Eco-Efficiency Performance of Airlines in Eastern Asia: A Principal Component Analysis Based Sustainability Assessment

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Abstract
Bringing sustainability practices to the aviation industry has helped in offsetting carbon emissions to a great extend. However, the question of whether these practices neutralize carbon emissions is yet unanswered. The research presents an eco-efficiency performance analysis on selected seven airlines in Eastern Asia based on data availability using Principal Component Analysis (PCA) as the evaluation technique. The study was carried out with five environmental indicators as inputs (Electricity Consumption, Jet fuel Consumption, GHG emissions, water consumption, and waste generated) and four value-added indicators as the outputs (revenue, passengers, employees, and cargo carried) to compare the sustainability performance levels for the selected airlines. The data related to the airlines required for the assessment was obtained from several database resources, including the GRI, annual airline sustainability reports, ICAO, and IATA. All Nippon Airlines (ANA) is the most eco-efficient and sustainably performing airline in Eastern Asia based on the selected indicators and the obtained datasets. It was observed that there is a discrepancy in the measuring units for the indicators in the metric system used in the published sustainability reports between airlines; thus, collecting complete and consistent data is best recommended to evaluate each airline's sustainability performance from a broader perspective.

Keywords: Carbon emissions, Eco-efficiency performance, Principal Component Analysis, Sustainability assessment.

1. Introduction
The aviation industry plays a significant role in shaping global business, thus promoting worldwide economic development (Chang et al., 2014; Cui and Li, 2020; Kucukvar et al., 2020). Air travel has catapulted the industry to grow significantly over the past decade, so has the Greenhouse Gas (GHG) emission rate. Industry experts have pointed out the need for green aviation practices within this sector to neutralize carbon emissions (ICAO, 2012; Jiang et al., 2018; EU Climate Action, 2020). Aircraft is unique in providing passengers and goods pathways to move across worldwide, adding sustainable value to the global economy and the nation's prosperity (Lewis, 2013). The airline industry has sought to accomplish this goal by limiting the carbon emission and stratospheric ozone depletion rate,

thereby promoting sustainable aviation practices in support of the United Nations Sustainable Development Goal 13: Climate Change (Kucukvar et al., 2017; Alsarayreh et al., 2020; Kutty et al., 2020; Kutty et al., 2020A).

Several futuristic attempts to downsize the avionic emissions have been initiated by airline trade associations worldwide. The “International Civil Aviation Organization” (ICAO) plans to initiate the “Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)” after 2021 to inhibit the GHG emissions from international airlines (Chao et al., 2019). The “International Air Transport Association” (IATA) has set three sustainability goals: improving fuel efficiency by an average of 1.5% per year, capping airline CO_2 emissions from 2020 onwards, and reducing the CO_2 emissions by 50% by 2050 (San et al., 2017). A reduction in the aviation industry's emissions amounts to a simultaneous reduction in climate change-related impacts, hence addressing the carbon neutrality goal of the UN Sustainable Development Agenda 2030.

Regardless of the efforts to significantly minimize the CO_2 emissions, the GHG emissions are expected to rise drastically as the aviation industry expands its wings to meet the growing demand (Wang et al., 2019). The targets set by the EU Climate Action (2020) to reduce the global CO_2 emissions by 2050, such as the use of sustainable and clean energy (Alameeri et al., 2017; Kutty et al., 2020B; Melo et al., 2020), economic progress by enhancing connectivity (Park et al., 2015), and improved climatic conditions (Kucukvar and Sammadi, 2015) can help the aviation industry in achieving the meta-goal of carbon neutrality. Endorsing development by implementing Sustainability Development Goals (SDGs) in the aviation industry and building a corporate image on sustainable mobility can promote sustainable operations through the industry's life cycle.

To this end, this research attempts to assess the eco-efficiency of seven East Asian airlines based on the availability of data. The eco-efficiency results will be deeply analyzed, and the airlines will be compared and grouped based on their eco-efficiency performance by visualizing the performance. The correlation of determination (R^2) value will analyze the correlation between the indicators and the eco-efficiency values. The quartiles method will be used to cluster the airlines based on their eco-efficiency performance. The documentation process consists of collecting, analyzing, normalizing, weighing sustainability indicators data using PCA, and then calculating the eco-efficiency results into an organized format to easily share and access.

This paper is organized into seven sections, including the introduction that details the airline industry's concerns to bring sustainability practices into action to address the carbon-neutral goals for long-term sustainable development. Section 3 describes and presents the methodology/steps used in carrying out the airlines' eco-efficiency assessment in Eastern Asia. This section also provides details on the data-gathering steps adopted, the normalization procedure, weighting and aggregation process, eco-efficiency calculations, and analysis. The results and findings were deeply analyzed and discussed in Section 4. Finally, Section 6 presents a summary of the significant results and outcomes of the study. Furthermore, recommendations for future research are also covered in this section.

