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Sustainability in the Skies: A Tri-Dimensional Performance Evaluation of Global Airlines with Hybrid MCDM Methods

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Gökyüzünde Sürdürülebilirlik: Küresel Hava Yolu İşletmelerinin Melez ÇKKV Yöntemleriyle Üç Boyutlu Performans Değerlendirmesi

Abstract

This study proposes a hybrid multi-criteria decision-making (MCDM) framework that combines entropy and TOPSIS to evaluate the corporate sustainability performance of ten global airlines, utilising 22 GRI-based economic, environmental, and social criteria. Using 2020 data, the analysis identifies China Southern, China Eastern, and American Airlines as top performers, while Qatar Airways ranks lowest due to weak social indicators. Key drivers include available seat kilometres, cargo volume, and water use, while gender metrics and fleet age contribute less. The findings provide data-driven insights for sustainable aviation strategies, bridging theoretical and empirical approaches in the sustainability performance literature.

Keywords : Sustainability, Corporate Sustainability, Corporate Sustainability Performance, Airlines, Logistics, MCDM, Entropy, TOPSIS.

JEL Classification Codes : L93, Q56, C44, M14.

Öz

Bu çalışma, ekonomik, çevresel ve sosyal 22 GRI tabanlı kriter üzerinden küresel hava yolu işletmelerinin kurumsal sürdürülebilirlik performansını değerlendirmek amacıyla entropi ve TOPSIS yöntemlerini birleştiren melez birçok kriterli karar verme (ÇKKV) çerçevesi sunmaktadır. 2020 verilerine dayalı analizde, China Southern, China Eastern ve American Airlines en yüksek performansı gösterirken, sosyal göstergelerdeki zayıflıklar nedeniyle Qatar Airways en düşük sırada yer almıştır. Öne çıkan belirleyici unsurlar koltuk-kilometre kapasitesi, taşınan kargo hacmi ve su tüketimidir. Bulgular, sürdürülebilir havacılık stratejileri geliştirmek isteyen politika yapıcılar ve sektör paydaşları için veri temelli yol gösterici bilgiler sunmaktadır.

Anahtar Sözcükler : Sürdürülebilirlik, Kurumsal Sürdürülebilirlik, Kurumsal Sürdürülebilirlik Performansı, Hava Yolları, Lojistik, ÇKKV, Entropi, TOPSIS.

1. Introduction

Civil aviation serves as a cornerstone of the global economy, driving cross-border trade, tourism, and business collaboration while fostering interconnectedness among nations. Its role extends beyond facilitating the movement of people and goods; it underpins economic growth by enabling international commerce, labour mobility, and cultural exchange. In 2024, the aviation industry supported 65.5 million jobs, generated $2.7 trillion in economic activity, and accounted for 35% of global trade by value (The Air Transport Action Group, 2024; Kiracı & Bakır, 2019). This industry's contributions to tourism are equally profound, as air travel stimulates destination economies through tourist expenditures, hotel stays, and local businesses "tap into diverse talent pools and optimise productivity, thereby catalysing economic growth.

However, the industry's environmental footprint presents a pressing challenge. Aviation contributes approximately 2% of anthropogenic CO_2 emissions (The Air Transport Action Group, 2024), with non-CO_2 effects elevating its total impact on global warming to 3.5% (Zieba & Johansson, 2022). These emissions exacerbate climate change, disrupt ecosystems, and degrade air quality, underscoring the urgent need to adopt sustainable practices. Strategies such as fuel-efficient technologies, emission-reduction protocols, and waste-management innovations are critical to reconciling aviation's economic benefits with ecological stewardship (Yılmaz & Atmanlı, 2016; Akdemir, 2020). Achieving this balance is vital not only for mitigating environmental harm but also for securing societal acceptance and long-term industry viability. In addition to reducing environmental damage, ensuring social acceptance and securing the long-term sustainability of industry necessitate measuring holistic sustainability performance in the skies. In this context, this study comprehensively analyses the corporate sustainability performance of ten global airlines using an integrated assessment framework based on a total of twenty-two criteria, comprising economic (8), social (7), and environmental (7) aspects. The primary purpose of this study is to evaluate the sustainability performance of these airline businesses, both objectively and systematically, using multi-criteria decision-making (MCDM) methods. In this context, the airlines' performances are comparatively presented using the Entropy method, which provides objective weighting, and the TOPSIS method, which focuses on ranking. This methodological approach aims to enhance the measurability of sustainability strategies and to inform decision-makers in policy development processes.

Utilising the Entropy-TOPSIS methodology, the research employs the entropy method to assign criterion weights and the TOPSIS technique to rank airlines. The entropy method objectively weights sustainability criteria by analysing data dispersion, minimising subjective bias. The subsequent TOPSIS ranking compares airlines to ideal solutions, prioritising those closest to optimal performance across all dimensions. This dual-method approach ensures robust, data-driven insights, enabling stakeholders to identify best practices and allocate resources effectively. A literature review contextualises the concepts and applications of sustainability and multicriteria decision-making in aviation. By bridging theoretical frameworks with empirical analysis, this study advances understanding of

aviation sustainability and offers actionable pathways for industry leaders to align operational strategies with global sustainability imperatives. The findings aim to guide industry stakeholders in refining sustainability strategies, aligning operational practices with global standards, and enhancing transparency in reporting.

2. Literature

2.1. Corporate Sustainability Performance

Corporate sustainability performance (CSP) refers to a business's ability to operationalise sustainable development principles by balancing economic viability, social equity, and environmental stewardship. Rooted in the Triple Bottom Line (TBL) framework (Elkington, 2000), CSP emphasises that businesses must transcend profit-centric models to address their impacts on people and the planet. This holistic approach integrates long-term value creation with ethical governance, resource efficiency, and stakeholder engagement (Dyllick & Hockerts, 2002; Montiel, 2008). Scholars define Corporate Social Responsibility (CSR) as the measurable outcomes of a business's strategies to mitigate negative externalities, enhance societal well-being, and maintain ecological integrity while ensuring economic resilience (Hahn et al., 2018). It extends beyond regulatory compliance to encompass initiative-taking such as reducing carbon footprints, fostering inclusive labour practices, and optimising resource efficiency (Eccles & Krzus, 2010; Linnenluecke & Griffiths, 2013).

The Environmental, Social, and Governance (ESG) criteria complement the TBL framework by providing standardised metrics to evaluate ethical practices, climate resilience, and social responsibility (Friede et al., 2015; Khan et al., 2016). While TBL guides the strategic integration of sustainability, ESG enables quantifiable benchmarking, together offering a holistic view of corporate responsibility (Eccles & Krzus, 2010). For instance, in the aviation industry, CSP entails optimising fuel efficiency, reducing emissions, engaging communities, and ensuring equitable labour practices, all while maintaining profitability (Karaman et al., 2018; Tsai et al., 2020). By aligning with global frameworks such as the Sustainable Development Goals (SDGs), businesses can systematically track and communicate their Corporate Social Responsibility (CSR) progress, thereby fostering accountability and stakeholder trust (Bansal & Song, 2017; Roszkowska-Menkes et al., 2024).

CSP, viewed as a strategic imperative, enables businesses to mitigate risks, enhance brand reputation, and secure competitive advantages in sustainability-conscious markets (Porter & Kramer, 2006; Schaltegger & Burritt, 2018). This multidimensional perspective highlights CSP as a dynamic, context-dependent construct that bridges corporate strategy with sustainable development imperatives, ensuring organisational resilience in the face of ecological and socio-economic uncertainties.

The theoretical basis of this study is grounded in the potential of Elkington's Triple Bottom Line (TBL) approach and multi-criteria decision-making (MCDM) methods to

provide a holistic analysis for evaluating sustainability performance. The TBL approach suggests that corporate success should be evaluated not only in terms of economic output but also in terms of sustainability dimensions, including social responsibility and environmental impact. In this context, CSP refers to the extent to which businesses simultaneously demonstrate environmental sensitivity, social inclusiveness, and economic durability. The framework in question has served as a fundamental guide in determining the criteria addressed in this study and in structuring the evaluation method. Determining the objective weights of the criteria using the Entropy method minimises the effect of subjective judgments in the evaluation process and provides an analytical basis for decision-making. Then, ranking airlines based on their proximity to the ideal solution using the TOPSIS method enables a comparative assessment of CSP levels. Thus, the combined use of the TBL approach and objective MCDM techniques provides theoretical and methodological integrity in industrial sustainability analyses.

