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Analyzing the Environmental Efficiency of Global Airlines by Continent for Sustainability

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Abstract: The study of environmental sustainability in the aviation industry mainly focuses on research targeting specific regions such as the United States, Europe, and China. However, for the environmental sustainability of the aviation industry, global airlines on all continents around the world must implement efficient environmental management. This study divides the world into six continents and attempts to verify environmental efficiency for airlines belonging to each continent. Using data from 2014 to 2018 of 31 global airlines, this study compares environmental efficiency in the aviation industry by continent and individual airline. Data envelopment analysis (DEA), which is actively used in efficiency studies was adopted as an analysis method. We find that, first, airlines in Europe and Russia have the highest environmental efficiency, and airlines in North America and Canada are the second highest, which can be a good benchmark for other airlines. Second, in technical efficiency (TE) values, airlines in Africa and the Middle East and Latin America generally have low efficiency; but, in the airlines in Africa and the Middle East, environmental efficiency is steadily improving slightly. In comparison, airlines in Latin America showed a decrease in environmental efficiency value, requiring a lot of effort and investment to improve efficiency. Third, for airlines in North America and Canada, the scale efficiency (SE) value was the lowest, even though there was a high level of overall environmental efficiency, indicating the need for efficiency improvement through economies of scale. This study has implications, in that, it suggests how airlines can perform efficient environmental management for sustainability according to the continent to which they belong.

Keywords: environmental efficiency; global airline; sustainability; environmental management; technical efficiency; pure technical efficiency; scale efficiency

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1. Introduction

Since the 2000s, various airlines have been launched and are pursuing fierce survival strategies. The global aviation industry has experienced rapid growth up until 2019. In 2019, there were 4.5 billion people traveling between cities and countries through airports. The world's population is 7.8 billion, and 58% of the total population traveled by air [1]. However, due to the global economic downturn, financial crisis, and rising oil prices in the international air transport market, airlines face a deteriorating business environment, such as rising operating costs, falling profit rates, and intensifying competition. For this reason, the aviation market needs strategies to secure competitiveness. Full-service carriers (FSCs) efficiently manage internal resources by improving service quality and implementing environmental management, such as carbon dioxide emission reduction, to compete with low-cost carriers (LCCs) [2]. Beyond the aviation industry, international organizations including International Civil Aviation Organization (ICAO) and various countries are proposing regulations and policies to reduce aircraft greenhouse gas emissions; therefore, efforts to manage environmental efficiency are required. However, empirical studies that investigate sustainability strategies of the global aviation industry and their effectiveness remain insufficient.

Efficiency studies in the aviation industry are mostly concerned about operational efficiency and use economic variables [3–6]. However, in 2012, the European Union Emission Trading System (EU ETS) was announced, and carbon emission regulations became mandatory for most airlines, and airlines began to focus on environmental management [7,8]. Most of the research subjects of existing studies on the environmental efficiency of airlines have been limited to global airlines mainly belonging to the American and European continents [9,10]. On the other hand, there are few studies on the environmental efficiency of global airlines in Latin America, Africa, and the Middle East.

Therefore, for environmental management of the global aviation industry, it is necessary to analyze the environmental efficiency of global airlines belonging to all continents [6]. Arjomandi and Seufert [6] measured the environmental performance of global airlines on all continents using the International Air Transport Association (IATA)'s regional classification, which divided the world into six continents. They analyzed the technical and environmental efficiency of the airline data from 2007 to 2010 using the data envelopment analysis (DEA) method. However, their research has limitations, in that, the analysis data is outdated and the number of airlines belonging to Latin America, Africa, and the Middle East is insufficient. Considering that efforts to reduce greenhouse gas in the aviation industry worldwide in earnest after 2010, the analysis is needed on environmental efficiency, based on the recent data.

This study uses data from 2014 to 2018 on six continents, and adds several variables validated in the latest literature on environmental management of the aviation industry to validate environmental efficiency with DEA.

2. Literature Review

2.1. Environmental Sustainability of the Aviation Industry

For sustainable management, the importance of green business practices and environmental sustainability has been emphasized by many researchers [11–15]. A qualitative literature review was conducted to define the concept of environmental sustainability in the aviation industry [16], and case studies of airports and airlines were conducted to derive the key drivers of environmental sustainability [17,18]. In addition, environmental productivity and financial productivity were analyzed through the reduction of CO_2 emissions [19], and an economic model was derived to estimate the energy efficiency of long- and short-haul aircraft [20]. Recently, a model capable of predicting uncertain aircraft fuel consumption was derived from a learning technique, and practical insights were provided through simulation using numerical data [21].

Research related to environmental sustainability has been conducted using several methods. Regression analysis has mainly been used to analyze the relationship between resource inputs and performance [19,22,23]. In previous studies, environmental variables were included as independent variables, and financial performance and environmental performance were set as dependent variables to identify the relationship of variables. Yan et al. [22] measured the impact of environmental innovations on airlines' financial performance and operational efficiency in emerging countries. Brugnoli et al. [19] found that CO_2 reduction per seat in aircraft was mainly caused by the change in aviation fuel cost and high demand for fuel-efficient aircraft. Brueckner and Abreu [23] showed that the reduction in flight delay had a significant effect on carbon emissions in an analysis of the causal relationship between fuel consumption and carbon emissions using data from 1995 to 2015 of the U.S. airlines.

Table 1 summarizes the main contents of previous studies on environmental sustainability of the aviation industry.

Table 1. Literature on environmental sustainability of the aviation industry.

