VERİMLİLİK DERGİSİ
JOURNAL OF PRODUCTIVITY

Efficiency of Air Transport Industry in European Union Nations with Regard to Environmental Factors

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ABSTRACT

Purpose: Evaluating the effectiveness of nations by analyzing the relationship between the outcomes of the aviation sector and the environmental resources associated with these outcomes is essential for policymakers to develop environmental regulations and for managers to take suitable actions. This study aims to evaluate the environmental effectiveness of the airline industry in European Union (EU) member states.

Methodology: We assessed the efficiency of data from 26 EU countries using Data Envelopment Analysis.

Findings: The study's findings determined that Austria, Luxembourg, Hungary, and Ireland had the lowest efficiency levels. Air pollution and greenhouse gas emissions primarily influence the efficiency of these countries. We identify Germany as the least efficient country, specifically when compared to France and Italy. These findings indicate that, despite the EU's implementation of environmental impact legislation, developed member states have not successfully enforced it.

Originality: Previous research has not examined the effectiveness of countries in terms of both passenger and flight volumes, as well as environmental considerations such as air pollution, greenhouse gas emissions, kerosene and jet fuel use, energy products, and overall environmental taxation.

Keywords: Air Transport, Environmental Impact, Data Envelopment Analysis, European Union, Efficiency.

JEL Codes: L93, O52, P48, Q5, R4.

Avrupa Birliği Ülkelerinde Hava Taşımacılığı Sektörünün Çevresel Faktörler Açısından Etkinliği

ÖZET

Amaç: Havacılık sektörünün çıktıları ve bu çıktılarla ilişkili çevresel kaynaklar arasındaki ilişkiyi analiz ederek ulusların etkinliğini değerlendirmek, politika yapıcıların çevresel düzenlemeler geliştirmesi ve yöneticilerin uygun eylemlerde bulunması için gereklidir. Bu çalışmanın amacı, Avrupa Birliği (AB) üye ülkelerindeki havayolu endüstrisinin çevresel etkinliğini değerlendirmektir.

Metodoloji: Veri Zarflama Analizi kullanılarak 26 AB ülkesinden elde edilen verilerin etkinliği değerlendirilmiştir.

Bulgular: Çalışmanın bulguları Avusturya, Lüksemburg, Macaristan ve İrlanda'nın en düşük etkinlik seviyelerine sahip olduğunu ortaya koymuştur. Hava kirliliği ve sera gazı emisyonları bu ülkelerin verimliliğini büyük ölçüde etkilemektedir. Özellikle Fransa ve İtalya ile kıyaslandığında Almanya'nın en az verimli ülke olduğu tespit edilmiştir. Bu bulgular, AB'nin çevresel etki mevzuatını uygulamasına rağmen, gelişmiş üye ülkelerin bu mevzuata başarılı bir şekilde uymadığını göstermektedir.

Özgünlük: Daha önceki araştırmalarda ülkelerin etkinliği hem yolcu ve uçuş hacmi hem de hava kirliliği, sera gazı emisyonları, kerosen ve jet yakıtı kullanımı, enerji ürünleri ve genel çevresel vergilendirme gibi çevresel hususlar açısından incelenmemiştir.

Anahtar Kelimeler: Hava Taşımacılığı, Çevresel Etki, Veri Zarflama Analizi, Avrupa Birliği, Etkinlik.

JEL Kodları: L93, O52, P48, Q5, R4.

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DOI: 10.51551/verimlilik.1536509
Research Article | Submitted: 20.08.2024 | Accepted: 25.12.2024
Cite: Akbıyık, T. and Avcı, T. (2024). "Evaluation of the Supply Process in Public Hospitals: A Qualitative Study", *Verimlilik Dergisi,* 59(1), 253-268.

1. INTRODUCTION

Air transportation has played a crucial part in global economic activity, seeing significant growth and transformation in the previous decade. In 2019, the aviation sector produced around USD 899 billion in global revenue (IATA, 2019, p. 15). The International Civil Aviation Organization forecasts that by 2040, nearly 10 billion passengers will fly annually (ICAO, 2018, p. 40). This growth underscores the escalating adverse effects of carbon pollution. The transportation sector accounts for over 25% of global carbon emissions, with aviation contributing approximately 2% (IEA, 2022 s.126). Airports, as vital components of transportation infrastructure, facilitate the annual movement of billions of passengers. According to Airports Council International (ACI, 2023, p. 4), airports worldwide served over 6.6 billion passengers, highlighting the need for effective airport operations in maximizing capacity and managing costs. The continuous growth of the aviation sector has led to increased air and noise pollution, significantly impacting adjacent populations and ecosystems (Lawton and Fujiwara, 2016).

The health implications of aviation air pollution are substantial, and specifically lead to respiratory and cardiovascular ailments. Adhering to the air quality criteria established by the World Health Organization (WHO) might potentially avert over 50,000 fatalities annually in European cities, according to estimates by Khomenko et al. (2021). The detrimental health effects of air pollution highlight the urgent need for stringent legislation and efficient approaches to mitigate aviation-related emissions and safeguard human health. Specifically, there was a distinct correlation between air pollution and increased hospital admissions for respiratory and cardiovascular ailments, chronic bronchitis, and asthma exacerbations. This highlights the notable influence on the well-being of the general population, as demonstrated in the research carried out by Viegi et al. (2020). Hence, it is imperative to enforce robust legislative actions to mitigate the substantial health risks associated with air pollution by addressing air emissions.

As sustainability becomes a greater priority, the sector is becoming increasingly concerned about its environmental and social effects. Integrating tactics focused on reducing greenhouse gas emissions and other detrimental pollutants has become a crucial element of airport activities (Winter et al., 2021). The implementation of a greenhouse gas emissions tax by the European Commission has had a substantial effect on the functioning of airlines and airports, resulting in increased adoption of ecologically sustainable practices. The European Union implemented the Emissions Trading Scheme (ETS) as part of its efforts to promote environmental sustainability and decrease business emissions. According to Anger (2010), the EU ETS has resulted in a 7.4% decline in carbon dioxide (CO_2) emissions from airplanes. Although the EU ETS represents progress in managing aircraft emissions, its capacity to substantially decrease pollution levels throughout Europe remains limited. Therefore, additional enhancements are required to achieve substantial ecological advantages. The primary aim of the measures taken by various stakeholders in the aviation industry to mitigate its environmental impacts is to maintain or increase passenger and freight traffic levels, while minimizing adverse environmental effects.

This study is significant for an industry that must validate its sustainability in light of growing environmental concerns. Historically, efficiency assessments in aviation have predominantly relied on economically focused output metrics such as revenue (profitability), flight frequency, and passenger volume, with insufficient consideration of environmental factors. This study addresses a critical research gap by integrating environmental variables (air pollutants, greenhouse gases (GHGs), kerosene and jet fuels, energy products, and environmental taxes) into the Data Envelope Analysis (DEA) framework to assess the economic and eco-efficiency of air carrier operations in EU Member States.

The primary aim of this study is to establish a comprehensive assessment of performance sustainability in European Union nations by analyzing the minimal environmental footprints within the airline sector, along with significant metrics, such as total passenger counts and flight numbers. This study offers a novel perspective on the limitations of previous research by identifying factors that harm the environment and conducting a dual analysis of environmental and economic efficiency in aviation operations rather than exclusively addressing each aspect independently, as has been the norm in scholarly discourse. This novel perspective embodies a wider trend in the global industry when an airline must be assessed not only in terms of economic performance but also on its sustainability initiatives. Song (2020) and Kim and Son (2021) conducted past analyses of airline sustainability using DEA; however, these studies focused on global factors without accounting for regional influences that may be specific to certain areas, such as the EU. Contemplating the endeavors of market liberalization. This study expands upon previous research by concentrating primarily on EU countries and recognizing the distinct regulatory frameworks and environmental policies that influence aviation efficiency levels variably between European states. This study further enriches the literature by integrating a systematic assessment of environmental consequences with operational results, offering an overview of the sustainability efficiencies maintained by EU countries. Our study is crucial, as it addresses a primary issue: the need for a regional and environmentally focused DEA assessment, which necessitates the incorporation of environmental considerations in evaluating aviation efficiency. This complexity makes other studies significant for policymakers and business leaders seeking to enhance the sustainability of the tourism sector while avoiding alienation in a region that is consistently subjected to heightened scrutiny of its environmental impact.