2.2. Corporate Sustainability Performance Measurement in the Aviation Industry

Assessing CSP in the civil aviation industry poses a multifaceted challenge, requiring robust frameworks that reconcile economic, social, and environmental dimensions. While MCDM models have gained prominence in evaluating CSP, existing literature often prioritises defining industry-specific criteria over advancing mathematical methodologies, despite the critical role of quantitative analysis in driving global sustainability progress (Searcy, 2012). Scholars have proposed diverse indicators and indices, such as the Dow Jones Sustainability Index (DJSI) and Global Reporting Initiative (GRI) standards, to benchmark performance. However, the heterogeneity of criteria across studies underscores the need for standardised, transparent measurement systems to enhance comparability and credibility.

2.3. Country-Specific Analyses

The regional and national contexts influence the selection of corporate sustainability performance (CSP) metrics, as presented in Table 1 in chronological order. For Chinese airlines, criteria such as return on equity (ROE), accident rates, environmental investments, and fleet composition have been evaluated using entropy and grey relational analysis (Wang et al., 2014). Similarly, fuel consumption, CO_2 emissions, fleet age, and ownership status are applied to assess 13 Chinese carriers through network data envelopment analysis (DEA) (Hadi-Vencheh et al., 2018). Chen et al. (2021) extend this approach by incorporating a slack-based network DEA to account for operational and environmental factors, such as kerosene consumption, available seat kilometres (ASK), and revenue ton-kilometres (RTK). In India, technical efficiency studies focus on operational costs, non-passenger revenue, and ASK (Jain & Natarajan, 2015), while Iranian airline evaluations emphasise fleet size, RTK, and carbon emissions using TOPSIS and fuzzy network models (Omrani et al., 2022; Heydari et al., 2020). In addition, Kılıç and Şimşek (2023) apply the fuzzy analytic hierarchy process (AHP) and fuzzy TOPSIS to assess the ground operations of Turkish low-cost

carriers, integrating service-oriented criteria such as ticketing efficiency, counter service quality, and personnel responsiveness.

Table: 1
Chronological Literature Review on Country-Specific Corporate Sustainability Performance in Aviation

Study	Method	Criteria	Dimensions	Scope	Region / Country
Wang et al. (2014)	Entropy, Grey Relational Analysis	ROE, net profit growth, accident rate, on-time performance, tax performance, employee income growth, CSR	Economic and Social	Corporate sustainability	China (8 Airlines)
Jain & Natarajan (2015)	DEA	ASK, operational costs, total revenue, non-passenger revenue	Technical Efficiency	Efficiency evaluation	India (2006-2010)
Hadi-Vencheh et al. (2018)	MCDM	Fuel consumption, fleet size, CO_2 emissions, ownership status, M&A activity	Economic and Environmental	Sustainability assessment	China (13 Airlines)
Heydari et al. (2020)	Fully Fuzzy Network DEA-Range Adjusted Measure	Employees, ASK, ATK, scheduled flights, fleet size, passenger/ton kilometres performed.	Operational Efficiency	Sustainability performance	Iran (14 Airlines)
Chen et al. (2021)	Slacks-Based Measure Network DEA	Kerosene consumption, ASK, ATM, RPK, CO_2 emissions	Operational and Environmental	Operational, Environmental performance	China (9 Airlines)
Omrani et al. (2022)	TOPSIS	Fleet size, ASK, ATK, employees, CO_2 emissions, RTK	Economic and Environmental	Sustainability performance	Iran (16 Airlines)
Kılıç & Şimşek (2023)	Fuzzy AHP, Fuzzy TOPSIS	Ticketing, online services, counter services, flight schedule, service personnel	Social and Operational	Ground Operations Performance of 3 LCCs	Türkiye (3 Airlines)

2.4. Regional and Global Perspectives

Broader analyses extend these frameworks to regional and global contexts, as referred to in Table 2. In East Asia, eco-efficiency studies integrate CO_2 emissions, energy usage, and passenger data with principal component analysis (Elhmoud et al., 2021). For the Asia-Pacific region, the decision-making trial and evaluation laboratory (DEMATEL) methodologies incorporate governance, supply chain efficiency, environmental policies, and labour practices (Chang et al., 2015). Latin American studies prioritise fleet size and operational efficiency by dynamic data envelopment analysis (Wanke & Barros, 2016).

Table: 2
Chronological Literature Review on Regional and Global Corporate Sustainability Performance in Aviation

Study	Method	Criteria	Dimensions	Scope	Region / Country
Arjomandi & Seufert (2014)	Bootstrapped DEA	Workforce size, TKA, CO_2 emissions	Technical and Environmental	Technical and Environmental performance	Global (48 Airlines)
Chang et al. (2014)	DEA	ATK, RTK, employee count, profit, carbon emissions	Economic and Environmental	Economic and Environmental efficiency	Global (27 Airlines)
Chang et al. (2015)	DEMATEL	Corporate governance, risk management, and environmental policies, fleet efficiency, labour practices	Economic, Social, and Environmental	Sustainability assessment of Asia-Pacific airlines	Asia-Pacific
Wanke & Barros (2016)	Virtual Frontier Dynamic DEA & Simplex Regression	Number of flights, employees, and aircraft	Operational Efficiency	Sustainability performance	Latin America (19 Airlines)
Bakır et al. (2019)	Entropy, WASPAS	Passenger reviews (legroom, comfort, cleanliness, value for money)	Social	Service quality of European low-cost carriers (LCCs)	Europe (13 Airlines)
Kiracı & Bakır (2019)	CRITIC, EDAS	ASM, CASM, RASM, RPM	Financial and Operational	Ranking	Global [13 Airlines (2005-2012)]
Chowdhury & Paul (2020)	Systematic Literature Review	MCDM applications, enablers/barriers of sustainability	Economic, Social, and Environmental	Broad analysis across industries (including aviation)	Global
Elhmoud et al. (2021)	PCA	CO_2 emissions, electricity/fuel/water usage, waste generation, revenue, passengers, cargo	Eco-Efficiency	Eco-efficiency	East Asia (7 Airlines)
Asker (2021)	Two-Stage DEA	ASK, employees, aircraft, RPK, load factor, net profit/net sales	Economic Efficiency	Efficiency evaluation	Global (36 Airlines)
Alkhatib & Migdadi (2021)	DEMATEL, AHP, TOPSIS	Greenhouse gas emissions, fuel efficiency, noise pollution, and water usage	Environmental	Sustainability ranking	Global (20 Airlines)
Sarkis & Zhu (2021)	Fuzzy TOPSIS	Fuel efficiency, waste management, labour rights, and community engagement	Economic, Social, and Environmental	Sustainability trade-offs in global low-cost carriers	Global
Kyriakou & Psarropoulos (2023)	AHP, WSM, TOPSIS	Technological performance, environmental impact, costs, circularity	Environmental and Economic	Sustainability assessment of 4 passenger aircraft with different fuels	Global
Current Study (2025)	Entropy + TOPSIS	22 criteria: Economic (8), Social (7), Environmental (7)	Economic, Social, and Environmental	Sustainability ranking	Global (10 Airlines)

On a global scale, Arjomandi and Seufert (2014) employ bootstrapped DEA to evaluate 48 international airlines based on workforce size, ton-kilometres available (TKA), and emissions. Chang et al. (2014) and Asker (2021) assess economic-environmental efficiencies using variables such as ASK, RTK, profit margins, and CO_2 emissions. Kiracı and Bakır (2019) utilise the criteria importance through intercriteria correlation (CRITIC) and evaluation based on distance from the average solution (EDAS) methods to rank airlines across continents based on financial and operational metrics, such as available seat miles (ASM) and revenue per available seat mile (RASM). Alkhatib and Migdadi (2021) advanced global assessments by combining DEMATEL, AHP, and TOPSIS to evaluate the green operations of 20 airlines, focusing on greenhouse gas emissions, fuel efficiency, and environmental compliance.