2. Research Rationale

Expanding the aviation industry to meet the travel demand has stained sustainable operations within this sector (Seemann et al., 2011). Sustainability assessment in the aviation industry justifies airlines' ability to maximize their value-added performance while reducing their emissions and resource consumption. Several studies have been carried out to evaluate the airlines' performance using different tools and frameworks. Yu hang et al. (2019) evaluated the Chinese and Indian airline operators' efficiency performance using Dynamic Network DEA model. The eco-efficiency and economic performance of 27 international airlines were evaluated by Chang et al. (2014) using the "Slack-Based Measure Data Envelopment Analysis” model. Cui et al. (2020) used BP Neural Network combined with DEA to assess carbon neutrality goals of 25 international airlines for a period from 2008 till 2018. Most research on airlines' eco-efficiency performance suffers from limitations such as the number of airlines, scope, and indicators considered in the study due to the lack of data availability. Besides, most studies have used complex techniques to evaluate the eco-efficiency performance, while simple techniques exist that decision-makers can use to evaluate the airline eco-efficiency. Thus, this paper simplifies the eco-efficiency performance assessment by combining PCA using a six-step approach to arrive at favorable results for any related eco-efficiency studies.

From a methodological perspective, little attention is given to Principal Component Analysis (PCA) in literature for eco-efficiency related studies. Onat et al. (2019) applied PCA and LCA in their research, presenting a novel incorporated framework to analyze Battery Electric Vehicles (BEV) for the US transportation system. Similarly, Park et al. (2015) attempted to evaluate the sustainability performance of the US manufacturing sector by combining PCA with “Economic Input-Output Life-Cycle Assessment (EIO-LCA).” The combined approach helped in identifying the least and the most sustainable manufacturing units in the United States. Jiang et al. (2018) conducted a study to examine the sustainable corporate performance of motor vehicle engine manufacturers in China and offered a three-dimensional sustainability evaluation technique using PCA. For the first time, this research used PCA and matching units in building a Corporate Sustainability Index (CSI). Luca and Carlucci (2014) conducted a study to develop a set of Sustainable Development (SD) indexes for Italy. PCA was used to investigate the correlation between the indicators and their involvement towards the sustainability target. Paula and Kološta (2015) expanded their research to include 27 European union member states to develop an accumulated SD index and used PCA as an effective method. Most of all, the studies have used PCA to decrease the data sets’ dimensionality. These studies justify PCA as a useful combinatorial tool in pulling out important information before analyzing the sustainability performance. Despite PCA being an essential tool in reducing the data size and eliminating noise, PCA receives less attention in aggregating indicators and eco-efficiency performance assessment literature. This research thus applies PCA to the eco-efficiency indicators for airline sustainability assessment justifying the research rationale.

3. Method

This research attempts to assess seven airlines' eco-efficiency performance in Eastern Asia using the six sequential steps depicted in Figure 1. The airlines' eco-efficiency assessment started with identifying the airline industry's environmental and value-added indicators to define sustainability performance. The published sustainability and annual airline reports were reviewed to collect the required data from various web-based resources. The collected data were then normalized using the min-max technique to a standard scale. Then, the normalized data were weighted using Principal Component Analysis (PCA) and then aggregated. The airline's eco-efficiency score was then calculated, and the airlines were ranked based on their eco-efficiency performance. Finally, the eco-efficiency assessment results were deeply analyzed by clustering the results into subsequent levels of efficiency. The results were then documented in a publishable format as a conference paper.

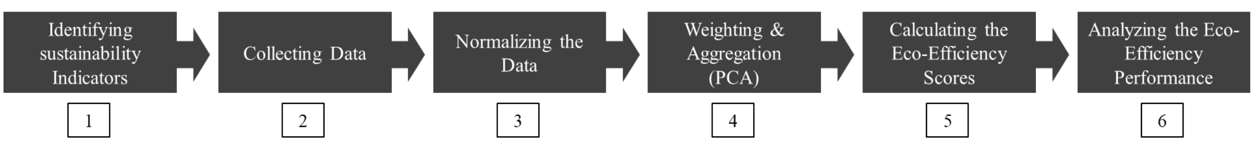


Figure 1. The six sequential steps used in the eco-efficiency assessment for airlines in Eastern Asia

4. Eco-Efficiency Assessment of East Asian Airlines

The aviation industry supports economic growth by adding value to the world’s Gross Domestic Product (GDP) (Srisaeng et al., 2015). Air travel has made possible passengers and cargo supplies faster with enhanced connectivity worldwide (Thokala et al., 2010; Xue et al., 2020). Moreover, the airline industry supports the employment of large and different groups of skilled employees. Several environmental impacts predominate from the operation stage's emissions throughout the aircraft life cycle (Xu and Cui, 2017; Wang et al., 2019). This can be measured by ecological indicators such as; energy resource consumption (electricity and jet fuels), Greenhouse Gas emissions (GHG), water consumption, and waste.