Author (Year)	Method	Object	Results
Abdullah et al. (2016) [24]	Literature review	Defining key success factors for the future green aviation insdustry	It demonstrates the need for a degree of understanding of key success factors when comparing airline performance measures. Through the benchmarking for high-performing green airlines, the green airline framework can be a solution for a future green airline industry.
Amankwah-Amoah (2020) [17]	Literature review, Case study	Reviewing green business practices (GBP), environmental sustainability policies in the global aviation industry with COVID-19:British Airways, Air France-KLM, Turkish Airlines, Ethiopian Airlines, Ryanair	Some airlines and industrial bodies sought to sidestep environmentally friendly commitments and practices to overcome new challenges such as cost pressures, survival threat, and deprioritizing environmental sustainability initiatives.
Lynes and Dredge (2006) [18]	Case study, Interview	Environmental commitment in the aviation industry: Scandinavian Airlines	It reviews environmental management drivers from Scandinavian Airlines System. Internal leadership in senior management positions played a key role in the positive outcomes of the airline's environmental performance.
Yan et al. (2016) [22]	Multiple regression	Secondary data manually collected from 40 airline companies in the emerging market economies	Process-based environmental innovations among technology- and process-based environmental innovations have a positive impact on airlines' profit.
Scotti and Volta (2015) [9]	Malmquist productivity index	Assessing the CO_2-sensitive productivity of European airlines from 2000 to 2010	The results show that airlines' relative CO_2 emissions have decreased from 2000 to 2010. In addition, the average productivity increase in environmentally sensible productivity growth is lower than that in traditional productivity growth. Finally, the improvements in load factor as well as a combined increase in stage length and aircraft size affect productivity changes positively, while fuel efficiency is significant only in the case of a CO_2-sensitive measure of productivity.
Brugnoli et al. (2015) [19]	Regression	Economic factors affecting the lower CO_2 emitting aircraft in Europe	Coupling with oligopolistic aircraft and aero engine industries seeking market share through product differentiation is the key driver for a fuel-efficient fleet change.
Girardet and Spinler (2013) [25]	Numerical economic model	Assessing the financial impact of the CO_2 costs for short- and long-haul aircraft based on present values and purchase options	An average influence of CO_2 costs on present values of €1.1 million for the short-haul plane and €4.1 million for the long-haul plane over the typical lifetime of an airplane. It underlines the importance of CO_2 and kerosene costs for long-haul aircraft.
Kang and Hansen (2018) [26]	Ensemble learning technique	Proposing a novel discretionary fuel estimation approach for dispatchers	The novel discretionary fuel estimation approach is found to substantially reduce unnecessary discretionary fuel loading while maintaining the same safety level compared to the current fuel loading practice.
Brueckner and Abreu (2017) [23]	Regression	Annual data on individual US airlines over the 1995–2015 period	The estimated fuel-price effect allows the emissions impact of an optimal emissions charge to be computed, and the estimated delay effect shows the emissions impact of an industry-wide reduction in flight delays.
Tan et al. (2017) [27]	Regression	Travel and tourism industry (airlines, casinos, hotels, and restaurants) across different economic regions in 2003–2014	Environmental performance (EP) positively affects the financial performance (FP) when aggregate EP is used. When individual dimensions of EP are considered, resource reduction is found to negatively affect the performance in the airline industry.

2.2. *Environmental Efficiency of the Aviation Industry*

Most precedent studies on the efficiency of the aviation industry have focused mainly on operational efficiency [3,24,25]. With the release of the EU ETS in 2012, carbon emission regulations were mandated for most global airlines. As a result, airlines began to pay attention to environmental efficiency [8,26]. Most of the aviation industry environmental efficiency studies have used data published by international aviation organizations such as

IATA and the ICAO or by the aviation authorities of each country. However, since international aviation organizations are determined to be affiliated through subscription, data on non-member airlines are not included. In addition, since the airlines affiliated with each international airline are different, the characteristics of the relevant international airlines can be reflected and the analysis results of the overall global airlines may be distorted.

Existing studies on the environmental efficiency of the aviation industry have mainly used limited areas such as the Americas and Europe for research. These regions correspond to continents with airlines with a long history [9]. Since then, a small number of researchers have studied environmental efficiency for global airlines including China and Asia [7,21,27]. However, existing studies have limitations in that they are limited to certain continents. Table 2 summarizes the literature that analyzed the environmental efficiency of the aviation industry. IATA's regional classification, which divides global airlines into six continents, was applied. Most previous studies have mainly focused on airlines belonging to Europe and Russia, North America and Canada, and China and North Asia. In contrast, Latin America, Asia Pacific, Africa, and the Middle East were excluded from the sample or included in a very small proportion.

Table 2. Objects of literature on environmental efficiency of the aviation industry.