Chowdhury and Paul (2020) contribute a systematic literature review that maps MCDM applications across various industries, including aviation, to address sustainability enablers and barriers. Bakır et al. (2019) assess the service quality of European low-cost carriers using the entropy and weighted aggregated sum product assessment (WASPAS) methods, with an emphasis on customer-centric criteria such as seat comfort, cleanliness, and staff service. Lastly, Kyriakou and Psarropoulos (2023) evaluate the sustainability of four aircraft types using the AHP and TOPSIS methods, with an emphasis on technological performance, circularity, and environmental impact.

2.5. Research Gaps and Methodological Advancements

Despite this proliferation of studies, a critical gap persists: no prior research holistically integrates economic, social, and environmental dimensions using combined weighting and ranking methodologies. Existing approaches often isolate specific criteria or regions, which limits cross-industry comparability. To address this, the present study employs the Entropy method, a data-driven weighting technique that minimises subjectivity, to assign criterion weights. This is followed by the TOPSIS method, which ranks airlines based on their proximity to ideal sustainability performance. This dual-method framework not only enhances methodological rigour but also provides actionable insights to help stakeholders prioritise sustainability initiatives, align with global standards, and foster industry-wide accountability.

By synthesising fragmented criteria and advancing an integrated evaluation model, this research contributes to bridging the gap between theoretical frameworks and practical implementation, offering methodological transparency, minimising subjective bias, and enhancing the interpretability of results for policymakers, regulators, and industry stakeholders aiming to create a scalable tool for the aviation industry's transition toward sustainable development.

3. Methodology

The mathematical notation for the entropy and TOPSIS methods used in the study is outlined in this section.

3.1. Entropy Method

Entropy, initially defined as a measure of system disorder and uncertainty (Heng et al., 2023), has emerged as a cornerstone of information-entropy weighting methodologies. Rooted in Shannon's (1948) pioneering work on information theory, this approach quantifies the relative informational utility of empirical data by assessing the dispersion and variability within decision matrices (Gazel et al., 2021; Wu et al., 2011). By deriving weights directly from dataset variability, entropy-based methods minimise subjective biases inherent in expert-driven weighting approaches, offering a robust framework for MCDA (Karakaş et al., 2016; Pekkaya & Dökmen, 2019). The Shannon entropy method, operationalised through a structured computational process (Aytekin & Karamaşa, 2017; Gazel et al., 2021), involves the following systematic steps:

Step 1. The decision matrix is formed as follows:

$$X = \begin{matrix} \\ A_1 \\ A_2 \\ \vdots \\ Ai \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} X_1 & X_2 & \cdots & X_j & \cdots & X_n \\ x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2n} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix}_{mxn} \quad \text{Equation (1)}$$

where x_{ij} denotes the success value of i^{th} alternative per the criterion j^{th} in the matrix being $i = 1, 2, 3 \ldots . m$ and $j = 1, 2, 3 \ldots . n$ while m is the number of alternatives and n is the number of criteria.

Step 2. A normalisation process is required to evaluate the criteria, as they have different scales (Aytekin & Karamaşa, 2017). Equation (2) used for the normalisation process is as follows:

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad \text{Equation (2)}$$

Step 3. Entropy (e_j) values are calculated in accordance with Equation (3) where the k value expresses the entropy constant and is calculated with the formula of $k = \frac{1}{ln(m)}$ (Bahadır & Türkmençalıkoğlu, 2021):

$$e_j = -k \sum_{i=1}^{m} r_{ij} \, ln \, r_{ij} \quad \text{Equation (3)}$$

Step 4. The degree of differentiation (d_j) is calculated (Aytekin & Karamaşa, 2017) through Equation (4):

$$\mathrm{d}_j = 1 - e_j \qquad \text{Equation (4)}$$

Step 5. Weighs (w_j) for the importance level of each criterion is computed with Equation (5) (Aytekin & Karamaşa, 2017):

$$w_j = \frac{\mathrm{d}_j}{\sum_{j=1}^{m} \mathrm{d}_j} \qquad \text{Equation (5)}$$

3.2. TOPSIS Method

Developed by Hwang & Yoon (1981), the TOPSIS method is a multi-criteria decision-making approach that ranks alternatives based on their proximity to an ideal solution, effectively incorporating both quantitative and qualitative criteria (Madanchian & Taherdoost, 2023). The method aims to determine the distance of each alternative from the ideal and negative ideal solutions, with the ideal solution defined by the best available values and the negative ideal by the worst available values (Hwang & Yoon, 1981). In this process, criteria are evaluated according to whether they represent a benefit or a cost; for a benefit criterion, the ideal is characterised by the maximum value, whereas for a cost criterion, it is represented by the minimum value. Conversely, the negative ideal solution is defined using the reverse approach. The applicability of the TOPSIS method is well supported by an extensive body of expert literature (Behzadian et al., 2012), which outlines the following steps.

Step 1. The decision matrix is formed to capture the alternatives across criteria (Hwang & Yoon, 1981) as follows:

$$X = \begin{matrix} \\ A_1 \\ A_2 \\ \vdots \\ Ai \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} X_1 & X_2 & \cdots & X_j & \cdots & X_n \\ x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2n} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix}_{mxn} \qquad \text{Equation (6)}$$

where x_{ij} denotes the success value of i^{th} alternative per the criterion j^{th} in the matrix being $i = 1, 2, 3 \ldots . m$ (number of alternatives) and $j = 1, 2, 3 \ldots . n$ (number of criteria).

Step 2. A normalisation process using the Euclidean norm is required to ensure comparability across criteria, as emphasised by Yoon & Hwang (1995), who stress the importance of scaling values to a uniform range. Thus, the normalised decision matrix is created using Equation (7) for the normalisation process, as indicated below.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}}$$ Equation (7)

Step 3. The weighted normalised decision matrix is created with the use of Equation 8, presented as follows:

$$v_{ij} = w_j \times r_{ij}$$ Equation (8)

Step 4. The distances of the alternatives to the ideal (A^+) and negative ideal (A^-) solutions (as defined as "best conceivable" and "worst conceivable" outcomes by Hwang & Yoon (1981)) are calculated using Equations (10) and (11) presented below:

$$A^+ = \{\max(v_{ij}) \, for \; benefit \; criteria; \min(v_{ij}) \, for \; cost \; criteria\}$$ Equation (9)

$$A^- = \{\min(v_{ij}) \, for \; benefit \; criteria; \max(v_{ij}) \, for \; cost \; criteria\}$$ Equation (10)

Step 5. The ideal (A^+) and negative ideal (A^-) separation measures are calculated with Equation (11) and Equation (12):

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2}$$ Equation (11)

$$S_{\bar{i}} = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}$$ Equation (12)

Step 6. The relative closeness value of the alternatives is computed, and the alternatives are ranked as in Equation (13), as validated by Chen (2000) for robustness in ranking:

$$C_i^+ = \frac{S_i^-}{S_i^+ + S_i^-}, 0 < C_i^+ < 1$$ Equation (13)

3.3. Case Study

Building on a systematic review of the existing literature, industry reports from leading airlines, and insights from an aviation sustainability consultancy, this study integrates a rigorous methodological framework to define corporate sustainability performance criteria within the civil aviation industry. Through a collaborative expert consensus process involving scholars and practitioners specialising in air transportation sustainability, twenty-two criteria are systematically identified and categorised into the tripartite pillars of sustainability: economic (8), social (7), and environmental (7) criteria (see Table 3). These criteria are subsequently applied to evaluate and rank ten globally recognized airlines -selected for their extensive international operations, market prominence, and high-revenue performance- including Turkish Airlines (ALT1), Lufthansa (ALT2), Qatar Airways (ALT3), American Airlines (ALT4), Delta Air Lines (ALT5), Southwest Airlines (ALT6), China Eastern Airlines (ALT7), British Airways (ALT8), Emirates (ALT9), and China Southern Airlines (ALT10).