4.1 Data Acquisition and Indicator Selection

In this research, five environmental indicators were selected to quantify East Asian airlines' impact on the environment. Four indicators were selected as the value-added indicators to evaluate airlines' eco-efficiency performance based on data availability. Table 1 highlights the selected set of indicators for the eco-efficiency assessment.

Table 1. Selected airline sustainability indicators

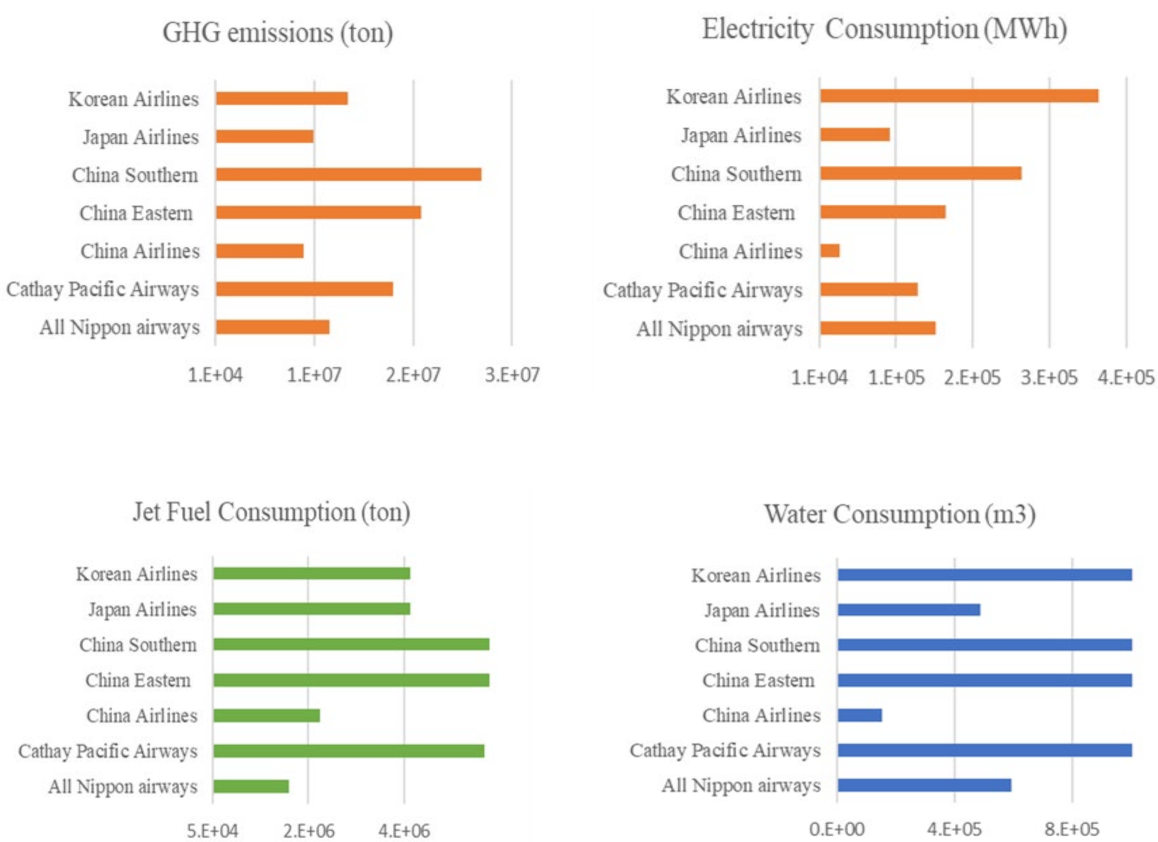
Environmental Indicators	Value-added indicators
GHG emissions (ton CO2)	Revenue ($)
Electricity Consumption (MWh)	Passengers
Jet Fuel Consumption (ton)	Cargo (ton)
Water Consumption (m3)	Employee
Waste Generated (ton)	

Airlines sustainability reports from the Global Reporting Initiative (GRI) database, airline websites, ICAO, and IATA databases were reviewed to gather the environmental indicators' data. The airlines' annual reports were reviewed to collect the data related to the revenue, passengers, cargo carried, and employees for a period from 2015 till 2019. The reports provided complete data for only seven leading East Asian airlines for the selected period, limiting the study to seven airlines for the assessment process. Table 2. shows the descriptive statistics of the indicators used in the study.

