ e_{n1} & e_{n2} & \cdots & \cdots & - \end{bmatrix}, \quad (46)$$

$$F=\begin{bmatrix} - & f_{12} & \cdots & \cdots & f_{1n} \\ f_{21} & - & \cdots & \cdots & f_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ f_{n1} & f_{n2} & \cdots & \cdots & - \end{bmatrix}, \quad (47)$$

$$G=\begin{bmatrix} - & g_{12} & \cdots & \cdots & g_{1n} \\ g_{21} & - & \cdots & \cdots & g_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ g_{n1} & g_{n2} & \cdots & \cdots & - \end{bmatrix}, \quad (48)$$

$$\begin{cases} e_{ab} = 1 \ \ if \ c_{ab} \geq \bar{c} \\ e_{ab} = 0 \ \ if \ c_{ab} < \bar{c} \end{cases}, \quad (49)$$

$$\bar{c} = \sum_{a=1}^{n} \sum_{b}^{n} c_{ab} / n(n-1), \quad (50)$$

$$\begin{cases} f_{ab} = 1 \ \ if \ d_{ab} \leq \bar{d} \\ f_{ab} = 0 \ \ if \ d_{ab} > \bar{d} \end{cases}, \quad (51)$$

$$\bar{d} = \sum_{a=1}^{n} \sum_{b}^{n} d_{ab} / n(n-1), \quad (52)$$

$$g_{ab} = e_{ab} \times f_{ab}, \quad (53)$$

where e_{ab}, f_{ab}, g_{ab} refer to sets of these index matrices. The final stage comprises the definition of the net superior c_a, inferior d_a, and overall o_a values via Equations (54)-(56).

$$c_a = \sum_{b=1}^{n} c_{ab} - \sum_{b=1}^{n} c_{ba}, \quad (54)$$

$$d_a = \sum_{b=1}^{n} d_{ab} - \sum_{b=1}^{n} d_{ba}, \quad (55)$$

$$o_a = c_a - d_a, \quad (56)$$

IV. ANALYSIS RESULTS

This study describes the creation of a novel model for the assessment of investment in green flight activities so as to attain a sustainable aviation industry. The first stage involved the weighting of the strategic priority investments of the circular economy-based aviation industry, which was followed by the evaluation of green flight activities for a sustainable aviation industry. All the stages of this model are explained in Figure 1.

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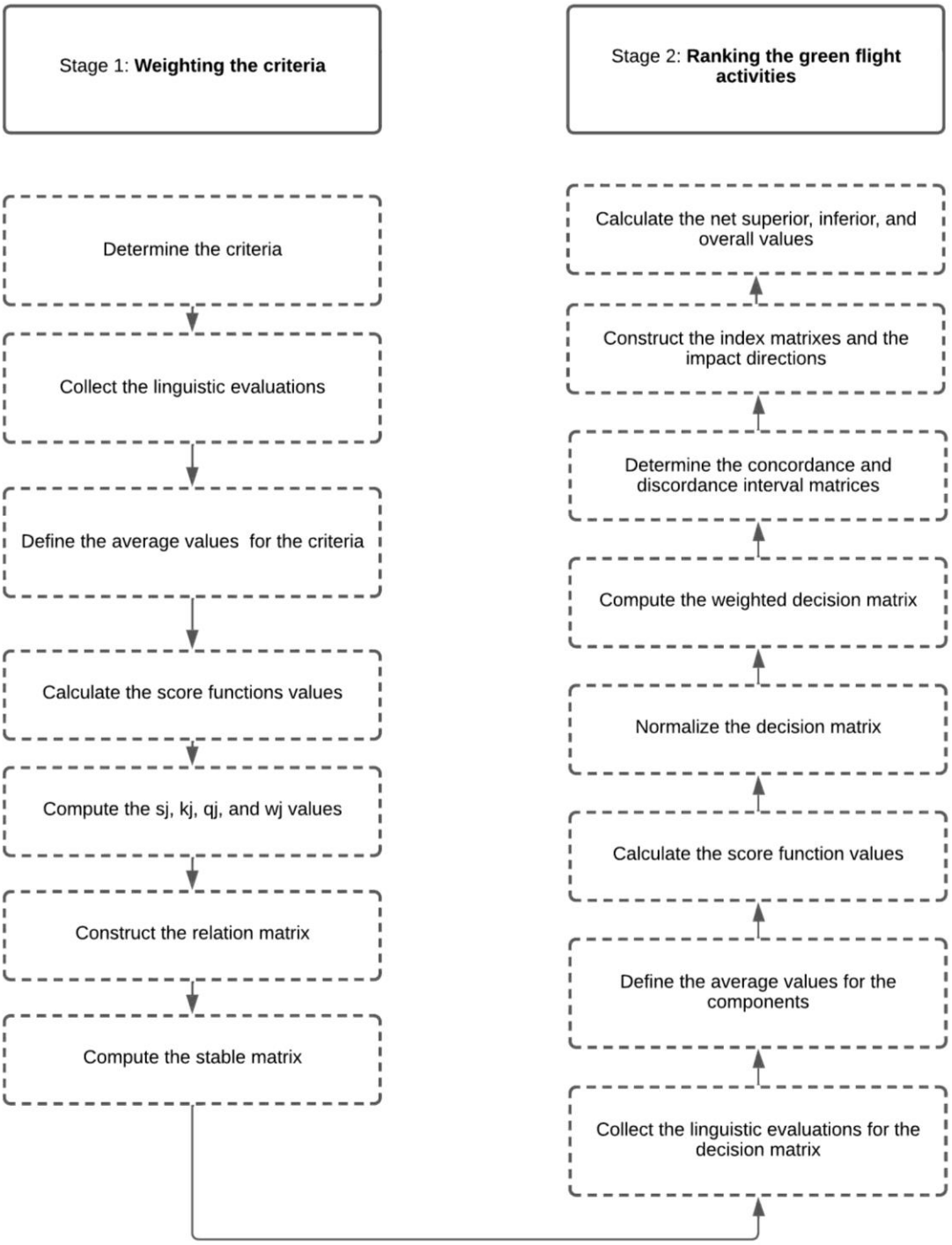


