QATAR UNIVERSITY

COLLEGE OF ENGINEERING

ECO-EFFICIENCY ASSESSMENT OF AIRLINES IN EASTERN ASIA

BY

EMAN RAJI ELHMOUD

A Project Submitted to

the College of Engineering

in Partial Fulfillment of the Requirement for the Degree of

Masters of Science in Engineering Management

January 2021

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COMMITTEE PAGE

The members of the Committee approve the project of
Eman Raji Elhmoud defended on 17/11/2020.

Galal Abdella
Thesis/Dissertation Supervisor

Tarek El Mekkawy
Committee Member

Murat Gunduz
Committee Member

Mohamed Kharbeche
Committee Member

ABSTRACT

ELHMOUD, EMAN, R., Masters: January: 2021, Masters of Science in Engineering Management

Title: Eco-efficiency Assessment of Airlines in Eastern Asia

Supervisor of Project: Galal, M, Abdella.

The aviation industry has played a dynamic character in the global development process. Significant growth can be seen in the air transport sector in the past couple of decades. The industry experts have fully recognized the need for sustainability assessment within this industry in a more incorporated manner. Sustainable aviation practices have significantly reduced Greenhouse Gas (GHG) emissions over the years. However, these practices have not shaped the aviation industry in achieving the United Nations Sustainable Development Goals (U.N. SDGs) to its full potential. This research presents the eco-efficiency performance analysis for selected seven airlines in Eastern Asia using Principal Component Analysis (PCA) technique. The study is 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 outputs (revenue, passengers, employees, and cargo carried) to compare sustainability performance levels of airlines. All the data required for the assessment have been obtained by reviewing the sustainability reports from several database resources (GRI, annual reports, ICAO, IATA). The presented study has shown that ANA (All Nippon Airlines) is the most efficient airline in Eastern Asia regarding sustainability performance, considering the selected indicators and the collected data. Finally, it was observed that there is a discrepancy in the data of indicators or units used

in the published sustainability reports between airlines; thus, collecting complete, governance, and consistent data is needed and recommended to evaluate each airline's sustainability performance.

DEDICATION

I dedicate my project to my family for their encouragement and continuous support.

ACKNOWLEDGMENTS

I would like to express my gratitude to my project supervisor, Dr. Galal Abdella, for his continuous support and valuable guidance in completing this project. Also, I would like to extend my gratitude to all the faculty members of the Engineering Management Master's Program at Qatar University for their support during the academic journey. Finally, this project would not have been possible without the support, daily encouragement, and patience of my family.

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CHAPTER 1: INTRODUCTION

This chapter will provide an overview of sustainable development in the aviation industry. Also, it will highlight the main objectives of the study. Finally, the scope, methodology, and report outline will be stated and briefed.

1.1 Background

The airline industry is a critical factor of economic contribution growth and provides for passengers and goods' movement across the world. Industries in the developing economic world have pursued reducing Greenhouse Gas emissions (GHG) over the years by implementing several sustainable, carbon-neutral practices (Alsarayreh et al., 2020; Kutty et al., 2020). The aviation industry is not exempted in this regard. Sustainable aviation practices have been adopted to achieve the "United Nations Sustainable Development Goals" (U.N. SDGs).

Figure 1. Sustainable Development Goals

Industry experts have fully recognized the need for sustainability assessment within the aviation industry in a more combined way. The aviation industry has halved its carbon footprint compared to its operation in the late 1990s (ATAG, 2020). The industry implemented new technologies such as the zero-emission engine, sustainable fuel options to reduce aviation emissions, particulate soot, cirrus clouds, and lead contrails (García-Olivares et al., 2020). ICAO "International Civil Aviation Organization" will initiate the "Carbon Offsetting and Reduction Scheme for International Aviation" (CORSIA) after 2021 to inhibit GHG emissions from international airlines (Chao et al., 2019). IATA "International Air Transport Association" sets three targets for more sustainability in airlines, which are; improving the efficiency of fuel by an average of 1.5% per year, capping airlines CO_2 emissions from 2020 forwards, and reducing 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 effects, hence presenting the Sustainable Development Goal 13: tackling climate-related challenges.