Table 2. Descriptive statistics for the selected set of indicators

Sustainability indicators	Min	Max	Average	Standard Deviation
GHG emissions (ton)	8.898E+06	2.690E+07	1.563E+07	6.579E+06
Electricity (MWh)	3.601E+04	3.746E+05	1.802E+05	1.123E+05
Jet Fuels (ton)	1.639E+06	8.540E+06	4.732E+06	2.421E+06
Water (m3)	1.509E+05	9.178E+06	3.790E+06	3.698E+06
Waste (ton)	3.664E+03	3.400E+04	1.497E+04	1.234E+04
Revenue ($)	1.077E+10	2.198E+10	1.683E+10	4.191E+09
Passengers	1.376E+07	1.400E+08	6.319E+07	4.858E+07
Cargo (ton)	9.150E+05	2.152E+06	1.613E+06	3.813E+05
Employee	1.241E+04	1.008E+05	4.562E+04	3.183E+04

Based on the selected carriers' data, airline operations' impact on environmental indicators varies among the airlines. This can be clearly understood from the bar graphs shown in Figure 2. It can be seen that China Southern Airlines has the highest GHG emissions, followed by China Eastern Airlines due to its high jet fuel consumption. China Airlines emits the lowest greenhouse gases due to its low fuel consumption. In terms of energy consumption, Korean Airlines is the largest consumer of electrical energy. China Southern Airlines is an enormous jet fuel consumption, while ANA airlines are found to be the lowest jet fuel consumer among the selected airlines. In terms of water consumption, China Southern, Cathay Pacific, and China Eastern airlines have the highest value than other airlines. On the contrary, All Nippon Airlines generates the highest amount of waste annually during its operational phase.



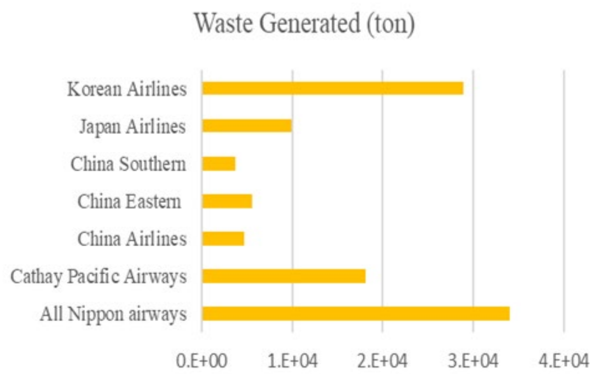


Figure 2. Results of data analysis on the selected set of environmental indicators for the seven East Asian airlines

The selected airlines have different contributions to the value-added indicators, as shown in Figure 3. China Airlines topped the list by reporting hikes in revenue for the year 2018. China Southern and Eastern Airlines are the maximum passenger-carrying flights, with China Southern being the largest airline by the number of employees. At the same time, Cathay Pacific Airlines has taken over the list as the largest air cargo carrier.