The subsequent sections of the study will be presented in the following manner: The second portion establishes the conceptual foundation of the subject by drawing upon existing knowledge on the environmental sustainability of airlines and the use of DEA in aviation. The third section provides an overview of the approaches used in this study. The next section examines and presents the findings, and the final section concludes with a discussion.

2. LITERATURE

2.1. Environmental Sustainability of the Aviation Industry

The aviation industry's substantial influence on the environment, specifically its contribution to global greenhouse gas emissions, has elevated environmental sustainability to a paramount concern. The rapid expansion of the sector driven by the growing demand for air travel amplifies its impact on the environment and necessitates robust measures to alleviate these effects. Therefore, the development of ecologically friendly aircraft technologies is crucial. Utilizing lighter materials and more efficient engines in aircraft design significantly contribute to a reduction in fuel consumption and emissions (Lin, 2013). In addition, sustainable aviation policies, such as the EU ETS and the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), aim to restrict and decrease carbon emissions by encouraging the use of sustainable fuels and efficient technologies (Heiaas, 2021; Bergantino and Loiacono, 2019). The integration of biofuels derived from renewable resources can significantly lower the carbon footprint of this sector (Kousoulidou and Lonza 2016). Nevertheless, the industry faces significant obstacles, including substantial costs related to growing technology, and the need for cohesive worldwide legislation (Walker and Cook, 2009). Furthermore, the effectiveness of these policies is greatly influenced by how the public perceives and participates. The inclination of passengers to endorse environmentally advantageous practices, such as participating in carbon offset programs and selecting airlines that prioritize environmental sustainability, is of utmost importance (Korba et al., 2023). It is essential to implement a holistic approach that incorporates technological advancements, policy formulation, and public involvement to promote sustainability of the aviation industry and mitigate its environmental effects (Aygün et al., 2023). Table 1 presents a concise overview of significant research on environmental sustainability in the aviation industry.

Table 1. Environmental sustainability studies in the aviation sector

Author(s)	*Scope of Study*	*Finding and Methods*
Lin (2013)	Development of green technology in aviation manufacturing, focusing on AVIC's goals and commitments.	Focused on the impacts of green aviation manufacturing. Discussed AVIC's commitments.
Amicarelli et al. (2021)	Airlines' commitment to aviation-related environmental issues, sustainable aviation fuel, and sustainable development strategies	Investigated airlines' environmental awareness and willingness to adopt sustainable practices using the $\chi 2$ test and logistic regression.
Aygün et al. (2023)	Identification and analysis of publications related to sustainability in civil aviation.	Bibliometric analysis of 123 scientific articles. Identified significant trends, influential authors, and gaps in the literature.
Yan et al. (2016)	Secondary data was acquired manually from 40 airline businesses in emerging market economies.	Multiple regression analysis reveals that both technology-based and process-based environmental advancements have a favorable influence on airlines' profitability.
Aksoy et al. 2022	Evaluation of the feasibility of investing in green flight measures for the aviation sector.	Prioritized strategic investments in green measures using multi-stage weight assessment ratio analysis and the ELECTRE technique.
Brugnoli et al. (2015)	Impact of economic variables on the adoption of low-CO2 emitting aircraft in Europe	Regression- The primary factor driving the transition to a fuel-efficient fleet is the combination of oligopolistic aircraft and aero engine sectors, which are focused on gaining market share by differentiating their products.

Note: Compiled by the authors and relying on (Kim and Son, 2021).

Table 2. Academic studies using DEA technique at airports

Author (s)	*Sample*	*Method*	*Inputs*	*Outputs*
Oum et al. (2003)	52 airports in Asia-Pacific, Europe, and North America, 1999	EW-TPF	Number of full-time equivalent employees; capital stock; soft cost input	Number of passengers; cargo volume; aircraft movements; commercial services revenue
Oum and Yu (2004)	76 airports in Asia-Pacific, Europe, and North America, 2000-2001	Variable Factor Productivity and second-stage regression	Number of full-time equivalent employees; soft cost input	Number of passengers; cargo volume; aircraft movements; commercial services revenue
Yoshida and Fujimoto (2004)	67 Japanese airports, 2000	DEA, EW-TPF, and second-stage regression	Runway length, terminal size, access cost, labor	Passengers, number of landing and departure movements, amount of cargo carried
Lin and Hong (2006)	20 International airports, 2003	DEA, FDH	Employees, runways, gates, number of check-in counters, parking spaces, number of aprons, baggage belts	Passengers, aircraft movements, cargo
Barros and Dieke (2007)	31 Italian airports, 2001-2003	Cross Efficiency and Super Efficiency models	Labour costs, capital, operational costs excluding labour cost	Aircraft movements, passengers, handling receipts, aeronautical sales, commercial sales, cargo
Chi-Lok and Zhang (2009)	25 Chinese airports, 1996-2005	DEA model, Tobit regression	Runways, terminal area	Cargo, aircraft movements, passengers
Perelman and Serebrisky (2010)	21 South American airports, 2000-2007	Bootstrap DEA, Malmquist index	Employees, aircraft parking spaces, terminal area	Passengers, cargo, aircraft movements
Curi et al. (2011)	18 Italian airports, 2000-2004	Bootstrap DEA	Employees, number of runways, apron size (m2)	Aircraft movements, passengers, cargo tonnes
Wanke (2012)	63 Brazilian airports, 2009	Principal Component Analysis-DEA bootstrapped efficiency estimates	Terminal area, aircraft parking spaces, runways, total runway length, airport area, public parking spaces	Passengers, cargo, aircraft movements
Gutiérrez and Lozano (2016)	21 European airports, 2013	DEA	Runway size, gates, apron stands, number of scheduled routes, number of airlines	Cargo, aircraft movements, passengers
Inglada et al. (2017)	33 Spanish airports, 1992-2012	DEA, Malmquist Index	Labor cost, fixed assets, other costs	Aircraft movements, passengers, cargo tons
Keskin and Köksal (2019)	48 Turkish airports, 2000-2015	AHP/DEA-AR	Employees, gates, runway area terminal area, operational expenditure	Passengers, cargo volume, total revenue
Pacagnella Junior et al. (2020)	33 Brazilian airports, 2014-2015	Two-stage DEA, Malmquist	Number of slots for aircraft, number of runways, number of aprons, terminal size, runway length	Number of take-offs and landings
Eren and Doğan (2022)	56 Turkish airports, 2015-2019	Network DEA	Runways, aprons, terminal, number of employees	Aircraft traffic, passenger traffic

Note: Compiled by the authors and relying on Cifuentes-Faura and Faura-Martinez (2023)

2.2. Data Envelopment Analysis in Aviation

DEA has been widely employed in the aviation sector, and has been the focus of substantial research. DEA is a nonparametric method extensively used in operations research. It is commonly employed to assess the effectiveness of various decision-making entities such as airlines and airports. Rai (2017) conducted a study utilizing data envelope analysis of the United States airline industry from 1985 to 1995. They found that airlines with high efficiency had much better stock returns than those with low efficiency. Cui and Yu (2021) conducted an extensive examination of 130 scholarly articles on DEA models pertaining to airline efficiency from 1993 to 2020. This review discusses various DEA models, such as radial, non-radial, and dynamic, and emphasizes the advantages and disadvantages of each model. Adler and Golany (2001) employed the DEA technique in conjunction with principal component analysis (PCA) to assess the efficiency of deregulated airline networks in Western Europe. Their study showed the efficacy of this approach in handling large-scale input-output datasets. Hermoso et al. (2019) integrated additional input-output characteristics such as company management aspects and social media predictors into the DEA approach. This facilitated a more comprehensive examination of airline effectiveness in the European airspace. Kao (2014) investigated network DEA models that considered the internal structure of systems. This methodology yields more intricate efficiency outcomes than conventional black-box approaches. The literature highlights the versatility and resilience of DEA in assessing airlines' and airports' efficiencies. This enhances the effectiveness of performance monitoring and strategic decision making in the aviation industry. The DEA method is mostly used in the aviation industry to evaluate airports' operational efficiency and effectiveness. Table 2 presents a concise overview of the significant studies that have utilized DEA to evaluate airport efficiency and effectiveness.