FIGURE 1. **Proposed Model**

A. Weighting of the Strategic Priority Investments of the Circular Economy-Based Aviation Industry (Stage 1)

Step 1 is related to the identification of the strategic priority investments of the circular economy-based aviation industry, concerning which similar studies reported in the literature were examined and four criteria were selected as listed in Table 1.

TABLE 1. **Selected Factors**

Criterion	Reference
Recycling of aircraft materials (RHL)	[4]
Management of waste (MGW)	[11]
Reducing the consumption of raw materials (CWE)	[7]
Providing for energy efficiency (PFF)	[15]

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The recycling of aircraft materials is a critical factor in terms of attaining sustainability in the circular economy-based aviation industry. The recycling of such products will result in a significant reduction in the total amount of waste and will encourage the more effective use of resources. The management of waste comprises a further significant criterion in terms of ensuring sustainability. A significant amount of waste is generated via the flying of airplanes; therefore, to minimize damage to the environment, such waste must be disposed of effectively. Reducing the consumption of raw materials will also contribute to a circular economy-based aviation industry. Finally, energy efficiency is a crucial issue in this context. A significant amount of gasoline is consumed by the airline industry and, clearly, taking action to reduce the consumption of gasoline will help to decrease carbon emissions. Taken together, these four criteria have the potential to minimize the aviation sector's negative impact on the environment.

Step 2 provides information on the collection of the evaluations of the various criteria from members of the expert team who were required to consider five different scales in the evaluation process. Subsequently, these scales were converted into degrees for both positive and negative issues, concerning which the values shown in Table A1 in the appendix were taken into consideration. Three experts, all of whom work as high-level managers in the airline industry with experience of more than 27 years in the sector, provided their evaluations. It is important to emphasize here that all three members of the team of experts have the qualifications and experience required to provide evaluations of the criteria and their alternatives. The evaluations of the criteria provided by the experts are shown in Table A2.

Step 3 focused on the determination of the average values of the positive and negative degrees. Table A3 provides information on the details of these values.

Step 4 concerned the calculation of the score function values for the criteria. These values were taken into consideration when conducting the normalization process, for the purpose of which, Equations (18)-(20) were applied. Details of these values are shown in Table 2.

TABLE 2. Score function values

	RHL	MGW	CWE	PFF
RHL	.000	.132	.201	.221
MGW	.260	.000	.188	.260
CWE	.158	.244	.000	.266
PFF	.235	.281	.260	.000

Step 5 related to the calculation of the essential values with respect to the identification of the relationship degrees. Equations (28)-(30) were used to define these values. Table A4 provides a list of the resulting values.