Table: 3
Main and Sub-Criteria of Evaluation for Corporate Sustainability Performance

Economic Criteria	Social Criteria	Environmental Criteria
Number of countries flown to (EC1)	Total number of employees (SC1)	Annual electricity consumption amount (Million kWh) (ENC1)
Number of aircraft (EC2)	Total number of female employees (SC2)	Annual natural gas consumption (Million m^3) (ENC2)
Number of passengers carried (Million) (EC3)	Female employee rate (%) (SC3)	Amount of water consumed annually (Tons) (ENC3)
Amount of cargo transported (Tons) (EC4)	Labor turnover rate (%) (SC4)	Annual ton fuel savings (Tons) (ENC4)
Average fleet age (EC5)	Training/hour value per employee (SC5)	Tons of CO_2 released annually (Tons) (ENC5)
Net profit ($ Million) (EC6)	The rate of female managers in the manager profile (%) (SC6)	Avoided CO_2 (Tons) (ENC6)
Revenue ($ Million) (EC7)	Number of new employees (SC7)	Annual fuel usage (Tons) (ENC7)
Available seat kilometres (ASK) (EC8)		

Having provided the basic information on the criteria used, the airlines included, and the steps to be followed for each MCDM method, the following sections begin by weighing the criteria using the entropy method and proceed to rank the airlines using the TOPSIS method to evaluate their corporate sustainability performance.

3.3.1. Descriptive Statistics of Criteria

The descriptive statistics of the criteria used in the study are analysed, and, in this regard, the distribution of each criterion is assessed in terms of the minimum, maximum, mean, and standard deviation. The degree of variability of the criteria serves as the foundation for the weighting process, which is conducted using the Entropy method. This method objectively quantifies the information conveyed by the criteria using these distributional characteristics, assigning greater weight to criteria with higher variability. Consequently, the criteria are categorised into three groups: high, medium, and low weight potential, based on their descriptive statistics. The descriptive statistics of the criteria are presented in Table 4.

Table: 4
Descriptive Statistics for Criteria

Criteria Code	Min	Max	Average	Standard Deviation	Variance
EC1	35	170	98	48	2.292
EC2	250	1.399	632	364	132.654
EC3	6	138	56	44	1.948
EC4	246.310	1.383.000.000	164.249.662	431.746.061	186.404.661.230.505.000
EC5	7	15	10	3	9
EC6	-12.385	-836	-5.036	3.677	13.522.174
EC7	2.152	17.337	10.462	5.099	25.996.893
EC8	214.722	152.070.000.000	15.283.254.772	48.061.977.964	2.309.953.725.795.310.000.000
SC1	28.688	125.207	67.580	33.676	1.134.063.764
SC2	13.128	47.744	28.663	13.594	184.789.016
SC3	37	58	44	6	42
SC4	2	24	6	6	40
SC5	18	134	38	34	1.180
SC6	12	43	28	10	107
SC7	534	21.716	4.333	6.302	39.720.795
ENC1	15.832	152.380	60.776	46.248	2.138.861.354
ENC2	1.410.000	9.500.000	4.321.264	2.277.752	5.188.155.863.629
ENC3	36.501	5.260.000	884.858	1.621.820	2.630.299.305.451
ENC4	11.300	600.000	138.184	208.723	43.565.214.993
ENC5	7.250.236	41.969.334	16.958.764	10.730.377	115.140.988.090.828
ENC6	26.800	2.000.000	436.717	674.502	454.952.521.552
ENC7	1.273.000	7.845.300	4.237.896	2.178.265	4.744.836.539.498

Criteria with High Weight Potential: The criteria in this group exhibit wide value ranges and high standard deviations, resulting in significant information diversity within the dataset. Therefore, the Entropy method assigned high weights to these criteria. High variance indicates that these criteria provide more decisive contributions to the decision-making process.

- EC4 - Cargo Amount Carried (Ton): Transportation capacity varies greatly depending on the fields of activity of airline businesses. Since some businesses focus on cargo while others focus on passenger transportation, the variance of this criterion is relatively high.
- EC8 - Available Seat-Kilometre (ASK): Differences in fleet size and flight distance between businesses cause significant changes in this capacity indicator. Since the ASK value is much higher in businesses with long-range and high-frequency flights, the variance increases.
- ENC5 - Annual CO_2 Emission (Tons): There are significant differences between airline businesses' activity volumes, fleet efficiency, and operational intensity. This causes some businesses to produce much higher levels of emissions and creates a wide range of CO_2 emissions.
- ENC2 - Annual Natural Gas Consumption (Million m^3): There are significant differences in natural gas consumption among businesses depending on heating, air conditioning, and energy needs. While some businesses do not utilise this resource at all, others consume large amounts; this is the primary factor that increases the variance.
- ENC7 - Annual Fuel Consumption (Tons): The fuel consumption of different aircraft types, fleet age, and operational efficiency levels has a direct impact. Businesses with long-haul operations and large fleets have significantly higher fuel consumption, which substantially increases the criterion's variance.

Criteria with Low Weight Potential: The value ranges for these criteria are narrow, and their standard deviations are low. The entropy method yields low weights because it assesses the information content of these criteria in a limited manner. These criteria play a less decisive role in explaining the decision-making process in the dataset.

- EC5 - Average Fleet Age: The average fleet age of airline businesses typically falls within a similar range. The similarity in aircraft purchasing policies and the fact that the industry is subject to similar regulations have kept the variance of this criterion low.
- SC6 - Number of Newly Hired Employees: Human resources mobility does not show significant differences between airlines. Growth strategies at similar scales and limited employment trends in the post-COVID-19 period have led to this criterion carrying limited information with low variance.
- SC3 - Female Employee Rate: Female employment rates are comparable in most businesses. Since policies regarding gender representation have developed at a

similar level, the variance of this criterion has remained low, and its contribution to the decision-making process has been limited.

3.3.2. Weighing Criteria with the Entropy Method

Criterion weighting is integral to multi-criteria decision analysis, as weights directly determine the relative influence of each metric on the evaluation outcomes. In this study, the 22 sustainability criteria, stratified into economic (8), environmental (7), and social (7) dimensions, are weighed using the entropy method, as explained in the subsection 'Entropy Method'. Data for the year 2020, sourced from authoritative and publicly accessible records (e.g., audited annual reports, regulatory filings, and corporate sustainability disclosures), are processed algorithmically in MS Excel 2023 to derive objective weights before applying the TOPSIS framework.

The criteria are classified into two distinct groups to align with their inherent objectives:

- Maximisation criteria (EC1, EC2, EC3, EC4, EC6, EC7, EC8, SC2, SC3, SC5, SC6, ENC4, ENC6), which reflect positive sustainability outcomes (e.g., efficiency gains, social equity).
- Minimisation criteria (EC5, SC1, SC4, SC7, ENC1, ENC2, ENC3, ENC5, ENC7), which correspond to adverse impacts (e.g., emissions, operational risks).

The decision matrix, provided in Appendix 1, is normalised using the entropy method and presented in Appendix 2. The entropy method assigns criterion weights based on the information each criterion contributes to the decision-making process, prioritising those with greater variability in their data distributions. In this framework, the initial step is to normalise criterion values to eliminate scale discrepancies. For instance, Turkish Airlines emerges as the most advantageous option in terms of Aircraft Flown and Female Employee Ratio (%). At the same time, Lufthansa outperforms in Annual Electricity Consumption (kWh) and Annual Fuel Usage (tons).

The entropy values computed for each criterion are detailed in Appendix 3. A critical consideration when interpreting these values is the inherent variability among criterion data points. Low variability (e.g., Available Seat Kilometres and Annual Natural Gas Consumption) corresponds to reduced informational utility, resulting in lower weights. Conversely, high variability (e.g., Cargo Volume Transported (tons), Net Profit (USD), and Female Employee Ratio (%)) indicates greater informational significance and warrants higher weights. For example, the pronounced variability in Cargo Volume Transported and Net Profit underscores their pivotal role in differentiating airline performance. In contrast, minimal variability in Available Seat Kilometres reflects its limited discriminative power in the evaluation.