Despite numerous studies (Chi-Lok et al., 2009; Curi et al.,2011; Gutiérrez et al., 2016; Keskin and Köksal, 2019) on efficiency and effectiveness in the airline sector, the majority focus primarily on economic outputs (e.g., profitability, flight frequency, and passenger volume), whereas environmental implications have historically received scant attention. The proposed strategy addresses a gap in the literature that lacks a growing focus on sustainability and suggests that carrier performance should encompass not only economic factors, but also ecological consequences.

3. METHODOLOGY

Data Envelopment Analysis is a nonparametric method used to test how well decision-making units (DMUs) work by comparing inputs and outputs measured at various scales or with different units. DEA, initially introduced by Charnes et al. (1978), assesses the relative efficiency of decision-making units by examining their input and output attributes and employs linear programming to assess the efficiency of decision-making units (DMUs) by comparing their inputs and outputs, regardless of the units in which these values are measured. DEA assesses efficiency by analyzing decision units that operate under comparable circumstances and accomplish identical goals. It is assumed that the factors influencing the efficiency remain consistent among the units, varying only in their extent and amplitude. This method is beneficial in situations where direct comparison of input and output values is challenging because of their measurement in various units (Muniz, 2006).

Two DEA models are commonly used in the literature. Charnes, Cooper, Rhodes (CCR) and Banker, Charnes, Cooper (BCC) models are fundamental in the field of DEA. The CCR model is based on the assumption of constant returns to scale, which implies that any changes in inputs result in commensurate changes in outputs. On the other hand, the BCC model assumes that there are different levels of efficiency at different sizes of operation; thus, returns to scale can vary. The CCR approach computes overall efficiency as a unified metric, whereas the BCC model differentiates between technical and scale efficiency. Input-oriented DEA models strive to decrease input usage to attain a specific output level, whereas output-oriented models attempt to maximize output levels using a preset set of inputs (Wu and Zhou, 2015). The table provided in Table 3 lists the formulations of the input- and output-oriented CCR and BCC models.

Table 3. Input and output oriented CCR and BCC models

Input Oriented CCR	Output Oriented CCR
$min\ z_0 = \theta$	$max\ z_0 = \theta$
$s.t.$	$s.t.$
$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_0$	$\sum_{j=1}^{n} \lambda_j x_{ij} \leq x_0$
$\theta x_0 - \sum_{j=1}^{n} \lambda_j x_{ij} \geq 0 \quad j = 1, \dots, n$	$\theta y_0 - \sum_{j=1}^{n} \lambda_j y_{rj} \leq 0 \quad j = 1, \dots, n$
$\lambda_0 \geq 0; \quad j = 1, \dots, n$	$\lambda_0 \geq 0;$
$r = 1, \dots, S; \quad i = 1, \dots, m$	$r = 1, \dots, S; \quad i = 1, \dots, m$
Input Oriented BCC	*Output Oriented BCC*
$min\ z_0 = \theta$	$max\ z_0 = \theta$
$s.t.$	$s.t.$
$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_0$	$\sum_{j=1}^{n} \lambda_j y_{rj} \leq x_0$
$\theta x_0 - \sum_{j=1}^{n} \lambda_j x_{ij} \geq 0$	$\theta y_0 - \sum_{j=1}^{n} \lambda_j y_{rj} \leq 0$
$\sum_{j=1}^{n} \lambda_j = 1$	$\sum_{j=1}^{n} \lambda_j = 1$
$\lambda_0 \geq 0; \quad j = 1, \dots, n$	$\lambda_0 \geq 0$
$r = 1, \dots, S; \quad i = 1, \dots, m$	$r = 1, \dots, S; \quad i = 1, \dots, m$

To use DEA, it is imperative to select the minimum number of control variables (CVBs) that possess both input and output variables. Charnes et al. (1991) stated that for the analysis to be dependable, CVBs should be either (m+p+1) or (m+p)*2, where m represents the number of inputs and p represents the number of outputs. Once relative efficiency is measured using the DEA approach, it is crucial to perform thorough analyses for each CVB to completely assess the results (Bal, 2013).

Hermoso-Orzáez et al. (2020) emphasize the necessity of incorporating emissions into any assessment of environmental efficiency, particularly within the context of the EU. The authors advocate the necessity of supplying data for the assessment of eco-efficiency, ultimately to evaluate the impact of air transport within the broader context of climate change and overall environmental sustainability, given that CO_2 is a greenhouse gas (Hermoso-Orzáez et al., 2020). This emphasis on emissions corresponds with the overarching EU objectives regarding sustainable development and tackling environmental issues across various sectors via specific policy frameworks, including the DEA method for assessing relative eco-efficiencies among member states (Hermoso-Orzáez et al., 2020). The consumption of kerosene and jet fuel in terajoules serves as an indication of the energy required for commercial aviation, which is directly related to both operational efficiency and environmental effects. According to an empirical comparative study on airline efficiency by Arjomandi et al. (2018), gasoline serves as a more relevant direct proxy for an airline's energy dependency and emissions.

Energy products are a significant input, encompassing all energy use apart from jet fuel (e.g., power for airport operations), and quantified in terajoules. This variable encompasses both indirect and direct energy contributions from the full aircraft production cycle. Matsumoto et al. (2020) asserted that various energy inputs must be considered within the operational system, including practical measures of efficiency and environmental efficiency. Ultimately, environmental taxes on air transport reflect the total annual expenditure in millions of euros. These tariffs serve as regulatory measures aimed at constraining specific forms of production and consumption, while promoting more sustainable practices within the industry. Consequently, environmental taxes are crucial for promoting eco-efficiency incentives and are deemed essential in the DEA model (Lacko and Hajduová 2018).

The data for the analysis includes information from the European Statistical Office (Eurostat) for 26 EU countries, including Norway. Owing to the absence of data for the Netherlands and Romania, these nations were omitted from the analysis. This study evaluated the environmental efficacy of EU countries by considering the number of passengers and flights. Table 4 lists the input and output data used in this efficiency study.

Thus, nations should decrease their inputs to achieve environmental efficiency. Hence, an input-oriented BCC model was employed. It is crucial to highlight that input-oriented DEA models can incorporate various forms of undesired input or output. DEA models, as described in the literature (Lozano et al., 2013; Tatari et al., 2012; Kucukvar et al., 2021), incorporate undesirable outputs, such as CO_2 emissions, waste, and other environmental impacts, as inputs. This study examines the EU nations listed in Table 5.

Table 4. Input and output variables used in the study

Inputs	*Description*
Air pollutants and greenhouse gases	From air transportation (tons)
Kerosenes and jet fuels	Used in air transportation (terajoules, excluding biofuel)
Energy products	Consumed in air transportation (terajoules)
Total environmental taxes	Collected from air transport (annual, million euros)
Outputs	
Commercial passenger air flight	Total number of commercial passenger flights includes both domestic and international routes.
Passenger on board	Total number of passengers carried on commercial passenger flights includes both domestic and international routes.

Table 5. List of countries included in DEA analysis

Countries	*Countries*	*Countries*
1. Belgium	11.Croatia	21.Slovakia
2.Denmark	12.Lithuania	22.Sweden
3.Germany	13.Luxembourg	23.Norway
4.France	14.Finland	24.Cyprus
5.Spain	15.Poland	25.Czechia
6.Italy	16.Malta	26.Hungary
7.Bulgaria	17.Austria	
8.Estonia	18.Portugal	
9.Ireland	19.Greece	
10.Latvia	20.Slovenia	

European nations maintain a significant level of engagement and integration because of their extensive network of regional airports, which fosters social and economic connectivity among member states. This network enhances accessibility and cohesion across the European Union, thereby bolstering the continent's status as one of the largest aviation markets globally (Paleari et al., 2010). Consequently, the study utilized a non-parametric one-stage DEA model, examining all countries jointly as a unified group without differentiating between distinct country classifications. This empirical approach facilitated direct cross-national comparisons of efficiency, uncovering discrepancies in environmental performance and the policy/economic issues impacting states within a cohesive framework. This study by Hermoso-Orzáez et al. (2020) examined the eco-efficiency rankings of EU countries, collectively supporting this methodology, which lacks categorization, thus assessing efficient leaders within a cohesive framework that enables EU-wide benchmarks for improvement across various national contexts. Kuljanin et al. (2019) utilized a standardized methodology to assess airline performance in Western, Central, and Southeastern Europe, revealing regional efficiency tendencies to facilitate policy and operational improvements, thus enhancing comparability across various economic circumstances. Matsumoto et al. (2020) utilized a DEA model to analyze temporal trends in environmental performance within the EU, thereby identifying prevalent inefficiencies and enabling policymakers to systematically address these challenges rather than through fragmented regional approaches, thus facilitating comparisons under diverse policy conditions.