Author (Year)	Object	Object Detail		Region (Continent)
Cui et al. (2014) [8]	9 countries in 2008–2012	China, India, Japan, USA, Brazil	France, Germany, Russia, UK	Europe and Russia (4), North America and Canada (1), China and North Asia (3), Latin America (1)
Cui and Li (2015) [10]	11 international airlines in 2008–2012	China Eastern Airlines, China Southern Airlines, Korean Air, Qantas Airways, Air France-KLM, Lufthansa	Scandinavian Airlines, Delta Air Lines, Alaska Airlines, Air China, Hainan Airlines	Europe and Russia (3), North America and Canada (2), China and North Asia (5), Asia Pacific (1)
Scotti and Volta (2015) [9]	18 major European airlines in 2000–2010	Air France, Finnair, Air Malt, Lufthansa, Alitalia, Malev Hungarian Airlines, Czech Airlines, British Airways, BMI, Austrian Airlines	Cyprus Airways, Tarom, Iberia, Scandinavian Airlines, Adria Airways, TAP Air Portugal, KLM, Virgin Atlantic Airways	Europe and Russia (18)
Xu and Cui (2017) [28]	19 international airlines in 2008–2014	China Eastern, China Southern, Korean Air, Qantas, Air France-KLM, Lufthansa, Scandinavian, Delta, Air China, Hainan	Emirates, Air Canada, Cathay Pacific, Singapore, All Nippon Airways, Eva Air, Turkish, Thai, Indonesia	Europe and Russia (4), North America and Canada (2), China and North Asia (10), Asia Pacific (2), Africa and the Middle East (1)
Cui and Li (2016) [29]	22 airlines in 2008–2012	Air Canada, Air China, Air France-KLM, All Nippon Airways, American Air, Asiana Airlines, British Airways, Cathay Pacific Airlines, China Eastern Airlines, China Southern Airlines, Delta Air Lines, Emirates Airline	Hainan Airlines, Japan Airlines, Korean Air, Lufthansa Airlines, Malaysia Airlines, Qantas Airways, Scandinavian Airlines, Singapore Airlines, Thai Airways, Turkish Airlines	Europe and Russia (5), North America and Canada (3), China and North Asia (12), Asia Pacific (1), Africa and the Middle East (1)

3. Methodology

3.1. Analysis Method

Efficiency refers to the ratio of outputs to inputs [30]. The representative method of measuring efficiency is DEA. It evaluates relative efficiency by deriving the most efficient production frontier from the actual inputs and outputs of the evaluation target based on linear programming, without assuming a specific function type and by measuring how far away the evaluation targets are from the production frontier.

DEA measures the relative efficiency between decision-making units (DMUs). Moreover, it presents benchmarking target organizations that should be considered as models for an inefficient DMU to become efficient. It suggests the amount of inputs that need to decrease or the amount of outputs that need to increase for the inefficient DMU to become efficient [30]. Because of these advantages, DEA is used as a method to analyze organizational performance and is particularly useful in evaluating the efficiency of various service companies such as airlines, airports, banks, and hotels [29–32]. Therefore, this study applied DEA to analyze the environmental efficiency of airlines for sustainable management.

Various DEA models have been developed, but the Charnes–Cooper–Rhodes (CCR) and Banker–Charnes–Cooper (BCC) models, which are used most often, were applied. The CCR model was developed by Charnes et al. [33]; it assumes constant returns to scale, while the BCC model was developed by Banker et al. [34] and assumes variable returns to scale. Based on this assumption, the efficiency derived from the CCR model corresponds to the technical efficiency (TE), and the efficiency measured by the BCC model corresponds to the pure technical efficiency (PTE). TE is a measure of how efficiently inputs are converted into outputs in the production process and can be divided into PTE and scale efficiency (SE). PTE is derived by removing the effect of scale from TE, and SE measures how efficiently each DMU meets the economies of scale and makes production activities more efficient. The CCR model does not take into account the scale profitability of each DMU, and it has the disadvantage of not being able to distinguish between PTE and SE because it assumes a constant scale when evaluating efficiency. With the BCC model, the overall efficiency of each DMU can be divided into PTE and SE [35]. The CCR and BCC models are divided into the input-oriented model that minimizes inputs with fixed outputs and the output-oriented model that maximizes outputs at given inputs [36]. As the targets of this study are airlines that pursue profit, it considered the management goal of maximizing outputs using given inputs. Accordingly, the output-oriented model was selected to analyze the extent of inefficiency in the outputs of airlines.

First, to analyze the efficiency of DMUs using the output-oriented CCR model, a linear programming model, as shown in Equation (1), is used.

$$\begin{gathered}\theta_{CCR}^{k*} = Max_{\theta,\lambda}\theta_{CCR}^{k}\\ \text{subject to}\\ x_m^k \geq \sum_{j=1}^{J} \lambda^j x_m^j \; (m = 1,\, 2,\, \ldots,\, M)\\ \theta_{CCR}^{k} y_n^k \leq \sum_{j=1}^{J} \lambda^j y_n^j \; (n = 1,\, 2,\, \ldots,\, N)\\ \lambda^j \geq 0 \; (j = 1,\, 2,\, \ldots,\, J)\end{gathered} \tag{1}$$

where, M is the number of inputs; N is the number of outputs; and J is the number of DMUs. When the input is X and the output is Y, if there is an input element vector $X = (x_1, x_2, \ldots, x_M) \geq 0$ and an output element vector $Y = (y_1, y_2, \ldots, y_N) \geq 0$, the combination of all the input and output elements that can be produced at this time is called the production possible set. Equation (1) is a formula to find the ratio, θ^{k*}, that can increase the outputs as much as possible without changing the inputs of the observation value under the premise that the k-th DMU belongs to the production possible set. $x_m^k \geq \sum_{j=1}^{J} \lambda^j x_m^j$ is a constraint on the inputs, which means that the usage of the m-th input cannot be less than the linear combination of the inputs x_m^j, which is used by the DMUs. The constraint on the outputs, $\theta_{CCR}^k y_n^k \leq \sum_{j=1}^{J} \lambda^j y_n^j$, means that the n-th factor cannot exceed the linear combination of the outputs y_n^j produced by all DMUs. λ^j indicates the extent to which the j-th DMU contributed to constructing an efficient frontier.