This variation-based weighting mechanism ensures that criteria that provide more information for the decision-making process are weighted proportionally more heavily,

thereby shaping results consistent with the empirical data structure. Although negative values are present in the net profit criterion, the column-based proportional normalisation approach yields normalised values that are transformed into positive values, with the Entropy method being consistently applied. The Entropy weights, which represent the information contribution of each criterion, are presented in Table 5.

Table: 5
Criteria for Evaluating Corporate Sustainability Performance with Entropy Values

#	Main Criteria	Sub Criteria	E_j	Wj (Entropy Values)
1	Economic	Number of Countries Flown to	0,951545302	0,011595323
2	Economic	Number of Aircraft	0,937271916	0,015010978
3	Economic	Number of Passengers Carried (Million)	0,871835947	0,030669958
4	Economic	Amount of Cargo Transported (Tons)	0,256987109	0,177804726
5	Economic	Average Fleet Age	0,983304971	0,003995159
6	Economic	Net Profit ($ Million)	0,896680401	0,024724622
7	Economic	Revenue ($ Million)	0,949724615	0,012031017
8	Economic	Available Seat Kilometres	0,018085279	0,234974493
9	Social	Total Number of Employees	0,951446591	0,011618945
10	Social	Total Number of Female Employees	0,954781571	0,010820876
11	Social	Female Employee Rate (%)	0,995860404	0,000990615
12	Social	Labour Turnover Rate (%)	0,874111776	0,030125347
13	Social	Training per Personnel/hour value	0,892616923	0,025697022
14	Social	Ratio of Female Managers in Manager Profile (%)	0,971322546	0,006862582
15	Social	Newly Hired Personnel	0,731273031	0,064306993
16	Environmental	Annual Electricity Consumption (Million kWh)	0,898196065	0,02436192
17	Environmental	Annual Natural Gas Consumption Amount (Million m^3)	0,949540392	0,012075102
18	Environmental	Annual Amount of Water Consumed (Tons)	0,572718276	0,102249518
19	Environmental	Annual Ton Fuel Savings (Tons)	0,648345304	0,084151793
20	Environmental	Tons of CO2 Released Annually (Tons)	0,933730539	0,015858437
21	Environmental	Prevented Carbon Dioxide (CO2) (Tons)	0,633113027	0,087796912
22	Environmental	Annual Fuel Usage (Tons)	0,948693936	0,012277661

The entropy-derived weighting results establish a quantitative hierarchy among the twenty sustainability criteria. At the aggregate level, available seat kilometres (ASK) emerges as the highest-weighted criterion, followed by freight volume (tonnage) and annual water consumption (tonnage). Conversely, the female employee ratio (%), the proportion of female managers (%), and the average fleet age are identified as the least influential metrics. However, domain-specific prioritisation reveals nuanced insights:

- **Economic Dimension:** Available seat kilometres (ASK) dominates as the most critical criterion, reflecting its direct link to operational scalability and revenue generation, while average fleet age ranks lowest, underscoring its marginal impact on short-term economic performance.
- **Social Dimension:** The new employee recruitment rate holds the highest weight, signalling its relevance to workforce dynamism and business growth, whereas the female employee ratio (%) is the least prioritised, suggesting a limited perceived influence on social equity outcomes within the current framework.
- **Environmental Dimension:** Annual water consumption (tonnage) is the most significant criterion, aligning with global water stewardship priorities, while annual fuel consumption (tonnage) - despite its ecological implications - ranks

lowest, potentially due to uniform industry-wide inefficiencies normalising its perceived variability.

These findings highlight disparities between aggregate and dimension-specific weightings, underscoring the need for contextual analysis in sustainability evaluations. Full results are catalogued in Table 5.

3.3.3. Evaluating the Compatibility Between Entropy Weights and Variance

This study examines the statistical properties of the criteria employed, specifically their variance, and the levels of information contribution derived using the Entropy method. It is generally accepted that greater variance in a criterion indicates greater discrimination within the sample, thereby contributing more significantly to the decision model. Accordingly, a positive correlation between variance and entropy weights is anticipated.

Based on the analysis conducted, the findings predominantly corroborate this assumption. For instance, both EC8 (Available Seat-Kilometre) and EC4 (Cargo Amount Carried) demonstrate considerable variability and are among the criteria assigned the highest weights using the Entropy method. Likewise, ENC6 (Prevented CO_2 Emission) and ENC4 (Fuel Savings) also display high variance and rank highly in terms of informational contribution. These results suggest that the criteria generate notable distinctions within the dataset and significantly contribute to the decision-making process.

Conversely, the criteria SC3 (Female Employee Ratio), SC6 (Number of New Hires), and EC5 (Average Fleet Age) exhibit low variance and have among the lowest Entropy weights, indicating that these criteria have similar values across businesses and contribute minimally to the decision-making process. These results largely reaffirm the anticipated correlation between the Entropy method and variance. Nonetheless, certain exceptions to this pattern are observed. For instance, criteria such as Annual CO_2 Emission (ENC5) and Annual Natural Gas Consumption (ENC2), when evaluated using the Entropy method, exhibit relatively low information contribution despite high variance. This anomaly is attributable to the asymmetric distributions evident in the structure of these variables. Such findings suggest that although a broad concordance exists between variance and entropy weights, the Entropy method is sensitive not only to the magnitude of variability but also to the distributional complexity inherent in the dataset. In this context, the Entropy method offers a comprehensive evaluation framework predicated on information content rather than solely on statistical distributions.

3.3.4. Performance Ranking with the TOPSIS Method

Following the entropy-based determination of criterion weights, these weights are integrated into the TOPSIS framework to evaluate and rank the sustainability performance of the ten global airlines under study. Appendix 4 presents the normalised decision matrix generated by the TOPSIS method for evaluating the alternatives, while Appendix 5 displays the weighted normalised decision matrix derived from the decision matrix in Appendix 1.

For instance, alternative ALT3 has a low normalised value for the SC4 criterion, indicating that Qatar Airways exhibits the lowest performance on the female employee ratio compared to the other alternatives. Conversely, Southwest Airlines demonstrates the highest performance on the female employee ratio criterion. In Appendix 5, the weighted normalised decision matrix is obtained by multiplying the normalised decision matrix by the corresponding criterion weights, thereby reflecting the relative importance of each criterion in the decision-making process. For example, the EC8 criterion (Seats Offered per Kilometre) has a high weight of 0.234974, so differences in performance on this criterion significantly influence the overall decision. In another case, the alternative ALT4 demonstrates a relative advantage of 0.17621 under the EC4 criterion, indicating that Cargo Transported is a key factor favouring American Airlines.

Table: 6
Airline Rankings under the TOPSIS Method

Businesses / Criteria	S_i^+	S_i^-	p_i	**Rank**
Turkish Airlines	0,9004772	0,1157593	0,113909799	5
Lufthansa	0,8995401	0,1103866	0,109301628	9
Qatar Airways	0,8993042	0,1049884	0,104539665	10
American Airlines	0,8846723	0,1886336	0,17575007	3
Delta Air Lines	0,8951308	0,1311552	0,127795929	4
Southwest Airlines	0,8968082	0,1140134	0,11279284	6
China Eastern Airlines	0,8632669	0,2611111	0,232227147	2
British Airways	0,8988269	0,1122894	0,111054903	8
Emirates	0,8975735	0,1121611	0,111079774	7
China Southern Airlines	0,3047592	0,8520801	0,736558772	1

Table 6 presents the ranking of alternatives obtained using the entropy-based TOPSIS method. In this ranking, the results show a clear hierarchy, with China Southern Airlines in first place, China Eastern Airlines in second, and American Airlines in third. Qatar Airways ranks at the bottom of the list for holistic sustainability performance. This ranking highlights operational and strategic disparities among airlines in aligning with the three key sustainability dimensions (economic, social, and environmental).