4. FINDINGS

This study employs the BCC model, which assumes constant returns to scale, to ascertain the environmental efficiency of EU countries in the European Union. Efficiency is determined by computing the ratio of the number of passengers to the number of flights. During the analytical phase, we employ the BCC model to calculate the scale and technical efficiency of each country. We present a thorough examination of the data from the assessments conducted with the input minimization model using the Frontier Analyst software. We chose the input reduction model because we determined that we could achieve the required total number of passengers and flights for the current airline by using fewer environmental inputs.

During the analytical phase, the study began by calculating countries' efficiency values. In this context, countries with high and low efficiency levels are identified. To enhance the effectiveness of underperforming countries, we must identify reference countries whose influences warrant consideration. Ultimately, we compute the necessary improvement ratios for these inefficient countries to achieve efficiency.

Table 6. Efficiency scores of countries for 2021

Countries	*BCC Model Efficiency Score*
Greece	100.00
Estonia	100.00
France	100.00
Spain	100.00
Cyprus	100.00
Lithuania	100.00
Sweden	100.00
Croatia	100.00
Italy	100.00
Portugal	100.00
Slovenia	100.00
Latvia	100.00
Slovakia	100.00
Denmark	69.3
Norway	64.7
Poland	49.7
Germany	44.5
Belgium	38.4
Finland	37.6
Bulgaria	28.8
Malta	21.2
Czechia	13.2
Austria	11.5
Luxembourg	8.1
Hungary	5.1
Ireland	4.0

An analysis of the variable return efficiency values shows that 13 nations (Greece, Estonia, France, Spain, Cyprus, Lithuania, Sweden, Croatia, Italy, Portugal, Slovenia, Latvia, and Slovakia) are expected to exhibit technological efficiency by 2021. Ireland has the lowest efficiency score of 4.0 as indicated by the variable return efficiency findings. According to the analysis results, Figure 1 illustrates the potential for improvement of inputs and outputs in the environmental and aviation sectors regarding efficiency in proportional terms.

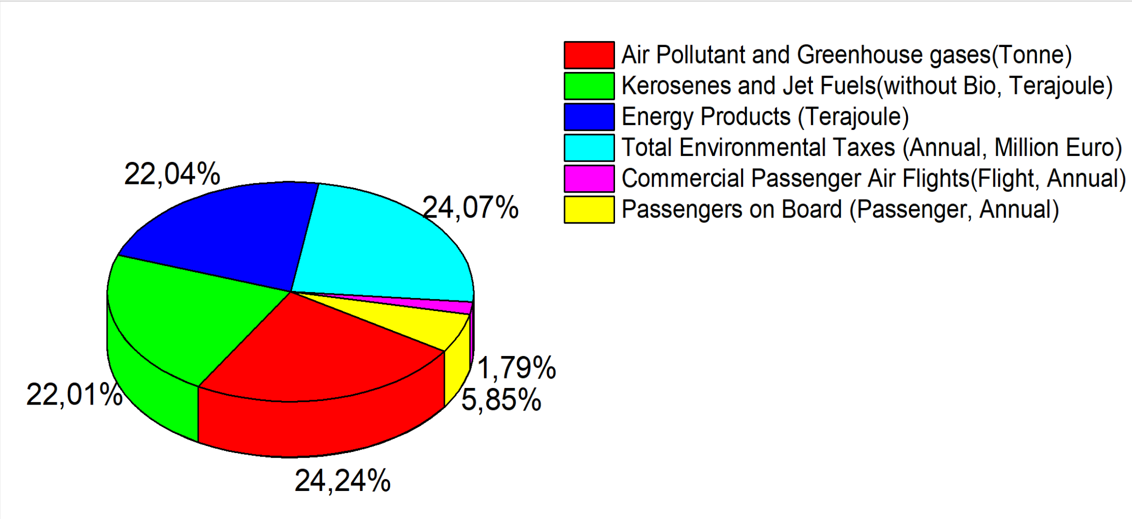

Figure 1. Total potential improvement results

The analysis shows that the primary variable for potential improvement is air pollution and greenhouse gases, constituting 24.24% of inefficiency. This underscores the imperative of prioritizing emission reductions through cleaner technologies and sustainable practices. Kerosene and jet fuels 22.01% and energy products 22.04% indicate significant inefficiencies, highlighting the imperative to optimize fuel usage and transition to renewable energy sources. These environmental factors collectively account for about 65% of inefficiencies. Moreover, the total environmental taxes 24.07% indicate the economic burden of these inefficiencies, which might be alleviated through enhanced resource management. Insignificant contributions stem from operational outputs, comprising commercial passenger air flights 1.79% and onboard passengers (5.85%), suggesting opportunities for improvement in flight planning and capacity use. Reducing environmental impacts and enhancing operations are crucial for increasing efficiency and sustainability in air transportation.

The program also determines the number of inefficient DMUs that are compared to efficient DMUs. Consequently, effective composite virtual units (CVUs) also produced internal efficiency rankings. Cyprus was used as a benchmark ten times in this context, Italy seven times, Greece six times, and both Sweden and Latvia five times. Furthermore, Slovakia, Slovenia, Spain, and Estonia were mentioned twice. Figure 2 shows a collection of citations and their respective occurrence rates.

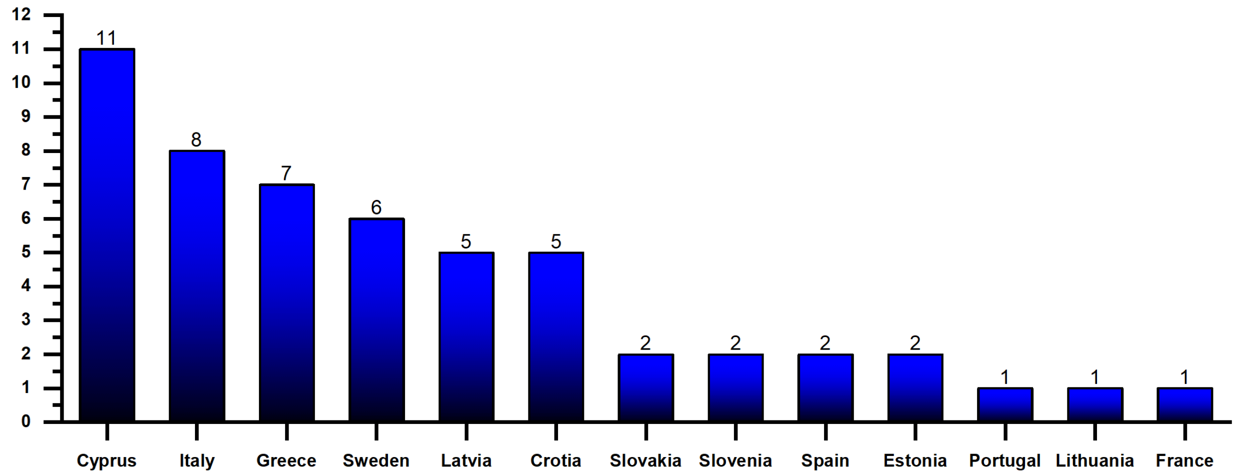

Figure 2. Reference set and reference frequencies

The analysis software also yields a critical result: It pinpoints the inputs that require reduction and outputs that require enhancement to improve the performance of inefficient decision units. Potential improvement percentages were used to measure this idea. TLhese percentages show how fast the current input and output values of the decision units approach the goal values, and how much they should be improved (Uzgoren and Sahin, 2013). This percentage was calculated using the following formula:

$$Potential\ Improvement\ (\%) = \frac{(Target\ Value - Realized\ Value)*100}{Realized\ Value} \quad (1)$$

Below are the target values and potential improvement ratios of the input/output variables for the four nations with the lowest efficiency values among the 13 countries listed (Denmark, Norway, Poland, Germany, Belgium, Finland, Bulgaria, Malta, Czechia, Austria, Luxembourg, Hungary, and Ireland). Table 7 displays the exact values of both the actual and target figures as well as the rate of development for Austria.