Step 6 includes the construction of the relation matrix, which is used to identify the cause-and-effect directions of the criteria. Table 3 shows details of the matrix.

TABLE 3. Relation matrix

	RHL	MGW	CWE	PFF
RHL		.286	.324	.389
MGW	.406		.271	.322
CWE	.278	.322		.400
PFF	.264	.411	.326	

Step 7 determines the causal directions for the indicators, in the context of which the matrix is transposed and limited by considering the power of 2_{t+1}, as in Table 4.

TABLE 4. Stable matrix

	RHL	MGW	CWE	PFF
RHL	.240	.240	.240	.240
MGW	.255	.255	.255	.255
CWE	.235	.235	.235	.235
PFF	.270	.270	.270	.270

The causal degrees are then computed using the threshold values. Details of the causal degrees are shown in Figure 2.

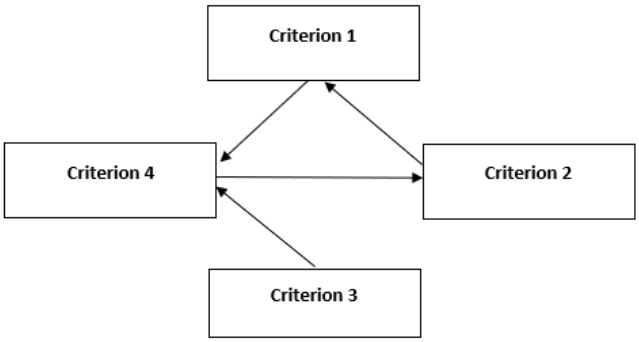


FIGURE 2. Causal directions

Figure 2 indicates that the recycling of aircraft materials and reducing the consumption of raw materials exert an important impact on energy efficiency. On the other hand, the management of waste has an influence on the recycling of aircraft materials. Finally, energy efficiency affects the management of the waste. These causal directions help to form an understanding of the critical factors.

Step 8 provides for the identification of the comparative weighting priorities. The stable matrix is also used to calculate the weightings. Details of the analysis results are provided in Table 5.

TABLE 5. Comparative weighing priorities

	Bipolar IFSs	Bipolar PFSs	Bipolar q-ROFSs
RHL	3	3	3
MGW	2	2	2
CWE	4	4	4
PFF	1	1	1

Table 5 shows that energy efficiency is the most important factor in terms of the strategic priority investments of the circular economy-based aviation industry. The management

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of waste also plays a significant role in this respect. These conclusions indicate that the proposed model provides coherent results. It is strongly recommended that companies should also focus on technological improvements as part of the process. The combination of these factors will help to ensure greater energy efficiency. In addition, waste that is generated after the flight process must be disposed of effectively. Otherwise, it will be impossible to avoid significant environmental problems.

B. Evaluation of Green Flight Activities for a Sustainable Aviation Industry (Stage 2)

Step 9 includes the collection of the expert evaluations of the decision-makers on the various activities. The process comprises the selection of the significant green flight activities to be considered, based on the activities set out in the European Environment Agency Aviation-Air Pollutant Emission Inventory Guidebook, 2019. Details of the green flight activities selected for this study are shown in Table 6.

TABLE 6. Selected green flight activities for a sustainable aviation industry

Activity	List of tasks
Pre-departure (PRT)	fueling and fuel handling, auxiliary power units, start-up of engines, service vehicles, anti-icing and de-icing, other services
Departure (DRE)	taxi-out, take-off, climb-out
Cruising (CSI)	climb, cruise, descent
Emergency (ECY)	Fuel dumping
Arrival (AAL)	final approach, landing, taxi-in
Post-arrival (PVL)	service vehicles, auxiliary power units, other services
Maintenance (MIE)	maintenance of aircraft engines, painting of aircraft, other scheduled maintenance, other non-scheduled maintenance

Source: European Environment Agency, Aviation-Air Pollutant Emission Inventory Guidebook, 2019.

The decision-makers were also asked to provide their evaluations of the selected green flight activities, details of which are shown in Table A5.

Step 10 concerns the definition of the average values of the degrees for the various activities, as shown in Table A6.