Figure 2. ICAO coalition for sustainable aviation (source: ICAO website)

Regardless of the efforts to significantly reduce CO_2 emissions through the upcoming years, GHG emissions are expected to rise drastically as the aviation industry expands (Wang et al., 2019). The aviation industry sets some targets to reduce CO_2 emissions by 2050, such as sustainable and clean energy consumption, economic progress by enhancing connectivity, and improved climatic conditions (E.U. Climate Action, 2020). Endorsing development by implementing Sustainability Development Goals through the aviation industry and building a corporate image can promote sustainable operations through the industry's life cycle.

Reducing the aviation industry's carbon footprint is considered a challenge because of air travel's benefits (passengers and cargo) in growing the economy (Hadi-Vencheh et al., 2018). Generating a balance between the impacts of the airline emissions and the non-CO_2 associated impacts remains an inquiry to consider when addressing the sustainability concerns in this sector (Kucukvar et al., 2020). An appropriate understanding of sustainability economics and eco-efficiency in the aviation industry is necessary. Furthermore, a background on the models, tools, approaches required to combat sustainability challenges in this industry needs to be examined to create a driver to challenge address.

1.2 Research Aims and Objectives

The increasing volume of air traffic and the benefits reaped in this sector has hindered sustainable airline operations. Several environmental impacts exist at the airline operation life cycle (L.C.) stages. This entails utilizing substituent materials and energy resources for sustainable outcomes at the phases of the L.C. Thus, bringing about radical changes to the aviation sector requires continuous monitoring of aviation emissions, eco-efficiency, and operational sustainability. This requires a thorough understanding of several methods and application tools used for assessment to foster novelty in this area of technological advancement.

The key objectives of this research are listed below:

- A broader understanding of the existing methods, applications, technologies, and sustainability assessment tools in the aviation industry.
- Improving the awareness of sustainability indicators for the aviation industry by reviewing the published sustainability reports and the international reporting guidelines.
- Quantifying the aviation industry's impact on the environment by analyzing the environmental indicators (energy consumption, GHG emissions, water consumption, and waste generated) indicates how this industry impacts the environment.
- Evaluating Eco-efficiency of the aviation industry in Eastern Asia to evaluate the sustainability performance of some selected airlines. The selected airlines' Eco-efficiency was established using five environmental indicators (electricity consumption, jet fuel consumption, GHG emissions, water consumption, waste generated) and four value-added indicators (revenue, passengers, cargo carried, employees).

1.3 Scope

The study's scope will cover the selected airlines in Eastern Asia by reviewing the published sustainability reports from various resources (GRI database, airline websites, ICAO, IATA). Seven airlines have been considered in the study based on the availability of the data. Furthermore, five environmental indicators and four value-added indicators were selected for the study based on their availability in the selected airlines' published sustainability reports.

1.4 Methodology

This research attempts to assess and analyze the eco-efficiency applied to seven airlines in Eastern Asia using six sequential steps. Figure 3 presents the flow of the study.

The airlines' eco-efficiency assessment methodology started with identifying the airline sector's environmental and value-added indicators to define airlines' performance. The published sustainability reports and annual reports were reviewed to collect the needed data from various resources. The collected data were normalized using the min-max technique to a standard scale. Then, the normalized data were weighted using the PCA "Principal Component Analysis" approach and aggregated. The airline's eco-efficiency score was calculated, and the airlines were ranked based on the eco-efficiency performance. Finally, Eco-efficiency assessment results were deeply analyzed by visualizing the results, and documentation was produced.