Table 7. Austria target values and potential improvement rates

Inputs/Outputs	*Realized*	*Target*	*Potential Improvement Rate (%)*
Air pollutants and greenhouse gases	3260505.44	351838.39	-89.21%
Kerosenes and jet fuels	333772.00	19357.59	-88.53%
Energy products	457067.00	26508.26	-88.53%
Total environmental taxes	116.37	26508.26	-91.97%
Commercial passenger air flight	113633.00	113633.00	0.00 %
Passenger on board	11187400.00	6.75	6.98%

Austria must significantly decrease its air pollutants and greenhouse gas emissions by 89.21%. Additionally, the use of kerosene, jet fuel, and energy products should be reduced by 88.53%. Finally, the country should aim to reduce its total environmental taxes by 91.97% to improve its efficiency. Table 8 lists the actual and target values and improvement rates for Luxembourg.

To improve efficiency, Luxembourg must achieve reductions of 94.66% in air pollutants and greenhouse gases, 91.91% in kerosene and jet fuels, 95.01% in energy products, and 91.91% in total environmental taxes. The output representing passengers on board should be augmented by 9.62%. Table 9 shows the actual and target values and improvement rates for Hungary. To improve efficiency, Hungary must achieve a 95.45% reduction in air pollutants and greenhouse gases, a 95.16% reduction in kerosene and jet fuel consumption, a 94.87% reduction in energy product usage, and total environmental taxes. The output representing commercial passenger air flights should be augmented by 7.11%.

Table 8. Luxembourg target values and potential improvement rates

Inputs/Outputs	*Realized*	*Target*	*Potential Improvement Rate (%)*
Air pollutants and greenhouse gases	4656653.50	325657.00	-94.66%
Kerosenes and jet fuels	62588.00	4377.01	-91.91%
Energy products	648299.00	34069.48	-95.01%
Total environmental taxes	4.75	0.33	-91.91%
Commercial passenger air flight	25771.00	25771.00	0.00 %
Passenger on board	2003363.00	2122836.13	9.62%

Table 9. Hungary target values and potential improvement rates

Inputs/Outputs	*Realized*	*Target*	*Potential Improvement Rate (%)*
Air pollutants and greenhouse gases	2252840.08	110339.27	-95.45%
Kerosenes and jet fuels	318053.00	15507.29	-95.16%
Energy products	318627.00	16334.27	-94.87%
Total environmental taxes	43.45	2.23	-94.87%
Commercial passenger air flight	38691.00	41864.41	7.11%
Passenger on board	4669368	4.669.368.00	0.00%

Table 10 shows the actual and target values and improvement rates for Ireland. To achieve efficiency, Ireland must reduce air pollutants and greenhouse gases by 96.62%, kerosene and jet fuel use by 95.24%, and energy products and total environmental taxes by 96.03%. Figure 6 displays a potential enhancement graph for Ireland's inputs and outputs.

Table 10. Ireland target values and potential improvement rates

Inputs/Outputs	*Realized*	*Target*	*Potential Improvement Rate (%)*
Air pollutants and greenhouse gases	6047706.11	198344.68	-96.62%
Kerosenes and jet fuels	940686.00	29253.41	-96.24%
Energy products	946093.00	31028.71	-96.03%
Total environmental taxes	135.68	4.45	-96.03%
Commercial passenger air flight	83216.00	83216.00	0.00%
Passenger on board	9106693.00	9106693.00	0.00%

Another piece of data derived from the same analysis includes the values of the input and output contributions. These data demonstrate the efficacy of the inputs and outputs in establishing the efficiency scores of decision-making units. The graphs below depict the input/output contribution ratios of the four countries with the lowest efficiency values.

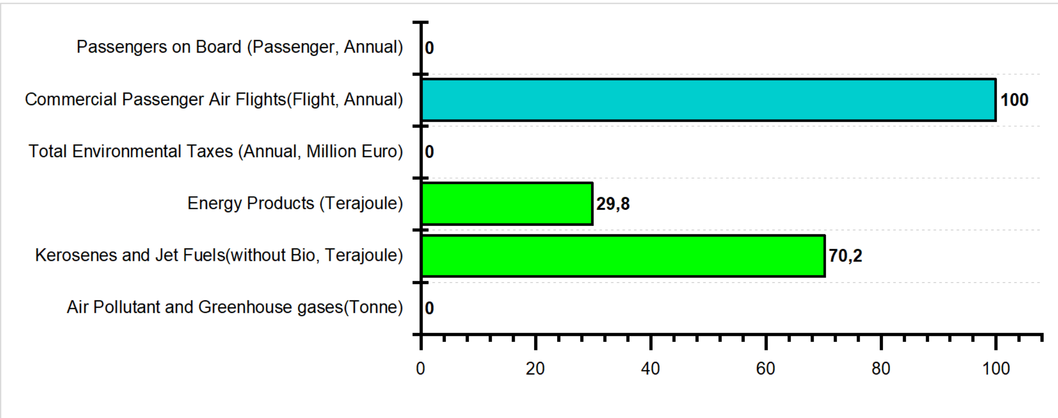

Figure 3. Inputs/outputs contribution ratios for Austria

The efficiency score for Austria indicated that the input of kerosene and jet fuels was 70.1% effective, the input of energy products was 29.8% effective, and the output of commercial passenger airflights was 100% effective. Figure 3 shows a graph of the input/output contribution rates for Austria. Similarly, the efficiency score for Luxembourg indicated that the input of kerosene and jet fuels was 14.2% effective, the input of the total environmental tax was 85.8% effective, and the output of commercial passenger air flights was 100% effective. Figure 4 shows a graph of the input/output contribution ratios for Luxembourg.

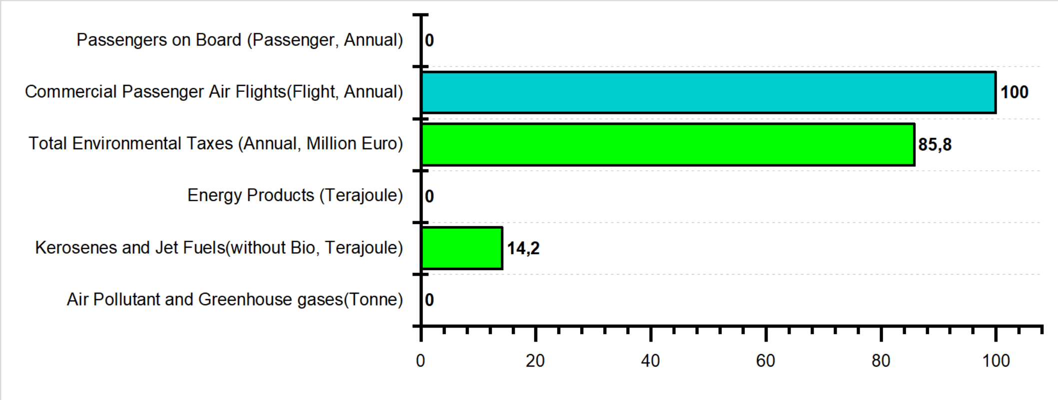

Figure 4. Inputs/outputs contribution ratios for Luxembourg

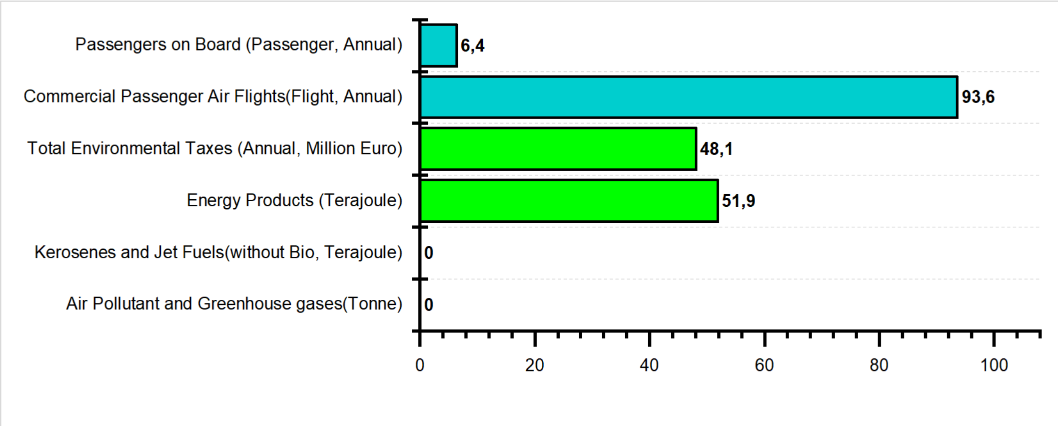

Figure 5. Inputs/outputs contribution ratios for Ireland

According to Ireland's efficiency score, the input data for energy products and the total environmental tax were 51.9% and 48.1%, respectively. On the other hand, the output data for the commercial passenger air flight and passenger on board were 93.6% and 6.4% efficient, respectively. Figure 5 shows the curve illustrating the input/output contribution ratios for Ireland. In the efficiency score for Hungary, the effectiveness of the energy product input was 22.1%, total environmental tax input was 77.9%, and number of passengers transported was 100%. Figure 6 shows the curve illustrating the input/output contribution ratios for Hungary.