Step 11 relates to the calculation of the score function values of the activities, which are taken into consideration in the normalization process. Details of these values are provided in Table 7.

TABLE 7. Score function values for the activities

	RHL	MGW	CWE	PFF
PRT	.202	.211	.232	.238
DRE	.164	.213	.247	.133
CSI	.244	.235	.221	.197
ECY	.260	.213	.223	.330
AAL	.270	.255	.221	.165
PVL	.304	.156	.173	.211
MIE	.221	.213	.205	.213

Step 12 provides information on the normalization of the decision matrix, for which Equation (31) is taken into consideration. The normalized matrix is presented in Table 8.

TABLE 8. Normalized matrix

	RHL	MGW	CWE	PFF
PRT	.316	.370	.402	.408
DRE	.256	.374	.427	.228
CSI	.382	.411	.383	.338
ECY	.407	.374	.385	.567
AAL	.422	.447	.383	.283
PVL	.475	.273	.299	.363
MIE	.346	.374	.354	.366

Step 13 relates to the generation of the weighted decision matrix using Equation (32), as shown in Table 9.

TABLE 9. Weighted matrix

	RHL	MGW	CWE	PFF
PRT	.076	.095	.094	.110
DRE	.061	.095	.100	.062
CSI	.092	.105	.090	.091
ECY	.098	.095	.090	.153
AAL	.101	.114	.090	.076
PVL	.114	.070	.070	.098
MIE	.083	.095	.083	.099

Step 14 focuses on the determination of the concordance and discordance interval matrices, which are generated via Equations (34)-(39). Table A7 provides information on these matrices.

Step 15 explains the generation of the concordance *E*, discordance *F* and aggregated *G* index matrices employing Equations (40)-(47). Details are provided in Table A8. The use of these matrices enables the definition of the causal relationships between the activities. The causal directions are illustrated in Figure 3.

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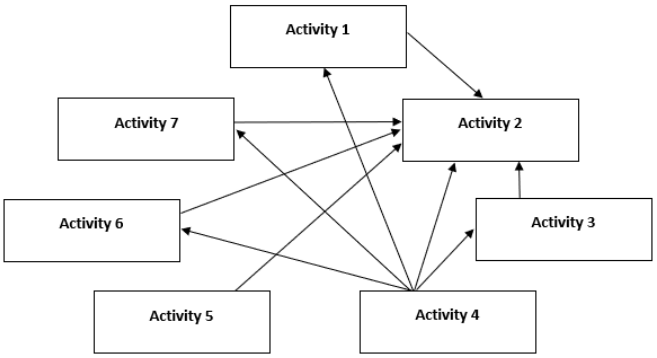


FIGURE 3. Causal relationships between the activities

Figure 3 indicates that emergency situations comprise the most influential activity with respect to a sustainable aviation industry. On the other hand, it is also evident that departures are also considered to be an influential factor. These two critical issues should be taken into consideration when determining the most appropriate strategies for the aviation industry.

Step 16 includes the calculation of the rankings of the alternatives. The net superior, inferior, and overall values of the activities are defined by Equations (48)-(50). Details are shown in Table 10.

TABLE 10. Net superior, inferior, and overall values of the activities

Activity	Net superior values	Net Inferior values	Overall values
PRT	.038	-.402	.440
DRE	-1.393	4.122	-5.515
CSI	.481	-.524	1.005
ECY	2.824	-5.102	7.926
AAL	.942	.248	.695
PVL	-1.501	.635	-2.136
MIE	-1.391	1.025	-2.416

Table 10 provides information on the calculation results as indicated using q-ROFSs. This study included the performance of a comparative evaluation applying IFSs and PFSs. Table 11 shows details of the comparative evaluation.

TABLE 11. Comparative overall ranking results for the activities

Activities	Bipolar q-ROF Multi SWARA-ELECTRE	Bipolar PF Multi SWARA-ELECTRE	Bipolar IF Multi SWARA-ELECTRE
PRT	4	4	4
DRE	7	6	6
CSI	2	2	2
ECY	1	1	1
AAL	3	3	3
PVL	5	5	5
MIE	6	7	7

Table 11 indicates that the ranking results are the same for all the fuzzy sets. Thus, the results of the proposed model are coherent and reliable. It was found that emergency situations comprise the most crucial activity regarding the sustainability of the aviation industry. Cruising is also considered significant. Therefore, airline companies should focus mainly on making improvements to the fuel dumping process. It is possible to introduce environmentally friendly activities via the introduction of new technologies.