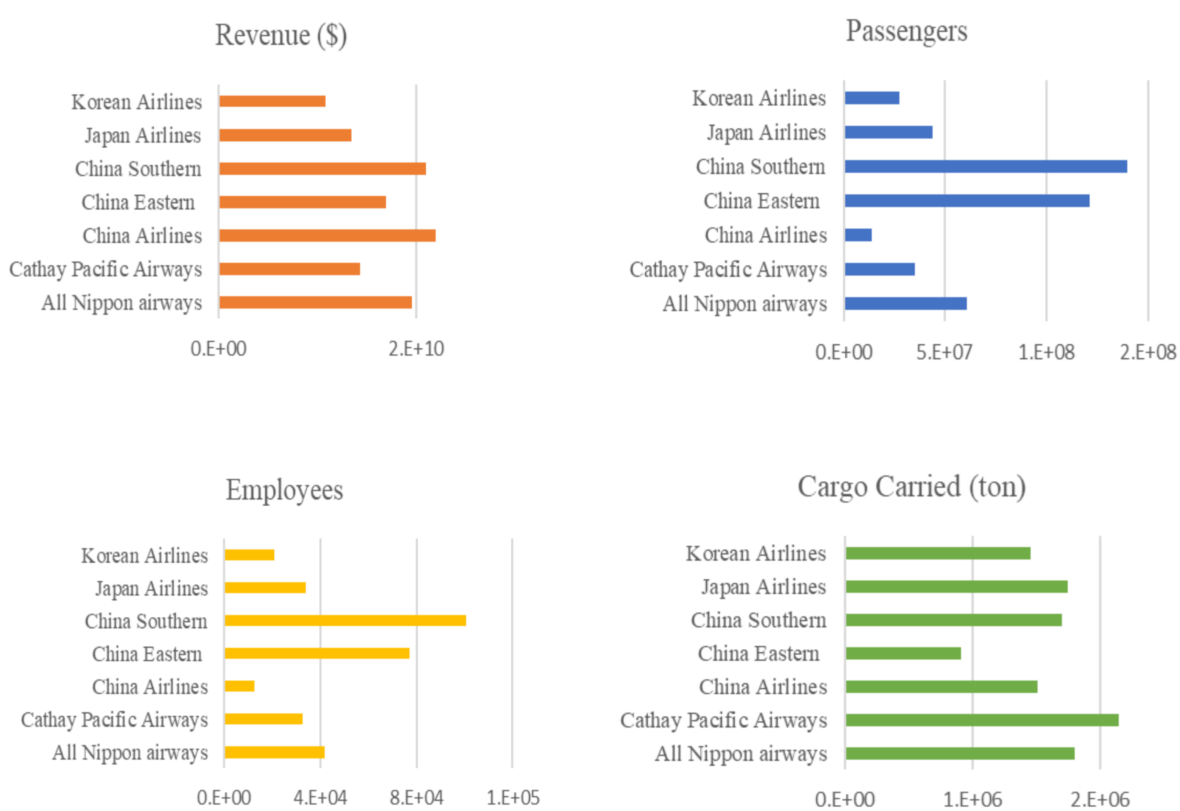


Figure 3. Results of data analysis on the selected set of value-added indicators for the seven East Asian carriers

4.2 Data Normalization

Since the data has different measuring units, normalization must convert the data into a notationally common scale to aggregate them. Several data normalization methods are available in the literature (Abdalla et al., 2020). In this study, we use the Min-Max normalization technique shown in Equation 1 for simplicity and ease of use.

$$X_i^* = a + \frac{(X_i - X_{i,min})\,(b-a)}{(X_{i,max} - X_{i,min})} \quad (1)$$

X_i* is the normalized data for each airline i, and X_i is the collected data for each indicator corresponding to the airline i. (a) is equal to 1 and (b) is equal to 2 for ranges from 1 to 2 intervals. The $X_{i,min}$ and $X_{i,max}$ represent each indicator's minimum and maximum value.

4.3 Weighting and Aggregation

The composite environmental index (CEI) was obtained using the PCA approach to combine all the five environmental indicators. This approach is also used to combine the four value-added indicators and obtain the composite value-added index (CVI). Table 3 provides the eigenvalues, variability %, and the cumulative % of the PCA components obtained using XLSTAT for each environmental and value-added indicators separately, where F1, F2,..., F5 are the obtained principal components.

Table 3. Eigenvalues, variability % and cumulative % of principal components

		Eigenvalue	Variability %	Cumulative %
Environmental Components	F1	3.098	61.954	61.954
	F2	1.387	27.738	89.687
	F3	0.395	7.900	97.587
	F4	0.092	1.841	99.428
	F5	0.029	0.572	100.000
Value-added Components	F1	2.334	58.342	58.342
	F2	0.941	23.533	81.875
	F3	0.723	18.075	99.950
	F4	0.002	0.050	100.000

The Kaiser's stopping rule that worked well in finding the smallest number of components required to obtain a good representation of the data was used to select the components. Components with eigenvalues greater than one were selected. The first components for both the environmental and value-added indicators with eigenvalues higher than one were selected. Simultaneously, the remaining components were omitted as they do not have remarkable impacts on the results. Table 4 presents the eigenvectors for the selected components.

PCA score for each East Asian airline was calculated using Equation (2)