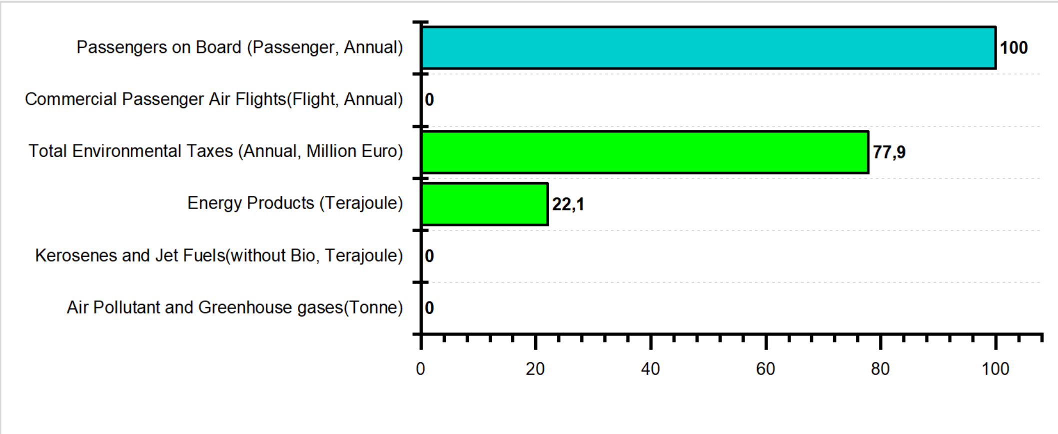

Figure 6. Inputs/outputs contribution ratios for Hungary

5. DISCUSSION and CONCLUSION

This study uses DEA, a commonly employed method in economic efficiency research, to assess the environmental efficiency of the airline industry in various countries. The analysis aimed to minimize inputs associated with environmental impacts from airline activities in 2021 while maintaining consistent levels of total passengers and flight numbers. The findings indicate that Greece, Estonia, France, Spain, Cyprus, Lithuania, Croatia, Italy, Portugal, Slovenia, Latvia, Slovakia, and Sweden are characterized by efficiency. Ireland ranks as the country with the lowest efficiency in terms of air pollution and greenhouse gas emissions, consumption of kerosene and jet fuels, utilization of energy products, and the correlation between overall environmental taxes and the total volume of flights and passengers. The primary environmental factor included in the countries' efficiency ranking was "air pollution and greenhouse gases," accounting for 24.24% of the overall assessment. Cyprus was used as a benchmark ten times among the efficient countries, while Italy was used seven times, Greece six times, Sweden five times, and Latvia five times. After analyzing the target values of the environmental inputs that must be decreased to achieve the same output, it was determined that Ireland, Hungary, Luxembourg, and Austria need to reduce air pollution and greenhouse gas inputs the most. Ireland, Hungary, Austria, and Luxembourg should implement measures to decrease their total environmental tax input and enhance their effectiveness. Ireland, Luxembourg, Hungary, and Austria must undertake essential measures to utilize energy resources. Ireland, Hungary, Luxembourg, and Austria must implement measures to decrease their consumption of kerosene and jet fuels. Regarding the impact on efficiency, Luxembourg should aim to increase the number of passengers transported by 9.62%, whereas Hungary should focus on increasing the overall number of flights by 7.11%. Based on these findings, it has been concluded that despite the measures implemented and goals established to mitigate the environmental effects of aviation in European Union countries, airline transportation remains inefficient in half of the member nations. Germany, a highly advanced European economy, has fallen behind in terms of airline efficiency when considering environmental factors. This suggests that even member countries such as France and Italy, which are fully efficient, do not fully adhere to the union's policies. Furthermore, the failure of numerous member states to achieve satisfactory environmental performance despite stringent policies underscores the challenges associated with policy implementation and compliance.

Our findings align with prior studies, although they also present different perspectives regarding the challenges of environmental efficiency for airlines operating within the EU. Although global demand for standardization and harmonized regulations presents evident economic efficiency advantages by enabling economies of scale that reduce compliance costs, prior research highlights significant environmental performance disparities regarding both local enforcement rigor and overall outcomes across EU countries, despite legislative homogenization through key initiatives such as the ETS and CORSIA. Kim and Son (2021) indicate that the EU ETS aims for a uniform emission reduction norm across nations; nevertheless, its practical implementation has resulted in disparities in compliance and effectiveness due to the different economic development of member states, among other variables. This aligns with findings from other research indicating that environmental compliance is affected by regional economics and fuel dependency (Efthymiou and Papatheodorou, 2019), which may explain the subpar performance of Ireland (developed) and Germany (developed), whereas Cyprus (an island nation akin to Iceland, with development concentrated on both sides treating a unit developed factor "island") and Italy (where government-provided social services function optimally) perform better. Reliance on conventional fuels and variations in aviation demand trends often affect environmental efficiency in the EU. Performance disparities between high-performing nations like Sweden and low-efficiency nations such as Ireland may suggest wider global economic factors, like energy use, rather than only compliance with regulations. Studies demonstrate that nations reliant on traded fuels generally produce elevated emissions, with aviation demand exacerbating environmental inefficiencies. This highlights the significant impact of fossil fuel use and demand variations on the EU's environmental performance (Kim and Son, 2021). Countries that incorporate a greater proportion of renewable energy typically attain enhanced efficiency results, chiefly via the utilization of sustainable aviation fuels (SAFs). The implementation of SAFs can diminish emissions but encounters economic obstacles in areas dependent on fossil fuels (Pechstein et al., 2020 ; Scheelhaase, 2023). Economic evaluations indicate performance disparities among nations, with Sweden reaping advantages from renewable energy adoption, whereas Ireland demonstrates inferior performance due to economic and infrastructural variances rather than exclusively regulatory factors (Jaśkowski, 2021). Countries with high Human Development Index (HDI) such as Denmark, Norway, and Finland encounter specific environmental issues in their aviation industries, including the extended reliance on fossil-based jet fuels and societal demands for substantial decreases in carbon emissions. Despite being leaders in both sectors, their aviation efficiency falls short due to the high demand for flights among Nordic nations and the reluctance of airlines to switch from subsidized conventional jet fuel (kerosene). Sustainable Aviation Fuels (SAFs) can diminish emissions compared to conventional jet fuels; however, high costs and limited production capacities impede their extensive implementation, particularly in regions with established infrastructure for traditional fossil fuels (Colantuono, 2021; Grimme, 2023).

Furthermore, their insufficient relative position in overall sustainability performance, compared to aviation inefficiencies, indicates that any action will probably yield only a negligible effect at most. Propelled by worldwide travel and regional connectivity, the escalating demand for aviation intensifies environmental limitations unless there is enhanced support for low-carbon fuels or more stringent regulations to reduce emissions in the industry (Grimme, 2023). These nations possess comprehensive environmental legislation; yet, there is an absence of targeted regulations to efficiently reduce aviation emissions, including incentives for sustainable aviation fuel and industry-specific carbon taxes (Climate Catalyst, 2023).Tailored industry solutions, such as increasing SAF production or innovating technologies to comprehensively decarbonize aviation, could help bridge that gap and link the sector more closely with these governments' overarching environmental objectives.

This study had some limitations. Reliance on country-level data may obscure variances among airlines within countries, potentially resulting in neglect of exemplary practices. This emphasis on the environmental effects of particular inputs and outputs may overlook other significant issues such as trash or water consumption. The analysis presents a single-year data snapshot, offering a cross-sectional rather than a longitudinal perspective, thereby precluding the ability to monitor energy efficiency increases over time and evaluate the impact of policy changes or technological advancements on these gains.