4. Conclusion and Discussion

This study proposes an integrated multi-criteria framework to evaluate corporate sustainability performance in the civil aviation industry, synthesising insights from academic literature, industry reports, and consultancy analyses. A 22-criterion taxonomy -stratified into economic (8 criteria), social (7 criteria), and environmental (7 criteria) dimensions- is developed to assess ten globally prominent airlines (Turkish Airlines, Lufthansa, Qatar Airways, American Airlines, Delta Air Lines, Southwest Airlines, China Eastern Airlines, British Airways, Emirates, and China Southern Airlines). These airlines are selected based on their adherence to the GRI framework, global operational footprint, and market dominance.

To mitigate subjective bias, the Entropy method is employed to weight the criteria objectively. Key findings include:

- **Economic Dimension:** ASK emerges as the most influential criterion, reflecting operational efficiency and revenue potential, followed by cargo volume (in tons) and net profit (in USD millions).
- **Social Dimension:** The new employee recruitment rate ranks highest, underscoring workforce expansion as a key social priority, followed by the number of training hours per employee and the workforce turnover rate (%).
- **Environmental Dimension:** Annual water consumption (in tons) is prioritised, aligned with resource stewardship imperatives, followed by prevented CO2 emissions (in tons) and annual fuel savings (in tons).

The TOPSIS-based rankings reveal significant disparities in sustainability performance:

- **Top Performers:** China Southern Airlines (1st), China Eastern Airlines (2nd), and American Airlines (3rd) demonstrate superior alignment with the tripartite sustainability benchmarks.
- **Mid-Tiers:** Delta Air Lines (4th) and Turkish Airlines (5th) exhibit moderate performance, with opportunities for improvement in environmental and social metrics.
- **Lower Tiers:** Southwest Airlines (6th), Emirates (7th), British Airways (8th), Lufthansa (9th), and Qatar Airways (10th) lag notably, particularly in environmental accountability and social equity.

Notably, while the narrow margins among the top five airlines (e.g., China Southern, China Eastern, American Airlines) suggest a comparable adoption of high-level sustainability strategies, China Southern's pronounced lead reflects operational exceptionalism in resource efficiency and governance. Conversely, European airlines (Lufthansa, British Airways) and Qatar Airways underperform, potentially attributable to regulatory fragmentation in Europe and reliance on legacy operational models that lag in environmental and social innovation. Qatar Airways' position at the bottom of the list can be attributed to its poor performance on social criteria, such as the ratios of female employees and female managers, and the average number of years of training per employee. These findings suggest that some airlines have not yet made sufficient progress on social sustainability, despite providing some level of transparency in environmental data. Qatar Airways' failure to demonstrate a competitive level in environmental indicators, such as carbon emissions, also indicates that the business's sustainability policies need to be reviewed in terms of scope and implementation.

In addition to the ranking results, the statistical properties of the sustainability criteria and the information contributions calculated using the Entropy method are evaluated together. While criteria such as EC8 (Available Seat-Kilometre) and EC4 (Cargo Amount Carried) show high variance, the Entropy method assigns high weights to these criteria; thus, the expected harmony between variance and information contribution is confirmed. Similarly, criteria such as EC5 (Average Fleet Age), SC3 (Female Employee Ratio), SC4

(Labour Turnover Rate), and SC6 (Number of New Hires) make limited contributions to the decision process with low variance and low entropy weights. However, this harmony is disrupted for criteria such as ENC5 (Annual CO_2 Emission) and ENC2 (Annual Natural Gas Consumption), and, despite high variance, low-entropy weights are observed. This situation is thought to be due to an imbalance in the distribution of the criteria in the business data. In general, the Entropy method is sensitive not only to the level of variability but also to the structural features of the data distribution; in this respect, it offers a more holistic evaluation.

4.1. Policy Implications

The findings of this study have important implications for policymakers, regulatory authorities, and industry representatives, highlighting ways to increase sustainability in the airline industry. Indicators such as seat-kilometre capacity (SKL), cargo volume, and water consumption, which carry high weight values, reveal that operational efficiency and resource management are determinants of sustainability performance. In this context, public authorities and international organisations can direct airlines to improve their performance by integrating these indicators into national reporting systems or by developing incentive and sanction mechanisms. In addition, the low performance of some airlines in social indicators, such as the female employee ratio, female representation in management, and the training period per employee, reveals the need for stronger regulations to support inclusive employment policies. In this context, it is recommended to develop policy tools that promote gender equality and employee development (e.g., employment incentives, certification programs, social compliance standards). The study's entropy- and TOPSIS-based methodology has the potential to make decision-making processes more objective and data-driven for policymakers. International aviation authorities (e.g., ICAO, IATA) and regional regulators can achieve more transparent and comparable results by integrating such multi-criteria assessment models into their sustainability monitoring mechanisms. As a result, the findings not only assess the current situation but also provide a data-based basis for policy reforms aimed at building a more sustainable and accountable governance structure across the industry. These recommendations can contribute to the development of policy sets that support industrial transformation and align with the SDGs.

4.2. Limitations

Despite its contributions, this article has some limitations.

Limitations 1: Exclusion of Non-GRI Compliant and Low-Cost Carriers (LCCs)

The sample of this study comprises solely large-scale airlines that adhere to the sustainability reporting standards set forth by the GRI framework and submit consistent data. Consequently, LCCs and regional- or developing-country-based airlines that do not publish GRI reports are excluded from the study. This exclusion, driven by data availability constraints, limits the generalizability of the findings to the entire aviation industry. Notably, given that the sustainability performance of LLCs may differ in their emphasis on service

quality or cost objectives, this exclusion diminishes the model's applicability across airline categories. Future research endeavours can address this inclusivity gap by incorporating alternative data sources or employing hybrid models supported by qualitative analyses.

Limitations 2: Data Constraints due to COVID-19

The data analysed in this study pertain to 2020, a year when the unique effects of the COVID-19 pandemic on the aviation industry are most intensely felt. The suspension of international flights, fleet reductions, a sudden decrease in passenger demand, and operational restrictions due to COVID-19 caused structural changes in both economic, environmental, and social indicators. Therefore, this year's data may have led to unusual deviations in some criteria and may not reflect long-term trends. This situation limits the generalizability of sustainability performance findings to their true potential and requires careful interpretation of the findings beyond COVID-19 conditions. The use of multi-year datasets in future studies will help mitigate the effects of such periodic shocks and enable more robust comparisons.

4.3. Future Research Directions

This study exclusively utilises data from 2020, representing a unique period characterised by the extraordinary impact of COVID-19 on the global aviation industry. Consequently, future research endeavours should include analyses based on multi-year (panel) data. Such an approach would facilitate a more precise understanding of the evolution of sustainability strategies employed by airline businesses over time, their crisis management capacities, and long-term recovery trajectories. Additionally, it would enable more comprehensive inferences by accounting for the effects of periodic shocks on the analysis outcomes.

In the current study, only quantitative data from GRI-compliant businesses are utilised. This circumstance constrains the evaluation framework with respect to data comprehensiveness. Future research endeavours may consider developing multidimensional data sets by integrating alternative reporting standards (e.g., SASB, TCFD, CDP, ISO 26000). Such an approach would facilitate a more comprehensive assessment of sustainability performance, encompassing not only environmental aspects but also sub-dimensions such as governance quality, human rights, and supply chain responsibility.

Furthermore, the present study relies exclusively on quantitative results and does not include stakeholders' viewpoints. Nonetheless, corporate sustainability is inherently a multi-stakeholder and perception-oriented phenomenon. Future research may integrate stakeholder perspectives, including those of passengers, employees, investors, regulatory authorities, and others, into the decision-making process using methodologies such as the Delphi technique, the Analytic Network Process (ANP), fuzzy decision models, and Multi-Stakeholder Decision-Making (MSDM). Consequently, this would facilitate not only performance ranking but also stakeholder prioritisation.