V. CONCLUSIONS AND DISCUSSION

This study attempted to provide an evaluation of investment in green flight activities aimed at ensuring the sustainability of the aviation industry. The first stage involves the weighting of the strategic priority investments for a circular economy-based aviation industry. This is followed by the assessment of green flight activity options for a sustainable aviation sector. It is shown that the recycling of aircraft materials and reducing the consumption of raw materials exert an important impact on energy efficiency. Similarly, the management of waste has an influence on the recycling of aircraft materials. Energy efficiency is found to be the key indicator of the strategic priority investments for a circular economy-based aviation industry. On the other hand, emergency is stated as the most crucial activity regarding the sustainability of the aviation industry.

The aviation industry occupies a very important position in a globalizing world. In connection, particularly, with increasing international trade, air transportation is becoming increasingly important. On the other hand, the greater is the number of flights, the greater is the negative impact on the environment. Therefore, it is necessary to make the aviation industry more environmentally friendly by taking effective action. The most important reason for the carbon emission problem faced by the industry clearly comprises the need for the use of fossil fuels. We propose that the results provided by this study will play an important and guiding role in ensuring sustainability in the aviation industry going forward.

To reduce emissions, the amount of energy used in the aviation industry must be reduced, which will require the introduction of more energy efficiency measures in the sector. Reducing fuel consumption will act to reduce the amount of carbon emissions. Moreover, to decrease the amount of fuel used, operational efficiency must be improved by, e.g. planning flight routes according to the weather conditions. This will help to shorten flight times and thus help to increase energy efficiency.

Many researchers have pointed out the significance of energy efficiency in the aviation industry. Ntakolia et al. [42] investigated the performance of the aviation industry and concluded that air traffic management is a crucial factor in terms of improving energy efficiency. This will, in turn, ensure the more efficient performance of the industry in general. Zhou and Zhang [43] stressed the positive correlation between shortening flight times and energy efficiency. Cui [44] attempted to identify ways in which to improve energy efficiency in the aviation industry and

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concluded that fuel consumption must be decreased to achieve this objective.

Priority should also be accorded to the use of renewable energy sources in the aviation sector, i.e. it is possible to enhance energy efficiency significantly via the use of energy generated via renewable alternatives. On the other hand, fossil fuels continue to be used in most airplanes today. Consequently, attention should be devoted to the research and development of airline fuel alternatives. The development of new technologies will eventually allow for airplanes to fly using clean energy alternatives. Furthermore, renewable energy alternatives should be used not only by airplanes but also for the provision of services at airports. This will, thus, contribute significantly to the minimization of the environmental pollution that is generated by the aviation industry.

The importance of the carbon emissions problem has been discussed extensively in the literature. Wang et al. [45] assessed the carbon emissions efficiency of the Chinese airline industry. They determined that technical efficiency is the most critical issue in terms of minimizing this problem. With the help of technological developments, airplanes will create lower amounts of carbon emissions. Liu et al. [46] also focused on civil aviation carbon emissions indicators via the evaluation of the performance of 15 international airlines in the period 2011–2017. They concluded that advanced technologies should be developed as soon as possible aimed at effectively addressing this issue.

The proposed model has also some superiorities in comparison with the previous ones in the literature. Ghenai et al. [47] examined the sustainability indicators of renewable energy systems. In this study, a new model has been created by classical SWARA methods. Similarly, Ijadi et al. [48] focused on the renewable energy technology selection problem by using this method. Heo et al. [49], Wang et al. [50] and Lee et al. [51] generated decision-making models by considering analytical hierarchy process methodology to evaluate energy investments. The main drawback of these models is that the causal relationship between the criteria cannot be identified. However, in this proposed model, classical SWARA methodology is improve and a new technique is created by the name of M-SWARA. Thus, it can become possible to understand the casual directions among the items. This situation provides a significant superiority for this proposed model.