Future studies should incorporate longitudinal studies to monitor efficiency over time, and comprehensive airline-level data to facilitate successful practices within countries. A wider array of environmental concerns and policy alternatives from countries in the upper echelons may yield more implementable recommendations. Investigating the relationship between environmental efficiency and financial success may reveal potential synergies or trade-offs. This may result in more comprehensive recommendations to enhance environmental efficiency in the EU aviation sector.

Author Contrubitions
Tuğba Akbıyık: Literature review, Conceptualization, Methodology, Data Curation, Analysis, Writing-original draft *Tunahan Avcı*: Modelling, Writing-review and editing

Conflict of Interest
No potential conflict of interest was declared by the authors.

Funding
Any specific grant has not been received from funding agencies in the public, commercial, or not-for-profit sectors.

Compliance with Ethical Standards
It was declared by the authors that the tools and methods used in the study do not require the permission of the Ethics Committee.

Ethical Statement
It was declared by the authors that scientific and ethical principles have been followed in this study and all the sources used have been properly cited.

REFERENCES

ACI. (2023). "Annual World Airport Traffic Report 2023", https://store.aci.aero/wp-content/uploads/2023/09/Preview-2023-ACI-WATR-09-2023.pdf, (Accessed: 10.06.2024).

Adler, N. and Golany, B. (2001). "Evaluation of deregulated Airline Networks Using Data Envelopment Analysis Combined with Principal Component Analysis with An Application to Western Europe", *European Journal of Operational Research*, 132, 260-273. https://doi.org/10.1016/S0377-2217(00)00150-8

Aksoy, T., Yüksel, S., Dincer, H., Hacioglu, U. and Maialeh, R. (2022). "Complex Fuzzy Assessment of Green Flight Activity Investments in the Sustainable Aviation Industry*", IEEE Access*, 10, 127297-127312.

Amicarelli, V., Lagioia, G., Patruno, A., and Grosu, R.M. and Bux, C. (2021). "Enhancing the Sustainability of the Aviation Industry: Airlines' Commitment to "Green" Practices", *Amfiteatru Economic*, 23(15), 934-947.

Anger, A. (2010). "Including Aviation in the European Emissions Trading Scheme: Impacts on the Industry, CO_2 Emissions, and Macroeconomic Activity in the EU", *Journal of Air Transport Management*, 16, 100-105. https://doi.org/10.1016/J.JAIRTRAMAN.2009.10.009

Arjomandi, A., Dakpo, K. and Seufert, J. (2018). "Have Asian airlines Caught Up with European Airlines? A By-Production Efficiency Analysis", *Transportation Research Part A: Policy and Practice*. https://doi.org/10.1016/J.TRA.2018.06.031

Aygün, S., Sağbaş, M. and Erdoğan, F.A. (2023). "Bibliometric Analysis of Sustainability in Civil Aviation", *Journal of Aviation,* 7(3), 448-456.

Bal, V. (2013). "Efficiency Data Envelopment Analysis to Determine the Private Universities", *Manas Journal of Social Studies*, 2(1), 1-14

Barros, C.P. and Dieke, P.U.C. (2007). "Performance Evaluation of Italian Airports: A Data Envelopment Analysis", *Journal of Air Transport Management*, 13(4), 184-191.

Bergantino, A. and Loiacono, L. (2019). "Market-Based Measures: The European Union Emission Trading Scheme and the Carbon Offsetting and Reduction Scheme for International Aviation", *Sustainable Aviation,* Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-030-28661-3_7

Brugnoli, A., Button, K., Martini, G. and Scotti, D. (2015). "Economic Factors Affecting the Registration of Lower CO2 Emitting Aircraft in Europe", *Transportation Research Part D: Transport and Environment*, 38, 117-124.

Charnes, A., Cooper, W.W. and Rhodes, E. (1978). "Measuring the Efficiency of Decision-Making Units", *European Journal of Operational Research*, 2(6), 429-444.

Charnes, A., Cooper, W.W. and Thrall, R.M. (1991). "A Structure for Classifying and Characterizing Efficiency and Inefficiency in Data Envelopment Analysis", *Journal of Productivity Analysis*, 2, 197-237.

Chi-Lok, A.Y. and Zhang, A. (2009). "Effects of Competition and Policy Changes on Chinese Airport Productivity: An Empirical Investigation", *Journal of Air Transport Management*, 15(4), 166-174.

Cifuentes-Faura, J. and Faura-Martínez, U. (2023). "Measuring Spanish Airport Performance: A Bootstrap Data Envelopment Analysis of Efficiency", *Utilities Policy*, 80, 101457.

Climate Catalyst. (2023). "Sustainable Aviation Fuel Policy in the European Union. Climate Catalyst", https://climatecatalyst.org/learning-hub/sustainable-aviation-fuel-policy-in-the-eu/, (Accessed: 10.06.2024).

Colantuono, R. (2021). "Market-Based Measures and Aviation Sustainability in the European Union: An Assessment", *SEEDS, Sustainability Environmental Economics and Dynamics Studies*, No. 0921.

Cui, Q. and Yu, L. (2021). "A Review of Data Envelopment Analysis in Airline Efficiency: State of the Art and Prospects." *Journal of Advanced Transportation*, 2021, 1–13. https://doi.org/10.1155/2021/2931734

Curi, C., Gitto, S. and Mancuso, P. (2011). "New Evidence on the Efficiency of Italian Airports: A Bootstrapped DEA Analysis," *Socio-Economic Planning Sciences*, 45(2), 84-93.

Efthymiou, M. and Papatheodorou, A. (2019). "EU Emissions Trading Scheme in Aviation: Policy Analysis and Suggestions." Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2019.117734

Eren, M. and Doğan, M.A. (2023). "Measurement of Process-Performances of Turkish Airports Using Network Data Envelopment Analysis", *Journal of Aviation*, 7(2), 272-283.

Eurostat. (2024). https://ec.europa.eu/eurostat/web/main/data/database, (Accessed: 10.06.2024).

Grimme, W. (2023). "The Introduction of Sustainable Aviation Fuels—A Discussion of Challenges, Options and Alternatives", *Aerospace*, 10(3), 218.

Gutiérrez, E. and Lozano, S. (2016). "Efficiency Assessment and Output Maximization Possibilities of European Small and Medium-Sized Airports", *Research in Transportation Economics*, 56, 3–14.

Heiaas, A. (2021). "The EU ETS and Aviation: Evaluating the Effectiveness of the EU Emission Trading System in Reducing Emissions from Air Travel", *Review of Business and Economics Studies,* 9(1), 84-120. https://doi.org/10.26794/2308-944X-2021-9-1-84-120

Hermoso, R., Latorre, M. and Martínez-Núñez, M. (2019). "Multivariate Data Envelopment Analysis to Measure Airline Efficiency in European Airspace: A Network-Based Approach", *Applied Sciences,* 9(24), 5312. https://doi.org/10.3390/app9245312

Hermoso-Orzáez, M.J., García-Alguacil, M., Terrados-Cepeda, J. and Brito, P. (2020). "Measurement of Environmental Efficiency in the Countries of the European Union with the Enhanced Data Envelopment Analysis Method (DEA) During the Period 2005–2012", *Environmental Science and Pollution Research*, 27, 15691-15715.

International Air Transport Association. (2019). "Data in Numbers - Airline Industry Economic Performance 2019", https://airlines.iata.org/sites/default/files/migrated/airlines/airlines/data-in-numbers-airline-industry-economi--p14-15-20data-airlines-202019-04.pdf , (Accessed: 10.06.2024).

ICAO. (2018). "Annual Report 2018", https://www.icao.int/annual-report-2018/Pages/default.aspx , (Accessed: 10.06.2024).

IEA. (2022). "World Energy Outlook 2022", https://iea.blob.core.windows.net/assets/830fe099-5530-48f2-a7c1-11f35d510983/WorldEnergyOutlook2022.pdf, (Accessed: 10.06.2024).

Inglada, V., Coto-Millan, P. and Inglada-Perez, L. (2017). "Evaluating Productivity and Efficiency of Spanish Airports After Air Transport Liberalization", *Revista De Evaluacion De Programas Y Politicas Publicas*, (9), 99–112.

Jaśkowski, M. (2021). "External Aspects of the EU ETS in Aviation in Light of CORSIA", *International Community Law Review*, 23(2-3), 271-282.

Kao, C. (2014). "Network Data Envelopment Analysis: A Review." European Journal of Operational Research, 239, 1-16. https://doi.org/10.1016/j.ejor.2014.02.039

Keskin, B. and Köksal, C.D. (2019). "A Hybrid AHP/DEA-AR Model for Measuring and Comparing the Efficiency of Airports", *International Journal of Productivity and Performance Management*, 68(3), 524-541.