Next, to analyze the efficiency of DMUs using the output-oriented BCC model, $\sum_{j=1}^{J} \lambda^j = 1$, which is a convexity constraint, must be added to Equation (1). The closer the objective functions, θ_{CCR}^{k*} and θ_{BCC}^{k*}, of the CCR and BCC models are to the value of 1, respectively, the more efficient is the DMU to be evaluated relative to the other DMUs; the closer it is to the value of 0, the relatively more inefficient that DMU is.

Lastly, SE is an index that measures how efficiently a DMU performs business activities in economies of scale, and it is calculated by Equation (2) [37].

$$\theta_{Scale}^{k*} = \frac{\theta_{CCR}^{k*}}{\theta_{BCC}^{k*}} \quad (2)$$

If the SE measured using Equation (2) has a value of 1, this means that the corresponding DMU is scale-efficient. If the value is not 1, this indicates that the DMU is operated in a larger or smaller scale than the optimal scale, which denotes inefficiency in terms of scale. If the SE is 1, the efficiency of the CCR and BCC models are the same, which indicates that the inefficiency of the constant returns to scale is not because of scale.

3.2. Input and Output Selection

Table 3 summarizes the inputs and outputs used in previous studies on the environmental efficiency of global airlines. Several previous studies used environmental variables in only one of inputs and outputs. Scotti and Volta [9] used economic variables including available seat kilometers (ASK) as inputs, and added CO_2 emissions to economic variables including revenue passenger kilometers (RPK). Xu and Cui [28] used aviation kerosene as one of inputs, and Liu et al. [20] selected outputs including CO_2 emissions and fuel consumption rate. Meanwhile, a few researchers used environmental variables as both inputs and outputs. Cui and Li [10] measured environmental efficiency by using inputs including volume of aviation kerosene and outputs including CO_2 emissions decrease index. Cui et al. [38] analyzed the environmental efficiency of global airlines by selecting inputs including volume of aviation kerosene and outputs including greenhouse gas emission.

For the sustainability of the aviation industry, environmental efficiency can be increased through reduction of energy consumption, elimination of waste, elimination of single-use plastic, introduction of aircraft weight reduction initiatives, promotion of alternative fuels, as well as reduction of carbon emissions. Some major airlines that invest heavily in the environment are showing results through various attempts to use alternative fuels and reduce aircraft weight. As a representative example, Air France-KLM discloses waste emissions and reductions in air noise in its sustainability report [39]. However, it is practically difficult to measure environmental efficiency using the various theoretically possible environmental footprints. The reason for this is that there are many global airlines that do not disclose related data, and even if it is announced, there are many periods of omission. Accordingly, in this study, aviation kerosene and CO_2 reduction, which were mainly used in previous studies that analyzed the environmental efficiency of aviation industry, are selected as input and output variables [3,7,10,26].

Table 3. Inputs and outputs of previous studies on environmental efficiency of global airlines.

Researcher (Year)	Input	Output
Cui and Li (2014) [7]	Labor, Capital, **Energy**	Passenger turnover volume, Freight turnover volume
Cui et al. (2014) [8]	Number of employees in energy industry, **Energy consumption amount,** Energy services amount	**CO_2 emissions per capita,** Industrial profit amount
Cui and Li (2015) [10]	Number of employees, Capital stock, **Aviation kerosene**	Revenue tonne kilometers (RTK), Revenue passenger kilometers (RPK), Total business income, **CO_2 emissions decrease index**
Cui et al. (2016) [38]	Number of employees, **Aviation kerosene**	Total revenue, **Greenhouse gas emission,** Capital stock
Scotti and Volta (2015) [9]	Available seat kilometers (ASK), Available freight tonne kilometers (AFTK)	Revenue passenger kilometers (RPK), Revenue freight tonne kilometers (RFTK), **CO_2 emissions**
Xu and Cui (2017) [28]	Number of employees, **Aviation kerosene,** Maintenance costs, Available seat kilometers (ASK), Available tonne kilometers (ATK), Fleet size, Number of destination, Revenue passenger kilometers (RPK), Revenue tonne kilometers (RTK), Sales costs	Available seat kilometers (ASK), Available tonne kilometers (ATK), Fleet size, Revenue passenger kilometers (RPK), Revenue tonne kilometers (RTK), Total business income, Intermediate: Available seat kilometers (ASK), Available tonne kilometers (ATK), Fleet size, Revenue passenger kilometers (RPK), Revenue tonne kilometers (RTK)
Liu et al. (2017) [20]	Capital, Labor	Revenue tonne kilometers (RTK), **CO_2 emissions,** Influencing factors: **Fuel consumption rate,** Movements—takeoffs and landings, Route distribution, Aircraft utilization rate
Choi (2017) [21]	Cost per available seat mile (CASM)	Revenue per available seat mile (RASM), Passenger yield, Load factor, Environmental variables: **Fuel expense,** Passenger revenue, Full-time equivalents (ETE), Total operating revenue

Note: Environmental efficiency variables are highlighted in bold.

Table 4 presents the inputs and outputs used in this study. This study selected aviation kerosene, operating cost, employee, and airline fleet. In addition, total revenue, RPK, RTK, passenger load factor, cargo load factor, and CO_2 reduction were used as outputs.

Table 4. Selection of inputs and outputs.