The main novelty of this study comprises the identification of specific strategies for green flight activities in the sustainable aviation industry via the application of an original decision-making model. However, the main limitation of this study lies in focusing solely on the aviation industry. Sustainability is a crucial factor that is faced by many other industries, and we recommend that further detailed assessments should be conducted for other sectors, such as banking and the automotive industries. In these evaluations, the criteria set proposed in this study can be taken into consideration. In addition, other models such as Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR) and the technique for order preference by similarity to the ideal solution (TOPSIS) should be considered in terms of conducting parallel comparative examinations. This situation provides an opportunity to test the validity of this proposed model. Additionally, different fuzzy sets can also be used. For instance, quantum fuzzy logic can be integrated into the decision-making methods to cope with the uncertainty problem in a more successful manner.

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Appendix

TABLE A1. Scales and degrees

Oral Scales		Positive Degrees (PSV)		Negative Degrees (NSV)	
for Criteria	for Activities	DGM	DGN	DGM	DGN
no (n)	lowest (w)	.40	.25	-.60	-.37
some (s)	low (p)	.45	.28	-.55	-.34
normal (m)	normal (f)	.50	.31	-.50	-.31
high (h)	important (g)	.55	.34	-.45	-.28
very high (vh)	perfect (b)	.60	.37	-.40	-.25

TABLE A2. Evaluations of the Experts

Decision Maker 1								
	RHL		MGW		CWE		PFF	
	PSV	NSV	PSV	NSV	PSV	NSV	PSV	NSV
RHL			N	H	M	M	M	M
MGW	VH	M			H	VH	M	N
CWE	M	H	H	S			H	S
PFF	N	N	VH	M	VH	M		
Decision Maker 2								
	RHL		MGW		CWE		PFF	
	PSV	NSV	PSV	NSV	PSV	NSV	PSV	NSV
RHL			M	H	H	M	H	N
MGW	VH	M			VH	VH	H	N
CWE	M	H	H	N			VH	S
PFF	M	N	VH	N	VH	M		
Decision Maker 3								
	RHL		MGW		CWE		PFF	
	PSV	NSV	PSV	NSV	PSV	NSV	PSV	NSV
RHL			S	VH	M	M	M	M
MGW	VH	M			H	VH	S	N
CWE	M	VH	S	S			H	S
PFF	S	N	VH	M	VH	M		

TABLE A3. Average values of the degrees for the criteria

	RHL				MGW				CWE				PFF			
	PSV		NSV		PSV		NSV		PSV		NSV		PSV		NSV	
	μ	N	μ	n	μ	n	μ	n	μ	n	μ	n	μ	n	μ	n
RHL					.45	.28	-.43	-.27	.52	.32	-.50	-.31	.52	.32	-.53	-.33
MGW	.60	.37	-.50	-.31					.57	.35	-.40	-.25	.50	.31	-.60	-.37
CWE	.50	.31	-.43	-.27	.52	.32	-.57	-.35					.57	.35	-.55	-.34
PFF	.45	.28	-.60	-.37	.60	.37	-.53	-.33	.60	.37	-.50	-.31				

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TABLE A4. Sj, kj, qj, and wj values

RHL	Sj	kj	qj	wj	MGW	Sj	kj	qj	Wj
PFF	.221	1.000	1.000	.389	RHL	.260	1.000	1.000	.406
CWE	.201	1.201	.833	.324	PFF	.260	1.260	.793	.322
MGW	.132	1.132	.736	.286	CWE	.188	1.188	.668	.271
CWE	**Sj**	**kj**	**qj**	**wj**	**PFF**	**Sj**	**kj**	**qj**	**Wj**
PFF	.266	1.000	1.000	.400	MGW	.281	1.000	1.000	.411
MGW	.244	1.244	.804	.322	CWE	.260	1.260	.793	.326
RHL	.158	1.158	.694	.278	RHL	.235	1.235	.643	.264

TABLE A5. Expert evaluations of the decision makers for the positive and negative degrees of activities