Regarding the methodology, while the Entropy-TOPSIS approach employed in this study offers an objective and robust ranking technique, this framework should be extended to include hybrid models (such as Entropy-Additive Ratio Assessment (ARAS), AHP-Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS), Best-Worst Method with TOPSIS or Preference Ranking Organisation METHod for Enrichment Evaluation (PROMETHEE) integration) in subsequent research. Consequently, the impacts of various algorithms can be compared during both the weighting and ranking phases. Furthermore, sensitivity analyses of these methods can be conducted to assess the extent to which individual criteria influence decision outcomes. Such analyses are crucial for providing more robust and reliable policy recommendations to decision-makers.

Finally, sustainability performance may vary depending on geographical, cultural, and regulatory contexts. Therefore, conducting regional comparative studies such as those between Europe and China or the Gulf and Europe can facilitate the development of more contextualised and practical roadmaps for regional policymakers. Consequently, it becomes feasible to treat sustainability as a strategic element of management that is not only quantified but also actively guided.

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Appendices

Appendix: 1
Decision Matrix

Criteria	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	SC1	SC2	SC3	SC4	SC5	SC6	SC7	ENV1	ENV2	ENV3	ENV4	ENV5	ENV6	ENV7
ALT1	127	363	28,00	1.487.233	8,40	-836,00	6734,00	74.960.000,00	28688	13128	46,00	5,00	18,50	25,00	534	34.636	3972203,00	36.501	22.760	9.060.000	71.695	2.900.000
ALT2	74	757	36,40	2.689.000	12,50	-7682,00	15523,00	108.834.000,00	125207	47152	44,80	5,40	24,50	17,20	2.345	78.640	9.500.000	143.905	45.680	11.048.504	26.800	3.507.000
ALT3	134	250	5,83	1.578.829	8,40	-4110,00	2152,00	93.385.000,00	36707	13948	36,50	4,00	28,00	23,00	4.653	15.832	2.807.660	377.647	15.769	14.246.972	49.376	3.245.258
ALT4	50	1399	95,00	1.383.000.000	12,60	-8885,00	17337,00	119.567.000,00	102700	40258	39,20	24,00	21,00	43,00	21.716	58.300	1.410.000	1.776.140	81.106	29.000.000	200.000	7.845.300
ALT5	52	942	55,00	11.845.000	15,00	-12385,00	17095,00	134.339.000,00	74000	31080	42,00	2,40	23,50	38,00	1.200	24.243	5.600.000	104.486	443.430	41.969.334	1.300.000	7.329.860
ALT6	107	718	138,00	7.850.250	12,00	-3074,00	9048,00	103.456.000,00	56367	32692	58,00	4,40	29,00	17,00	980	49.799	4.310.000	314.570	127.500	12.591.984	488.910	1.273.000
ALT7	170	614	74,62	177.700.000	7,24	-1715,00	8218,00	152.070.000.000,00	77005	29454	38,25	2,30	31,00	12,30	4.281	152.380	5.980.000	5.260.000	600.000	13.842.000	2.000.000	4.380.000
ALT8	70	288	11,66	246.310	13,90	-4550,00	6700,00	63.730.000,00	33898	15830	46,70	6,00	31,40	37,70	1.900	129.407	2.590.000	57.033	18.057	7.250.236	35.847	2.271.605
ALT9	157	259	15,80	1.900.000	7,30	-5550,00	8400,00	64.062.000,00	40801	15341	37,60	5,40	38,60	29,00	1.200	36.652	3.120.000	166.100	16.239	11.260.610	51.154	3.494.233
ALT10	35	734	96,85	54.200.000	7,10	-1572,00	13412,00	214.721,97	100431	47744	47,54	5,80	134,36	33,40	4.521	27.873	3.922.780	612.200	11.300	19.318.000	143.390	6.132.700

Appendix: 2
Normalised Decision Matrix for ENTROPY

Criteria	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	SC1	SC2	SC3	SC4	SC5	SC6	SC7	ENV1	ENV2	ENV3	ENV4	ENV5	ENV6	ENV7
ALT1	0,13	0,06	0,05	0,00	0,08	0,02	0,06	0,00	0,04	0,05	0,11	0,08	0,05	0,09	0,01	0,06	0,09	0,00	0,02	0,05	0,02	0,07
ALT2	0,08	0,12	0,07	0,00	0,12	0,15	0,15	0,00	0,19	0,16	0,10	0,08	0,06	0,06	0,05	0,13	0,22	0,02	0,03	0,07	0,01	0,08
ALT3	0,14	0,04	0,01	0,00	0,08	0,08	0,02	0,00	0,05	0,05	0,08	0,06	0,07	0,08	0,11	0,03	0,06	0,04	0,01	0,08	0,01	0,08
ALT4	0,05	0,22	0,17	0,84	0,12	0,18	0,17	0,00	0,15	0,14	0,09	0,37	0,06	0,16	0,50	0,10	0,03	0,20	0,06	0,17	0,05	0,19
ALT5	0,05	0,15	0,10	0,01	0,14	0,25	0,16	0,00	0,11	0,11	0,10	0,04	0,06	0,14	0,03	0,04	0,13	0,01	0,32	0,25	0,30	0,17
ALT6	0,11	0,11	0,25	0,00	0,11	0,06	0,09	0,00	0,08	0,11	0,13	0,07	0,08	0,06	0,02	0,08	0,10	0,04	0,09	0,07	0,11	0,03
ALT7	0,17	0,10	0,13	0,11	0,07	0,03	0,08	1,00	0,11	0,10	0,09	0,04	0,08	0,04	0,10	0,25	0,14	0,59	0,43	0,08	0,46	0,10
ALT8	0,07	0,05	0,02	0,00	0,13	0,09	0,06	0,00	0,05	0,06	0,11	0,09	0,08	0,14	0,04	0,21	0,06	0,01	0,01	0,04	0,01	0,05
ALT9	0,16	0,04	0,03	0,00	0,07	0,11	0,08	0,00	0,06	0,05	0,09	0,08	0,10	0,11	0,03	0,06	0,07	0,02	0,01	0,07	0,01	0,08
ALT10	0,04	0,12	0,17	0,03	0,07	0,03	0,13	0,00	0,15	0,17	0,11	0,09	0,35	0,12	0,10	0,05	0,09	0,07	0,01	0,11	0,03	0,14

Appendix: 3
Entropy Values for Criteria

Criteria	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	SC1	SC2	SC3	SC4	SC5	SC6	SC7	ENV1	ENV2	ENV3	ENV4	ENV5	ENV6	ENV7
ALT1	-0,27	-0,16	-0,15	-0,01	-0,20	-0,07	-0,18	0,00	-0,13	-0,14	-0,24	-0,20	-0,15	-0,22	-0,05	-0,16	-0,22	-0,02	-0,07	-0,16	-0,07	-0,18
ALT2	-0,20	-0,25	-0,18	-0,01	-0,25	-0,29	-0,28	-0,01	-0,31	-0,30	-0,23	-0,21	-0,18	-0,17	-0,16	-0,26	-0,33	-0,07	-0,11	-0,18	-0,03	-0,21
ALT3	-0,27	-0,13	-0,05	-0,01	-0,20	-0,20	-0,08	0,00	-0,16	-0,15	-0,21	-0,17	-0,19	-0,21	-0,24	-0,10	-0,18	-0,13	-0,05	-0,21	-0,05	-0,20
ALT4	-0,15	-0,33	-0,30	-0,14	-0,26	-0,31	-0,30	-0,01	-0,29	-0,28	-0,22	-0,37	-0,16	-0,29	-0,35	-0,22	-0,11	-0,32	-0,17	-0,30	-0,14	-0,31
ALT5	-0,16	-0,28	-0,23	-0,04	-0,28	-0,34	-0,30	-0,01	-0,24	-0,24	-0,23	-0,12	-0,17	-0,27	-0,10	-0,13	-0,26	-0,05	-0,36	-0,35	-0,36	-0,30
ALT6	-0,24	-0,25	-0,35	-0,03	-0,25	-0,17	-0,21	0,00	-0,21	-0,25	-0,27	-0,18	-0,20	-0,17	-0,09	-0,20	-0,23	-0,12	-0,22	-0,19	-0,25	-0,11
ALT7	-0,30	-0,23	-0,27	-0,24	-0,19	-0,12	-0,20	0,00	-0,25	-0,23	-0,21	-0,12	-0,20	-0,14	-0,23	-0,35	-0,27	-0,31	-0,36	-0,20	-0,36	-0,23
ALT8	-0,19	-0,14	-0,08	0,00	-0,27	-0,22	-0,18	0,00	-0,15	-0,16	-0,24	-0,22	-0,21	-0,27	-0,14	-0,33	-0,17	-0,03	-0,06	-0,13	-0,04	-0,16
ALT9	-0,29	-0,13	-0,10	-0,01	-0,19	-0,24	-0,20	0,00	-0,17	-0,16	-0,21	-0,21	-0,23	-0,24	-0,10	-0,17	-0,19	-0,07	-0,05	-0,18	-0,05	-0,21
ALT10	-0,12	-0,25	-0,30	-0,11	-0,18	-0,11	-0,26	0,00	-0,28	-0,30	-0,24	-0,22	-0,37	-0,26	-0,24	-0,14	-0,22	-0,18	-0,04	-0,25	-0,11	-0,28