Variable		Description	Researcher (Year)
Input	Aviation kerosene	Fuel consumption	Azadeh et al. (2007) [40], Cui et al. (2014) [8], Clinch et al. (2001) [41]
	Operating cost	Operating cost	Cui and Li (2014) [7], Blomberg et al. (2012) [42]
	Employee	Number of employees	Liu et al. (2017) [20]
	Airline fleet	Number of fleets	Xu and Cui (2017) [28]
Output	Total revenue	Total revenue	Sarki (2000) [3], Onüt and Soner (2006) [43]
	RPK	Revenue passenger kilometers	Scheraga (2004) [44], Cui and Li (2015) [10]
	RTK	Revenue tonne kilometers	Scotti and Volta (2015) [9], Cui and Li (2015) [10]
	Passenger load factor	RPK/ASK	Sarki (2000) [3], Onüt and Soner (2006) [43]
	Cargo load factor	RTK/ATK	Xu and Cui (2017) [28]
	CO_2 reduction	Reduction in CO_2 emission	Clinch et al. (2001) [41], Cui and Li (2015) [10], Scotti and Volta (2015) [9]

3.3. Data Collection

The study adopted data from 2014 to 2018 of 31 global airlines on six continents. From the "World's Top 100 Airlines" announced by Skytrax, airlines were selected consecutively from 2014 to 2018. Skytrax is the reliable organization that measures airline service quality and customer satisfaction of global airlines. It has selected global airlines with excellent quality and customer satisfaction, and published "World's Top 100 Airlines" every year. Therefore, it has been mentioned in several studies [45–47]. In order to ensure continental representation of the selected samples, crosschecks with analysis samples of prior studies on environmental efficiency of the aviation industry confirmed that most airlines were consistent [6]. In addition, in terms of business model, in the case of the Africa and the Middle East continent, LCCs are rare, so this study was limited to FSCs for comparative analysis between continents.

Table 5 presents the sample of global airlines used in this study by continent. These airlines provide annual, sustainability, and corporate responsibility reports on their websites. Data from 45 global airlines were collected, but airlines with missing variables were deleted. Finally, an analysis was conducted on a sample of 31 global airlines from 2014 to 2018. Because the country to which the airlines belong and the currency used in that country are different, it was necessary to unify the currency unit of the collected data. Accordingly, financial variables were converted to the U.S. dollar based on the exchange rate as of December 2019. The exchange rate came from x-rates.com which is an exchange rate information site recommended for use by the Federal Reserve Banks in the United States.

The 31 global airlines selected as the sample belong to six continents: Europe and Russia (11), North America and Canada (2), Latin America (2), China and North Asia (7), Asia Pacific (4), and Africa and the Middle East (5). IATA's regional classification was applied to the continental classification of these airlines [6]. Data for the economic variables were collected from the annual reports published by the airlines, and data for the environmental variables were collected from the airlines' sustainability and corporate responsibility reports. The descriptive statistics of the data are shown in Table 6.

Table 5. Sample of global airlines.

Object	Airline		Continent
31 global airlines of 6 continents in 2014–2018	Singapore Airlines All Nippon Airways Cathay Pacific Airways Emirates Qantas Airways Lufthansa Thai Airways Japan Airlines Garuda Indonesia China Southern Airlines Austrian Airlines Air New Zealand KLM Royal Dutch Airlines British Airways Virgin Atlantic Aeroflot	Air France Iberia Turkish Airline Air Canada Finnair China Airlines Korean air Delta Air Lines Aegean Airlines Etihad Oman Air South African Airways LATAM Avianca Kenya Airways	Europe and Russia (11) North America and Canada (2) Latin America (2) China and North Asia (7) Asia Pacific (4) Africa and the Middle East (5)

Table 6. Descriptive statistics.

	Variable	Mean	Std. dev.	Min	Max
Input	Aviation kerosene (10^6 ton)	26,451	55,233	24	187,000
	Operating cost (10^6 dollars)	9005	8757	573	1,350,851
	Employee	32,683	32,624	1678	199,902
	Airline fleet	278	288	30	1439
Output	Total revenue (10^8 dollars)	10,571	9584	25	44,438
	RPK (10^4 person − kilometers)	83,115	72,344	8371	292,221
	RTK (10^4 ton − kilometers)	11,396	9845	1059	72,975
	Passenger load factor (%)	78.85	5.32	62.50	96.88
	Cargo load factor (%)	31.46	21.39	9.49	93.47
	CO_2 reduction (10^4 ton)	24,095	36,858	5950	201,501

4. Results

This study conducted a longitudinal efficiency analysis to understand the trends in environmental efficiency for the sustainable management of airlines. In a longitudinal efficiency analysis, if a pooled sample is created, all data can be compared regardless of the year [48]. Therefore, data for the five years of the study period were pooled. Relative efficiency was calculated by comparing a total of 155 DMUs (31 global airlines × 5 years) by considering the inputs and outputs data of each year for each airline as a separate DMU. In addition, this study matched the continents to which the airlines belong and the efficiency trend by period and continent. Lastly, by examining the environmental efficiency of individual airlines in more detail, the cause of inefficiency was identified and methods to improve efficiency were suggested.

4.1. Analysis of Changes in Environmental Efficiency by Continent

Tables 7–9 show the environmental efficiency values of airlines by continent from 2014 to 2018. Table 7 reveals that the TE values exceed 0.660. These TE values increase and decrease over time. After dividing the TE into PTE and SE, the PTE values in Table 8 are greater than 0.710, increasing overall. Meanwhile, the SE values in Table 9 are higher or lower than 0.900. These SE values increase or decrease repeatedly. This means that global airlines achieve economies of scale in terms of environmental efficiency.

Table 7. Environmental efficiency by continent: TE.