$$\text{PCA Value} = C_1Z_1 + C_2Z_2 + C_3Z_3 + C_4Z_4 + C_5Z_5 \quad (2)$$

Table 4. Eigenvectors of the selected principal components

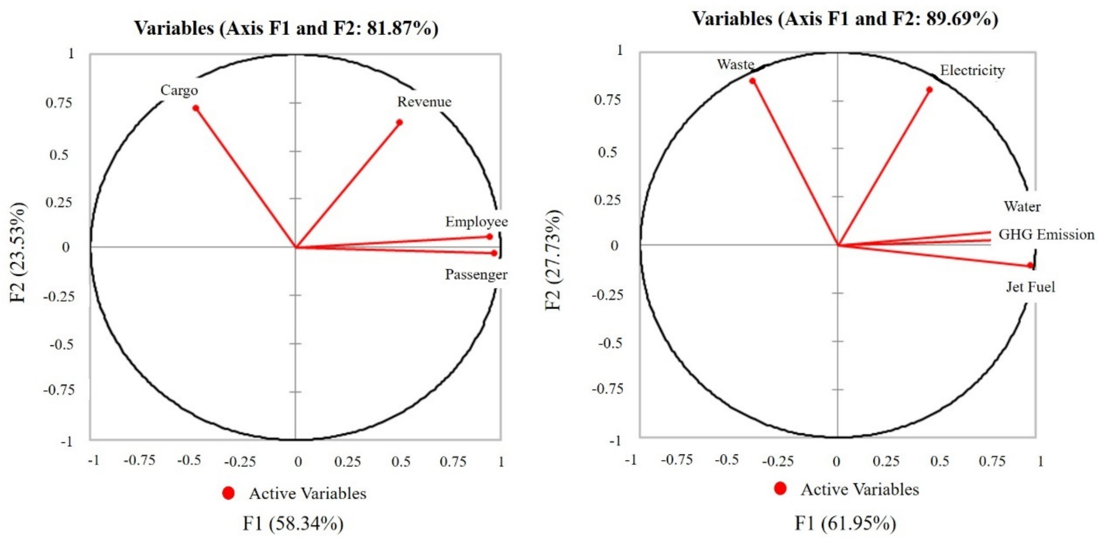
Environmental indicators		Value-Added indicators	
	F1		F1
Electricity	0.264	Revenue	0.335
jet fuel	0.556	Passenger	0.635
GHG	0.550	Employee	0.620
waste	-0.244	Cargo	-0.317
water	0.509		

The correlation between the indicators and the first PC is, as shown in Table 5. There is a positive correlation between all the environmental indicator values and the principal component except the waste indicator; a negative correlation with the component is observed. Hence, the PCA score is increased by increasing all the environmental indicator values except the waste indicator. Alternatively, the PCA score is increased, and the value of waste is decreased. On the other hand, there is a positive correlation between all the value-added indicators and the principal component except the cargo indicator, where there is a negative correlation.

Table 5. The correlation between indicators and the first component

Environmental indicators		Value-Added indicators	
	F1		F1
Electricity	0.465	Revenue	0.511
Jet fuel	0.979	Passenger	0.970
GHG	0.968	Employee	0.948
waste	-0.429	Cargo	-0.484
water	0.895		

Figure 4a displays the variables factor map for the environmental indicators' vector by presenting the variance' percentage from each active variable along with the first and the second principal direction. The opposite direction displays the negative correlation between waste and the other remaining indicators. Figure 4b displays the variables factor map for the value-added indicators' vector, where all the indicators have a positive direction except the cargo indicator.



(a) (b)

Figure 4. Variable factor map for a) environmental indicators' vector b) value-added indicators' vector

The first principal component was selected to compute the "Composite Environmental Index (CEI)". Similarly, for computing the Composite Value-added Index (CVI), the first component was selected. These selected components have a high percentage of variance (61.954% for the environmental indicators and 58.342% for value-added indicators) and cover most of the dataset's information. CEI and CVI were computed using Equations (3) and (4).

$$CEI = (0.465\ X_1^* + 0.979\ X_2^* + 0.968\ X_3^* + (-0.429\ X_4^*) + 0.895\ X_5^*) \tag{3}$$
$$CVI = (0.511\ Y_1^* + 0.970\ Y_2^* + 0.948\ Y_3^* + (-0.484\ Y_4^*)) \tag{4}$$

Where X_i* in Equation (3) is the corresponding environmental indicator (i = 1…5), and Y_j* in Equation (4) is the corresponding value-added indicator (j = 1…4).

4.4 Eco-Efficiency Calculations

The steps to calculate the selected seven East Asian airlines' eco-efficiency performance can be seen in Figure 5.

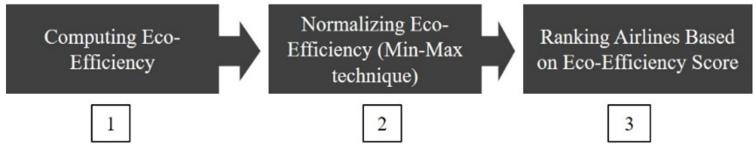


Figure 5. Steps to calculate eco-efficiency

The eco-efficiency score for each airline is the ratio of the value-added index over the environmental index and is computed using Equation (5).

$$\text{Eco-Efficiency} = \text{CVI/CEI} \tag{5}$$

Each airline's raw eco-efficiency scores are re-scaled using the Min-Max technique (Eq. 6) to normalize the scores and range them from one to two.

$$\text{Normalized } E_i = a + \frac{(E_i - E_{min})(b-a)}{(E_{max} - E_{min})} \tag{6}$$

Here, "**a**" is equal to 1 and "**b**" is equal to 2. $\mathbf{E_i}$ is the raw eco-efficiency score for airline **i**, and $\mathbf{E_{max}}$ and $\mathbf{E_{min}}$ are the maximum and minimum eco-efficiency scores for the selected set of airlines, respectively. The airlines are then ranked based on their eco-efficiency scores.