Appendix: 4
Normalised Decision Matrix for TOPSIS

Criteria	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	SC1	SC2	SC3	SC4	SC5	SC6	SC7	ENV1	ENV2	ENV3	ENV4	ENV5	ENV6	ENV7
Weights	0,011595323	0,015010978	0,030669958	0,177804726	0,003995159	0,024724622	0,012031017	0,234974493	0,011618945	0,010820876	0,000990615	0,030125347	0,025697022	0,006862582	0,064306993	0,02436192	0,012075102	0,102249518	0,084151793	0,015858437	0,087796912	0,012277661
ALT1	0,37306	0,15929	0,12705	0,00107	0,24511	-0,04315	0,18475	0,00049	0,12136	0,13208	0,32994	0,17956	0,11689	0,27020	0,02287	0,14612	0,25999	0,00650	0,02981	0,14485	0,02926	0,19450
ALT2	0,21738	0,33218	0,16516	0,00193	0,36475	-0,39654	0,42589	0,00072	0,52967	0,47441	0,32133	0,19393	0,15480	0,18589	0,10043	0,33176	0,62180	0,02564	0,05982	0,17664	0,01094	0,23521
ALT3	0,39363	0,10970	0,02645	0,00113	0,24511	-0,21215	0,05904	0,00061	0,15529	0,14033	0,26180	0,14365	0,17691	0,24858	0,19927	0,06679	0,18377	0,06728	0,02065	0,22778	0,02015	0,21766
ALT4	0,14688	0,61390	0,43106	0,99104	0,36766	-0,45863	0,47566	0,00079	0,43446	0,40505	0,28117	0,86190	0,13268	0,46474	0,93001	0,24595	0,09229	0,31645	0,10622	0,46364	0,08164	0,52619
ALT5	0,15275	0,41337	0,24956	0,00849	0,43770	-0,63930	0,46902	0,00088	0,31305	0,31270	0,30125	0,08619	0,14848	0,41070	0,05139	0,10227	0,36653	0,01862	0,58073	0,67099	0,53064	0,49161
ALT6	0,31431	0,31507	0,62617	0,00563	0,35016	-0,15868	0,24824	0,00068	0,23845	0,32892	0,41601	0,15801	0,18323	0,18373	0,04197	0,21009	0,28210	0,05605	0,16698	0,20132	0,19957	0,08538
ALT7	0,49938	0,26943	0,33859	0,12734	0,21126	-0,08853	0,22547	1,00000	0,32576	0,29634	0,27435	0,08260	0,19586	0,13294	0,18334	0,64285	0,39140	0,93716	0,78579	0,22130	0,81637	0,29377
ALT8	0,20563	0,12638	0,05291	0,00018	0,40560	-0,23487	0,18382	0,00042	0,14340	0,15927	0,33496	0,21547	0,19839	0,40745	0,08137	0,54593	0,16952	0,01016	0,02165	0,11591	0,01463	0,15236
ALT9	0,46119	0,11365	0,07169	0,00136	0,21301	-0,28649	0,23046	0,00042	0,17260	0,15435	0,26969	0,19393	0,24388	0,31343	0,05139	0,15462	0,20421	0,02959	0,02127	0,18003	0,02088	0,23436
ALT10	0,10281	0,32209	0,43945	0,03884	0,20718	-0,08115	0,36797	0,00000	0,42486	0,48036	0,34099	0,20829	0,84891	0,36098	0,19362	0,11759	0,25675	0,10907	0,01480	0,30885	0,05853	0,41132

Appendix: 5
Weighted Normalised Matrix for TOPSIS

Criteria	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	SC1	SC2	SC3	SC4	SC5	SC6	SC7	ENV1	ENV2	ENV3	ENV4	ENV5	ENV6	ENV7
Weights	0,011595323	0,015010978	0,030669958	0,177804726	0,003995159	0,024724622	0,012031017	0,234974493	0,011618945	0,010820876	0,000990615	0,030125347	0,025697022	0,006862582	0,064306993	0,02436192	0,012075102	0,102249518	0,084151793	0,015858437	0,087796912	0,012277661
ALT1	0,00433	0,00239	0,00390	0,00019	0,00098	-0,00107	0,00222	0,0001158	0,00141	0,00143	0,00033	0,00541	0,00300	0,00185	0,00147	0,00356	0,00314	0,00066	0,00251	0,00230	0,00257	0,00239
ALT2	0,00252	0,00499	0,00507	0,00034	0,00146	-0,00980	0,00512	0,0001682	0,00615	0,00513	0,00032	0,00584	0,00398	0,00128	0,00646	0,00808	0,00751	0,00262	0,00503	0,00280	0,00096	0,00289
ALT3	0,00456	0,00165	0,00081	0,00020	0,00098	-0,00525	0,00071	0,0001443	0,00180	0,00152	0,00026	0,00433	0,00455	0,00171	0,01281	0,00163	0,00222	0,00688	0,00174	0,00361	0,00177	0,00267
ALT4	0,00170	0,00922	0,01322	0,17621	0,00147	-0,01134	0,00572	0,0001848	0,00505	0,00438	0,00028	0,02597	0,00341	0,00319	0,05981	0,00599	0,00111	0,03236	0,00894	0,00735	0,00717	0,00646
ALT5	0,00177	0,00621	0,00765	0,00151	0,00175	-0,01581	0,00564	0,0002076	0,00364	0,00338	0,00030	0,00260	0,00382	0,00282	0,00330	0,00249	0,00443	0,00190	0,04887	0,01064	0,04659	0,00604
ALT6	0,00364	0,00473	0,01920	0,00100	0,00140	-0,00392	0,00299	0,0001599	0,00277	0,00356	0,00041	0,00476	0,00471	0,00126	0,00270	0,00512	0,00341	0,00573	0,01405	0,00319	0,01752	0,00105
ALT7	0,00579	0,00404	0,01038	0,02264	0,00084	-0,00219	0,00271	0,2349741	0,00379	0,00321	0,00027	0,00249	0,00503	0,00091	0,01179	0,01566	0,00473	0,09582	0,06613	0,00351	0,07168	0,00361
ALT8	0,00238	0,00190	0,00162	0,00003	0,00162	-0,00581	0,00221	0,0000985	0,00167	0,00172	0,00033	0,00649	0,00510	0,00280	0,00523	0,01330	0,00205	0,00104	0,00199	0,00184	0,00128	0,00187
ALT9	0,00535	0,00171	0,00220	0,00024	0,00085	-0,00708	0,00277	0,0000990	0,00201	0,00167	0,00027	0,00584	0,00627	0,00215	0,00330	0,00377	0,00247	0,00303	0,00179	0,00286	0,00183	0,00288
ALT10	0,00119	0,00483	0,01348	0,00691	0,00083	-0,00201	0,00443	0,0000003	0,00494	0,00520	0,00034	0,00627	0,84891	0,00248	0,01245	0,00286	0,00310	0,01115	0,00125	0,00490	0,00514	0,00505