Continent	2014	2015	2016	2017	2018	Average
Europe and Russia	0.879	0.884	0.890	0.891	0.893	0.888
North America and Canada	0.839	0.856	0.829	0.831	0.843	0.839
Latin America	0.671	0.683	0.674	0.667	0.680	0.675
China and North Asia	0.854	0.820	0.808	0.804	0.792	0.816
Asia Pacific	0.815	0.800	0.804	0.808	0.834	0.812
Africa and the Middle East	0.676	0.693	0.730	0.723	0.726	0.709
Average of the Whole	0.756	0.756	0.764	0.762	0.770	0.761

Table 8. Environmental efficiency by continent: PTE.

Continent	2014	2015	2016	2017	2018	Average
Europe and Russia	0.915	0.917	0.918	0.925	0.926	0.920
North America and Canada	0.879	0.929	0.912	0.906	0.913	0.908
Latin America	0.726	0.711	0.730	0.724	0.728	0.724
China and North Asia	0.875	0.854	0.853	0.850	0.842	0.855
Asia Pacific	0.834	0.838	0.846	0.857	0.880	0.851
Africa and the Middle East	0.731	0.747	0.783	0.775	0.810	0.769
Average of the Whole	0.802	0.808	0.815	0.817	0.824	0.813

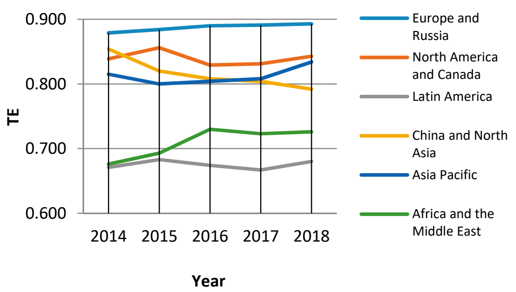
Table 9. Environmental efficiency by continent: SE.

Continent	2014	2015	2016	2017	2018	Average
Europe and Russia	0.961	0.965	0.970	0.963	0.965	0.965
North America and Canada	0.954	0.921	0.909	0.918	0.924	0.925
Latin America	0.924	0.960	0.924	0.921	0.935	0.933
China and North Asia	0.976	0.960	0.948	0.946	0.941	0.954
Asia Pacific	0.977	0.954	0.951	0.942	0.948	0.954
Africa and the Middle East	0.925	0.927	0.932	0.932	0.896	0.922
Average of the Whole	0.943	0.936	0.938	0.933	0.934	0.937

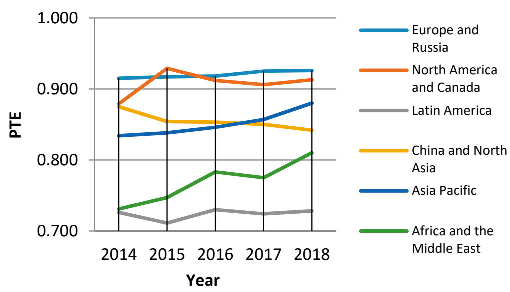
The causes of changes in environmental efficiency by continent from 2014 to 2018 were analyzed based on the input and output variables. In this study, the inputs used to analyze the environmental efficiency of global airlines are operating cost, employee, airline fleet, and aviation kerosene. The outputs are divided into economic and physical outputs [49,50]. The economic output is mainly total revenue, and the physical outputs are RPK, RTK, passenger load factor, cargo load factor, and CO_2 reduction. For airlines, the biggest environmental impact is from greenhouse gases [50]. In particular, CO_2 is the most important greenhouse gas among aviation emissions [51]. When analyzing changes in inputs and outputs over time, total revenue, RPK, and CO_2 reduction as outputs increase more prominently than inputs. In particular, the reason for the increase in TE values in 2016 and 2018 is due to a sharp CO_2 reduction over the period. In addition, the increase in total revenue, RPK, and CO_2 reduction leads to the increase in PTE values.

Figure 1 is a schematic diagram of the environmental efficiency values presented in Tables 7–9 by year. The figure shows that TE and PTE are high or medium, and the difference between continents is large. However, SE is high, and the difference between continents is very small. As shown in Figure 1a, Regarding TE, airlines in Europe and

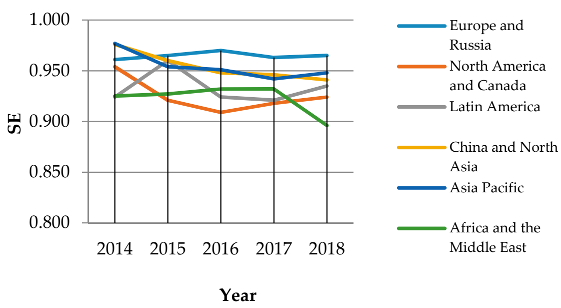
Russia have the highest environmental efficiency and increase slightly. Next are airlines in North America and Canada, but their TE is only slightly higher than that of the airlines in China and North Asia and Asia Pacific. Meanwhile, airlines in Africa and the Middle East and Latin America similarly have low environmental efficiency. The environmental efficiency values of the two continents show similar levels. However, looking at the overall trend, the environmental efficiency values of the airlines in Africa and the Middle East are on the rise, while those of the airlines in Latin America are on the decline. Figure 1b presents PTE values corresponding to the environmental efficiency of global airlines. Airlines in Europe and Russia are the most efficient overall from 2014 to 2018, with the exception of airlines in North America and Canada, which were the most efficient in 2015. Next, airlines in China and North Asia and Asia Pacific have similar PTE values. However, while the PTE values of airlines in China and North Asia are decreasing, those of airlines in Asia Pacific are increasing. Lastly, similar to TE, PTE values of airlines in Africa and the Middle East and Latin America are relatively low compared to that in other continents. However, unlike TE, the growth of PTE values of airlines in Africa and the Middle East is large, while those of airlines in Latin America remain at a similar level. In terms of SE shown in Figure 1c, airlines in Europe and Russia have the highest efficiency. On average, airlines in China and North Asia and Asia Pacific rank second highest. The SE values of the rest of the continents have similar patterns of increasing and decreasing. Airlines in North America and Canada rank lowest from 2015 to 2017.