Decision Maker 1								
	RHL		**MGW**		**CWE**		**PFF**	
	PSV	**NSV**	**PSV**	**NSV**	**PSV**	**NSV**	**PSV**	**NSV**
PRT	G	P	G	F	F	P	B	F
DRE	P	F	F	P	B	F	P	B
CSI	F	P	B	G	G	F	G	G
ECY	B	F	P	P	G	F	B	W
AAL	F	W	B	F	B	G	P	G
PVL	B	W	P	F	P	F	G	G
MIE	G	P	B	F	P	W	G	F
Decision Maker 2								
	RHL		**MGW**		**CWE**		**PFF**	
	PSV	**NSV**	**PSV**	**NSV**	**PSV**	**NSV**	**PSV**	**NSV**
PRT	G	G	G	F	G	P	G	F
DRE	P	F	F	P	G	F	P	G
CSI	G	P	B	G	G	F	G	G
ECY	B	F	G	P	G	F	B	W
AAL	G	W	B	F	G	G	G	G
PVL	B	W	P	G	P	F	G	G
MIE	G	G	G	G	P	G	G	G
Decision Maker 3								
	RHL		**MGW**		**CWE**		**PFF**	
	PSV	**NSV**	**PSV**	**NSV**	**PSV**	**NSV**	**PSV**	**NSV**
PRT	F	G	F	F	F	P	B	G
DRE	F	G	P	P	B	F	F	B
CSI	F	W	B	G	P	W	G	G
ECY	B	F	P	P	G	F	B	W
AAL	F	W	F	W	B	G	F	G
PVL	F	W	P	F	F	F	F	W
MIE	F	P	F	F	F	W	G	F

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TABLE A6. Average values of the positive and negative membership and non-membership degrees for the activities

	RHL				MGW				CWE				PFF			
	PSV		NSV		PSV		NSV		PSV		NSV		PSV		NSV	
	μ	n	μ	n	μ	n	μ	n	μ	n	μ	n	μ	n	μ	n
PRT	.53	.33	-.48	-.30	.53	.33	-.50	-.31	.52	.32	-.55	-.34	.58	.36	-.48	-.30
DRE	.47	.29	-.48	-.30	.48	.30	-.55	-.34	.58	.36	-.50	-.31	.47	.29	-.42	-.26
CSI	.52	.32	-.57	-.35	.60	.37	-.45	-.28	.52	.32	-.53	-.33	.55	.34	-.45	-.28
ECY	.60	.37	-.50	-.31	.48	.30	-.55	-.34	.55	.34	-.50	-.31	.60	.37	-.60	-.37
AAL	.52	.32	-.60	-.37	.57	.35	-.53	-.33	.58	.36	-.45	-.28	.50	.31	-.45	-.28
PVL	.57	.35	-.60	-.37	.45	.28	-.48	-.30	.47	.29	-.50	-.31	.53	.33	-.50	-.31
MIE	.53	.33	-.52	-.32	.55	.34	-.48	-.30	.47	.29	-.55	-.34	.55	.34	-.48	-.30

TABLE A7. C and D matrices

	C							D						
	PRT	DRE	CSI	ECY	AAL	PVL	MIE	PRT	DRE	CSI	ECY	AAL	PVL	MIE
PRT	.000	.510	.505	.235	.505	.760	.505	.000	.123	.830	1.000	.759	1.000	.630
DRE	.490	.000	.235	.490	.235	.490	.490	1.000	.000	1.000	1.000	1.000	1.000	1.000
CSI	.495	.765	.000	.255	.505	.490	.730	1.000	.348	.000	1.000	.666	.635	.810
ECY	.765	.765	.745	.000	.505	.760	1.000	.094	.109	.154	.000	.243	.297	.000
AAL	.495	.765	.495	.495	.000	.490	.730	1.000	.263	1.000	1.000	.000	.484	1.000
PVL	.240	.510	.510	.240	.510	.000	.240	.650	.572	1.000	1.000	1.000	.000	.829
MIE	.495	.510	.270	.000	.270	.760	.000	1.000	.462	1.000	1.000	.831	1.000	.000

TABLE A8. E, F and G matrices

	E							F							G						
	PRT	DRE	CSI	ECY	AAL	PVL	MIE	PRT	DRE	CSI	ECY	AAL	PVL	MIE	PRT	DRE	CSI	ECY	AAL	PVL	MIE
PRT	0	1	0	0	0	1	0	1	1	0	0	0	0	1	0	1	0	0	0	0	0
DRE	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
CSI	0	1	0	0	0	0	1	0	1	1	0	1	1	0	0	1	0	0	0	0	0
ECY	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
AAL	0	1	0	0	0	0	1	0	1	0	0	1	1	0	0	1	0	0	0	0	0
PVL	0	1	1	0	1	0	0	1	1	0	0	0	1	0	0	1	0	0	0	0	0
MIE	0	1	0	0	0	1	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0

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