5. Results and Interpretation

5.1 Visualizing the Eco-efficiency Performance

Airlines' eco-efficiency scores were calculated following the steps presented in section 4.4. Table 6 presents the eco-efficiency results for the selected seven airlines in Eastern Asia.

Table 6. CEI, CVI, and normalized eco-efficiency results for the selected airlines.

SL.No	Airline	CVI	CEI	Eco-efficiency	Normalized eco-efficiency
1.	ANA	2.676	2.807	0.953	2.000
2.	CATHAY PACIFIC	2.002	4.777	0.419	1.000
3.	CHINA AIRLINES	2.222	2.955	0.752	1.623
4.	中國東方航空 CHINA EASTERN	3.742	4.892	0.765	1.648
5.	CHINA SOUTHERN AIRLINES	4.020	5.910	0.680	1.489
6.	JAL JAPAN AIRLINES	2.202	3.325	0.662	1.456
7.	KOREAN AIR	1.925	3.877	0.496	1.145

The eco-efficiency scores have a positive relation with CVI and a converse relation with CEI. Based on the results shown in table 6, All Nippon Airlines (ANA) are the most eco-efficient airlines in Eastern Asia as they have the lowest CEI value among all the airlines due to their low GHG emissions and Jet fuel consumption. The second highest eco-efficient airline is China Eastern Airlines since they hold a high CVI value, and China Airlines is the third most eco-efficient airline in Eastern Asia.

Three airlines in China were included in this study: China Airlines, China Eastern, and China Southern airlines. Two among them (China Airlines and China Eastern) made a list ranking No.2 and No. 3 for the eco-efficient airlines in Eastern Asia. Following the top three, China Southern Airlines and Japan Airlines took the fourth and fifth spot on the best eco-efficient airlines in Eastern Asia. Although China Southern has the maximum CVI, CEI's highest value makes the airlines the fourth eco-efficient carrier in the region. On the contrary, the Cathay Pacific airlines are viewed as the lowest eco-efficient airlines in Eastern Asia due to their high CEI value, the reason being the high water and jet fuel consumption. Thus, airlines with higher CEI values lead to marking them as the least eco-efficient airlines.

5.2 Correlation Analysis

There are several methods available in the literature to perform the correlation analysis. The most common among them is Pearson's correlation coefficient (R) and the determination coefficient (R^2). The coefficient of determination (R^2) is selected in this study to analyze the correlation between the selected environmental indicators and eco-efficiency, as shown in table 7. It is also used to analyze the correlation between the selected four value-added indicators and eco-efficiency, as shown in table 8.

Table 7. Correlation of determination matrix for environmental indicators and eco-efficiency

Electricity	1					
Jet fuel	0.161	1				
GHG	0.203	0.858	1			
Waste	0.137	0.289	0.135	1		
Water	0.117	0.68	0.717	0.046	1	
Eco-efficiency	0.109	0.152	0.032	0.001	0.321	1
	Electricity	Jet-Fuel	GHG emission	Waste	Water	Eco-efficiency

The correlation between environmental indicators and eco-efficiency range from 0.001 to 0.321 ($0.001 \leq R2 \leq 0.321$). Eco-efficiency has the highest correlation with water and the lowest correlation with waste indicator. The correlation between value-added indicators and eco-efficiency falls under the range of $0.049 \leq R2 \leq 0.431$. Eco-efficiency has the highest correlation with revenue and the lowest correlation with employee indicators. This means if revenue increases, the eco-efficiency increases, and vice versa.

Table 8. Correlation of determination matrix of value-added indicators and eco-efficiency

Revenue	1				
Passenger	0.115	1			
Employee	0.116	0.983	1		
Cargo	0.004	0.14	0.07	1	
Eco-efficiency	0.431	0.085	0.049	0.103	1
	Revenue	Passenger	Employee	Cargo	Eco-efficiency

5.3 Performance Analysis using Clustering Technique

The airlines in Eastern Asia have been clustered into groups based on their efficiency performance. The Quartiles method is used for this purpose. The quartiles method divides the data into three points (low, medium, and upper) to create four equal quarters of the dataset. The quartiles definition and the obtained values are presented in table 9.