(**a**) TE



(**b**) PTE



(**c**) SE

Figure 1. Change in environmental efficiency by year.

These results indicate that airlines in Europe and Russia are the most efficient. The airlines in Europe and Russia demonstrate high environmental efficiency management capabilities compared with airlines in the other continents, with achieving optimization of producing a lot of outputs versus inputs. Therefore, airlines in the other continents can benefit from benchmarking those in Europe and Russia. However, the TE and PTE values of airlines in Europe and Russia are around 0.900, suggesting that there is still room for improvement. Therefore, the airlines in Europe and Russia need to continue their efforts to improve environmental efficiency. In addition, while airlines in North America and Canada are the second most efficient, their SE is the lowest in 2015–2017, suggesting a need to achieve economies of scale. In addition, the TE and PTE values of airlines in China and North Asia and Asia Pacific are at the middle level among all airlines. Lastly, the TE and PTE values of airlines in Africa and the Middle East and Latin America are at the lowest level among all airlines by continent. Meanwhile, the SE values for each year are similar. This means that airlines in Africa and the Middle East and Latin America need to focus on improving inefficient operations in environmental management for sustainability.

4.2. Comparison of Environmental Efficiency by Airline

Table 10 presents the results of the analysis of environmental efficiency by airline in 2018. The PTE average of 31 airlines was 0.824. These results mean that the overall environmental inefficiency of the global aviation industry is 17.6%. Such inefficiency can be attributed to ineffective environmental management of the global airlines.

Table 10. Environmental efficiency by airline in 2018: PTE.

DMUs	PTE	
	Efficiency	Reference Set
1 (Lufthansa)	1.000	
2 (Austrian Airlines)	0.916	1(0.027), 7(0.060), 19(0.425), 22(0.037), 28(0.451)
3 (KLM Royal Dutch Airlines)	0.942	1(0.427), 10(0.269), 27(0.304)
4 (British Airways)	0.935	1(0.061), 7(0.438), 22(0.501)
5 (Virgin Atlantic)	0.970	10(0.027), 19(0.359), 27(0.403), 28(0.211)
6 (Aeroflot)	0.759	1(0.635), 10(0.174), 27(0.191)
7 (Air France)	1.000	
8 (Iberia)	0.795	1(0.027), 7(0.060), 19(0.425), 22(0.037), 28(0.451)
9 (Turkish Airlines)	0.863	1(0.094), 7(0.327), 10(0.218), 22(0.361)
10 (Finnair)	1.000	
11 (Aegean Airlines)	0.982	7(0.059), 10(0.015), 19(0.638), 27(0.027), 28(0.261)
Average of Europe and Russia	0.924	
12 (Air Canada)	0.925	1(0.340), 7(0.028), 10(0.137), 27(0.495)
13 (Delta)	0.901	1(0.412), 19(0.275), 28(0.313)
Average of North America and Canada	0.913	
14 (Avianca)	0.563	1(0.305), 10(0.273), 22(0.186), 27(0.236)
15 (LATAM)	0.581	1(0.172), 7(0.064), 10(0.149), 19(0.225), 28(0.390)
Average of Latin America	0.572	
16 (Singapore Airlines)	0.863	7(0.042), 10(0.176), 19(0.461), 22(0.068), 28(0.253)
17 (All Nippon Airways)	0.736	1(0.285), 7(0.136), 10(0.294), 19(0.018), 27(0.267)
18 (Cathay Pacific)	0.736	1(0.349), 19(0.265), 28(0.386)
19 (Japan Airlines)	1.000	
20 (China Southern Airlines)	0.595	10(0.097), 22(0.266), 27(0.325), 28(0.312)
21 (China Airlines)	0.863	1(0.279), 7(0.153), 19(0.385), 22(0.146), 28(0.037)
22 (Korean Air)	1.000	
Average of China and North Asia	0.828	
23 (Qantas)	0.778	1(0.018), 7(0.593), 10(0.106), 19(0.215), 27(0.068)
24 (Thai Airways)	0.978	10(0.290), 10(0.381), 19(0.074), 22(0.255)
25 (Garuda Indonesia)	0.940	1(0.037), 19(0.262), 22(0.580), 27(0.121)
26 (Air New Zealand)	0.823	1(0.346), 10(0.153), 22(0.329), 27(0.172)
Average of Asia Pacific	0.880	
27 (Emirates)	1.000	
28 (Etihad Airways)	1.000	
29 (Kenya Airways)	0.691	1(0.614), 10(0.019), 19(0.283), 22(0.054), 28(0.030)
30 (Oman Air)	0.739	7(0.283), 22(0.184), 27(0.409), 28(0.124)
31 (South African Airways)	0.715	1(0.096), 7(0.185), 10(0.053), 19(0.317), 22(0.258), 27(0.091)
Average of Africa and the Middle East	0.829	
Average of the Whole	0.824	

Table 10 shows the reference set of the inefficient DMUs and its linear combination ratio. Reference set refers to efficient airlines that inefficient airlines must benchmark in order to be efficient. These are composed mainly of airlines that have the structure of inputs and outputs similar to those of airlines identified to be inefficient.