Khomenko, S., Cirach, M., Pereira-Barboza, E., Mueller, N., Barrera-Gómez, J., Rojas-Rueda, D., Hoogh, K., Hoek, G. and Nieuwenhuijsen, M. (2021). "Premature Mortality Due to Air Pollution in European Cities: A Health Impact Assessment", *The Lancet Planetary Health*, 5(3), e121 - e134. https://doi.org/10.1016/S2542-5196(20)30272-2

Kim, H. and Son, J. (2021). "Analyzing the Environmental Efficiency of Global Airlines by Continent for Sustainability", *Sustainability*, 13, 1571. https://doi.org/10.3390/SU13031571

Korba, P., Sekelová, I., Koščáková, M. and Behúnová, A. (2023). "Passengers' Knowledge and Attitudes Toward Green Initiatives in Aviation", *Sustainability,* 15(7), 6187. https://doi.org/10.3390/su15076187

Kousoulidou, M. and Lonza, L. (2016). "Biofuels in Aviation: Fuel Demand and CO2 Emissions Evolution in Europe Toward 2030", *Transportation Research Part D: Transport and Environment*, 46, 166-181. https://doi.org/10.1016/J.TRD.2016.03.018

Kucukvar, M., Alawi, K.A., Abdella, G.M., Bulak, M.E., Onat, N.C., Bulu, M. and Yalçıntaş, M. (2021). "A Frontier-Based Managerial Approach for Relative Sustainability Performance Assessment of the World's Airports", *Sustainable Development*, 29(1), 89-107.

Kuljanin, J., Kalic, M., Caggiani, L. and Ottomanelli, M. (2019). "A Comparative Efficiency and Productivity Analysis: Implication to Airlines Located in Central and South-East Europe", *Journal of Air Transport Management,* 78, 152-163. https://doi.org/10.1016/J.JAIRTRAMAN.2019.01.009

Lacko, R. and Hajduová, Z. (2018). "Determinants of Environmental Efficiency of the EU Countries Using Two-Step DEA Approach", *Sustainability,* 10(10), 3525. https://doi.org/10.3390/SU10103525

Lawton, R.N. and Fujiwara, D. (2016). "Living with Aircraft Noise: Airport Proximity, Aviation Noise and Subjective Wellbeing in England", *Transportation Research Part D: Transport and Environment*, 42, 104-118.

Lin, L.C. and Hong, C.H. (2006). "Operational Performance Evaluation of International Major Airports: An Application of Data Envelopment Analysis", *Journal of Air Transport Management*, 12(6), 342-351.

Lin, Z. (2013). "Making Aviation Green", *Advances in Manufacturing*, 1, 42-49. https://doi.org/10.1007/S40436-013-0008-3

Lozano, S., Gutiérrez, E. and Moreno, P. (2013). "Network DEA Approach to Airports Performance Assessment Considering Undesirable Outputs", *Applied Mathematical Modelling*, 37(4), 1665-1676.

Matsumoto, K., Makridou, G. and Doumpos, M. (2020). "Evaluating Environmental Performance Using Data Envelopment Analysis: The Case of European Countries", *Journal of Cleaner Production*, 272, 122637. https://doi.org/10.1016/j.jclepro.2020.122637

Muñiz, M., Paradi, J., Ruggiero, J. and Yang, Z. (2006). "Evaluating Alternative DEA Models Used to Control for Non-Discretionary Inputs", *Computers & Operations Research*, 33(5), 1173-1183.

Organisation for Economic Co-operation and Development. (2020). "CO2 Emissions from Air Transport", https://www.oecd.org/en/publications/co2-emissions-from-air-transport_ecc9f16b-en.html, (Accessed: 03.01.2025).

Oum, T.H. and Yu, C. (2004). "Measuring Airports' Operating Efficiency: A Summary of the 2003 ATRS Global Airport Benchmarking Report", *Transportation Research Part E: Logistics and Transportation Review*, 40(6), 515-532.

Oum, T.H., Yu, C. and Fu, X. (2003). "A Comparative Analysis of Productivity Performance of the World's Major Airports: Summary Report of the ATRS Global Airport Benchmarking Research Report—2002", *Journal of Air Transport Management*, 9(5), 285-297.

Pacagnella Junior, A.C., Hollaender, P.S., Mazzanati, G.V. and Bortoletto, W.W. (2020). "Infrastructure and Flight Consolidation Efficiency of Public and Private Brazilian International Airports: A Two-Stage DEA and Malmquist Index Approach", *Journal of Advanced Transportation*, 2020, 1-15.

Paleari, S., Redondi, R. and Malighetti, P. (2010). "A Comparative Study of Airport Connectivity in China, Europe and US: Which Network Provides the Best Service to Passengers?", *Transportation Research Part E: Logistics and Transportation Review*, 46(2), 198-210.

Pechstein, J., Bullerdiek, N. and Kaltschmitt, M. (2020). "A 'Book and Claim' Approach to Account for Sustainable Aviation Fuels in the EU-ETS—Development of a Basic Concept", *Energy Policy*, 136, 111014.

Perelman, S. and Serebrisky, T. (2010). "Measuring the Technical Efficiency of Airports in Latin America", World Bank Policy Research Working Paper, (5339).

Rai, A. (2017). "Measurement of Efficiency in the Airline Industry Using Data Envelopment Analysis", *Investment Management & Financial Innovations*, 10(1), 38-45.

Scheelhaase, J. and Maertens, S. (2020). "How to Improve the Global 'Carbon Offsetting and Reduction Scheme for International Aviation' (CORSIA)?", *Transportation Research Procedia*, 51, 108-117.

Song, K., Choi, S. and Han, I. (2020). "Competitiveness Evaluation Methodology for Aviation Industry Sustainability Using Network DEA", *Sustainability*, 12(24), 10323. https://doi.org/10.3390/su122410323

Song, Z., Li, Z. and Liu, Z. (2024). "Comparison of Emission Properties of Sustainable Aviation Fuels and Conventional Aviation Fuels: A Review", *Applied Sciences*, 14(13), 5484.

Tatari, O. and Kucukvar, M. (2012). "Eco-Efficiency of Construction Materials: Data Envelopment Analysis", *Journal of Construction Engineering and Management*, 138(6), 733-741.

Uzgoren, E. and Sahin, G. (2013). "Measurement of the Performances of Dumlupinar University Vocational High Schools Using Data Envelopment Analysis", *International Journal of Management Economics and Business*, 9(18), 1-14.

Viegi, G., Baldacci, S., Maio, S., Fasola, S., Annesi-Maesano, I., Pistelli, F., Carrozzi, L., Grutta, S. and Forastiere, F. (2020). "Health Effects of Air Pollution: A Southern European Perspective", *Chinese Medical Journal*, 133, 1568-1574. https://doi.org/10.1097/CM9.0000000000000869

Walker, S. and Cook, M. (2009). "The Contested Concept of Sustainable Aviation", *Sustainable Development*, 17, 378-390. https://doi.org/10.1002/SD.400

Wanke, P.F. (2012). "Capacity Shortfall and Efficiency Determinants in Brazilian Airports: Evidence from Bootstrapped DEA Estimates", *Socio-Economic Planning Sciences*, 46(3), 216-229.

Winter, S., Crouse, S. and Rice, S. (2021). "The Development of 'Green' Airports: Which Factors Influence Willingness to Pay for Sustainability and Intention to Act? A Structural and Mediation Model Analysis", *Technology in Society*, 65, 101576. https://doi.org/10.1016/J.TECHSOC.2021.101576

Wu, J. and Zhou, Z. (2015). "A Mixed-Objective Integer DEA Model", *Annals of Operations Research*, 228, 81-95.

Yan, W., Cui, Z. and Gil, M.J.Á. (2016). "Assessing the Impact of Environmental Innovation in the Airline Industry: An Empirical Study of Emerging Market Economies", *Environmental Innovation and Societal Transitions*, 21, 80-94.

Yoshida, Y. and Fujimoto, H. (2004). "Japanese-Airport Benchmarking with the DEA and Endogenous-Weight TFP Methods: Testing the Criticism of Overinvestment in Japanese Regional Airports", *Transportation Research Part E: Logistics and Transportation Review*, 40(6), 533-546.