Table 9. Quartiles definition and values

Quartiles	Category	Definition	Value
1st quartile	Lower quartile	The lowest 25% of data	1.300
2nd quartile	Median quartile	Median that divides data into two parts	1.489
3rd quartile	Upper quartile	Spread the highest 25% of data from the lowest 75%	1.635

The Four quarters range on a scale of "Poor," "Fair," "Good," and "Excellent." The intervals of each quarter are defined based on the quartile values, as shown in table 10.

Table 10. The quarter's definition

No.	Rating Scale	Score
1	Poor	Below 1.300
2	Fair	Between 1.300 and 1.489
3	Good	Between 1.489 and 1.635
4	Excellent	Higher than 1.635

Table 11 categories the airlines based on their eco-efficiency performance as per the color code. The results show that All Nippon Airlines and China Eastern airlines maintain excellent performance.

Table 11. Cluster-based eco-efficiency performance of airlines

Airlines	Colour Code Rating
All Nippon Airlines	4
Cathay Pacific Airlines	1
China Airlines	3
China Eastern Airlines	4
China Southern Airlines	3
Japan Airlines	2
Korean Air	1

Color Code Key
Poor Fair Good Excellent

6. Conclusion and Future Research

In this research, the eco-efficiency performance for selected seven airlines in Eastern Asia was studied and analyzed. The research focused on five environmental indicators (Electricity, Jet fuel, GHG emissions, water consumption, and waste generated) and four added-value indicators (revenue, passengers, employees, cargo carried) to measure the airlines' sustainable performance. PCA was used as the weighting approach to computing the eco-efficiency of the airlines. The results show that All Nippon Airlines is the most eco-efficient airline in Eastern Asia, while Cathay Pacific airlines are the least eco-efficient.

This research's scope was subject to the data's availability in the airlines' published sustainability reports. It was observed that there is a lack of information needed for sustainability performance since not all airlines are dedicated to publishing the yearly sustainability reports. Hence some airlines were excluded from this study due to the missing data in their reports or not publishing them. It was also observed that there is a discrepancy in the values of indicators or units used in the published reports. It is recommended that the airline industry must be obliged to publish the annual sustainability reports with a consistent structure to be used to measure sustainability performance easily and for benchmarking internationally.

The principal component analysis is one of the most sophisticated approaches but mostly used with a combination of other tools to evaluate Eco-efficiency. This framework still needs more attention from researchers and scholars as it is not used widely compared to its capacity and capability to manage complex data. The study can further be extended to analyze the world's major carriers' eco-efficiency performance and benchmark the level of eco-efficiency performance to better global aviation sustainability. For more information on the tools and techniques used for sustainability assessment in the aviation industry, the readers can refer to Elhmoud et al. (2020). Future works may include more sustainability indicators covering all the sustainability dimensions (socio-economic and environmental) for a socio-ecoefficiency performance assessment. The authors suggest variable selection using stepwise regression (Abdella et al., 2017) and LASSO-based approaches (Abdella and Shaaban, 2020; Abdella et al., 2020) to substitute PCA for future eco-efficiency related studies. Multivariate regression models are best suggested in selecting response variables for the aggregation purpose during sustainability assessment. (Abdella et al., 2016; Abdella et al., 2019A). The readers may refer to Abdur-Rouf et al. (2018) to get more information on the applications of statistical computation methods in sustainability-related studies.

Furthermore, it is best recommended to use penalized-based weighting methods throughout the aggregation process of indicators to rule out multicollinearity (Gumus et al., 2016; Kutty et al., 2020B). The airline's performance can be derived by implementing a time series analysis for annual sustainability performance to measure the improvements or deviations using historical information. More research can be carried out to identify the underlying causes of inefficient airlines' low eco-efficiency performance. The authors highly recommend the use of integrated Life Cycle Sustainability Assessment (LCSA) methods to support eco-efficiency and sustainability-related assessments (Kucukvar et al., 2018; Kucukvar and Tatari, 2012; Kucukvar et al., 2016; Kucukvar et al., 2016A; Onat et al., 2017; Kutty et al., 2020C); input-output analysis (Tatari et al., 2012; Egilmez et al., 2013; Egilmez et al., 2016; Sen et al., 2020);and ecological footprinting (Shaikh et al., 2017; Kucukvar et al., 2019; Kucukvar et al., 2019A; Onat et al., 2019B), integrated with other decision support models, such as the prognosticate approach (Abdella et al., 2019; Al-Sheeb et al., 2019) including the three pillars of sustainability. Furthermore, research can be carried out to study the impact of the COVID-19 pandemic on sustainable aviation practices covering environmental, socio-economical, and healthcare sustainability dimensions for the pre and post- COVID-19 recovery stages.

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