For example, Avianca (0.563) was the airline with the lowest environmental efficiency among all airlines. The airline's low efficiency, along with LATAM (0.581), the airline on the same continent, has led Latin America to be the least efficient of all continents. The output targets that Avianca must achieve to become an efficient airline are determined by the linear combination ratio of the reference set. In this study, since the output-oriented model is applied, the product vector obtained by multiplying the reference object's product vector by each linear combination ratio is the target of benchmarking.

Avianca was founded in 1919 as Colombia's national airline. It is the second oldest airline in the world after KLM Royal Dutch Airlines. The main reason that Avianca showed relatively lower environmental efficiency than other airlines was that it had less physical outputs such as RTK, cargo load factor, and CO_2 reduction rather than economic outputs such as total revenue. This poor performance made Avianca to go bankrupt in May 2020. Therefore, it is necessary to reestablish its environmental policy to further reduce CO_2 emissions while striving to improve the performance of the cargo sector compared to other airlines.

5. Discussion and Conclusions

5.1. Main Findings

This study evaluated the environmental efficiency of 31 global airlines in 2014–2018 for the sustainable management of airlines. It also compared the environmental efficiency of global airlines by continent according to IATA's regional classification of continents. The analysis results of this study are summarized as follows:

First, the TE values exceeded 0.660, increasing and decreasing over time. In particular, TE values increased as CO_2 reduction decreased in 2016 and 2018. However, the environmental efficiency of global airlines needs to be improved [52]. Recently, for the sustainability of the aviation industry, it has been emphasized that environmental efficiency should be improved by reducing carbon emissions and by using alternative fuels [17,53,54]. The PTE values were above 0.710, continuing to rise from 2014 to 2018. These increases in PTE values were due to increases in total revenue, RPK, and CO_2 reduction. Lastly, SE values are around 0.900, increasing and decreasing repeatedly. In other words, global airlines achieved high scale efficiency in environmental management.

Second, a comparison of the environmental efficiency of airlines in terms of TE revealed that the efficiency level of all continental airlines in the period 2014–2018 was high or medium, and the difference between continents was large. In particular, the airlines from Europe and Russia were more environmentally efficient than the airlines from other continents, followed by those from North America and Canada, China and North Asia, Asia Pacific, Africa and the Middle East, and Latin America. This is in line with the results of previous studies [6,52] howing that the environmental efficiency of airlines in Europe and Russia is higher than those of airlines from other continents. Because the European Union is actively implementing various environmental regulations, such as the European Emissions Trading Scheme, which introduced the world's first carbon dioxide emission cap in 2005 [55,56] it is inferred that airlines have steadily improved their environmental efficiency.

Third, after dividing TE into PTE and SE, airlines in Europe and Russia and North America and Canada were found to be more efficient in terms of PTE, and the efficiency of the other airlines by continent was in the order of China and North Asia, Asia Pacific, Africa and the Middle East, and Latin America. The airlines in North America and Canada (2014), Europe and Russia (2015), and North America and Canada (2016–2018) ranked the second highest. The airlines in Africa and the Middle East and Latin America similarly have low environmental efficiency. Interestingly, SE was high, and the difference between continents was very small. In terms of SE, airlines in Europe and Russia ranked the highest, and on average, airlines in China and North Asia and Asia Pacific ranked the second highest. SE values on the rest of the continents continued to increase and decrease, but airlines in North America and Canada showed the lowest efficiency.

5.2. Implications and Limitations

This study has important implications for the global aviation industry. First, this study analyzed environmental efficiency according to the continent revealing what extent the airlines in each continent have achieved environmental efficiency and how to improve environmental efficiency for sustainable management. Overall, for the period 2014–2018, the environmental efficiency of airlines differed by continent. Airlines in Europe and Russia showed the highest environmental efficiency among airlines from all continents in terms of TE, PTE, and SE. Meanwhile, airlines in North America and Canada were the most efficient in 2015 in terms of PTE. These results suggest that airlines in the other continents should benchmark airlines in Europe and Russia.

Second, this study provides some practical implications for the sustainable management of global airlines based on the environmental efficiency analysis results for each airline. To improve environmental efficiency, it is necessary to focus on managing the main causes of inefficiency. This study contributes by providing information that could identify the cause of the environmental inefficiency of airlines. In this way, it is possible to establish a strategy for improving environmental efficiency to secure sustainable competitiveness.

However, this study has several limitations. First, it was difficult to obtain data related to the environmental efficiency of global airlines. Many airlines do not disclose data on their environmental footprint such as reduction of energy consumption, elimination of waste, elimination of single-use plastic, introduction of aircraft weight reduction initiatives, and promotion of alternative fuels. Therefore, this study used CO_2 reduction, which most airlines commonly disclose in annual, sustainability, and corporate sustainability reports, as a major environmental variable. Therefore, if the aviation industry discloses key indicators that can be used to measure environmental management related to sustainability management, future studies could examine environmental efficiency for sustainability in more depth. Second, based on previous studies and Skytrax's "World's Top 100 Airlines," this study selected several airlines belonging to each continent. However, the representativeness of the sample needs to be supplemented. Future research should consider various aspects including continental features so that airlines representing each continent can be selected as sample. Third, this study analyzed FSCs because DEA is a method used to compare homogeneous DMUs. Therefore, it is necessary to analyze global airlines by classifying airlines in terms of business model.

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