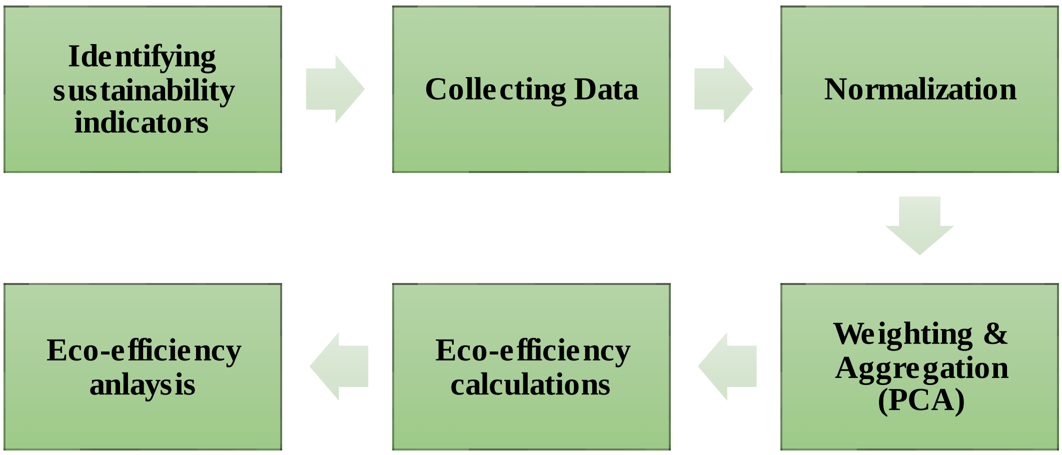

Figure 3. Overview of the project methodology

1.5 Report Outline

This project begins with a background on sustainable development in the aviation industry, objectives definition, scope, and methodology. A small-scale literature review had been performed in Chapter 2 to identify the tools and methods used for aviation industry sustainability assessment concerning three main aspects (environmental, social, and economic), to review the techniques and models used in eco-efficiency assessment for airlines operation sustainability, and to highlight the applications of PCA approach in the eco-efficiency assessment. Chapter 3 describes and presents the methodology/steps performed to assess airlines' Eco-efficiency in Eastern Asia. Also, it provides details on the data gathering, normalization, weighting, aggregation, and eco-efficiency calculations and analysis. Then, the results and findings are deeply analyzed and discussed in Chapter 4. Finally, Chapter 5 presents a summary of the major results and outcomes and recommendations. Furthermore, the description of future works is highlighted in this chapter. All used literature is listed in the references part, and the additional information and tables in the Appendix for further explanation.

CHAPTER 2: LITERATURE REVIEW

This chapter sheds light on the various tools and methods used for aviation industry sustainability assessment concerning three main aspects (environmental, social, and economic) through a small-scale literature review. This chapter further highlights the techniques and models used in eco-efficiency assessment for airlines' operation sustainability and providing more PCA applications in eco-efficiency assessment.

2.1 Sustainability assessment methods and tools in the aviation industry

The sustainable aviation industry is integral to modern humanity. It can be attained by developing such a system that could honor the environment, develop economic worth, and improve social life quality. The main three aspects integral to aviation sustainability are environmental sustainability, including natural resources-system dependence. The other significant aspect is economic sustainability, which explains economic improvement, economic capability, and financial manageability. The third aspect is related to social suitability, which elaborates the social justice, individual health, security, and life superiority (Alameeri et al., 2017).

According to Bertoni et al. (2015), the aviation industry could gain sustainability by implementing new technologies that are more effective with lower environmental effects. Several studies suggested that fuel savings, Air-to-air refills, substitute fuels, better engines, impulsion environmentally friendly systems, and organized flight routes could help achieve the aviation industry's sustainability (Agarwal, 2010; Warwick and Norris, 2011; ICAO, 2012). The idea of absolute sustainability had emerged in recent years, where economic and social dimensions coated within the environmental dimension, which can be evaluated with the life cycle perspective. Over the last two decades, there are numerous models and frameworks presented to understand the sustainability in the aviation industry such as Aviation Environmental Management Systems (AEMS), Fleet-level Environmental Evaluation Tool, Cleaner Production System (CPS), “Life Cycle Assessment (LCA)” or engineering, “Life Cycle Costing (LCC),” “Social Life Cycle Assessment (S-LCA),” Eco-design, Sustainable aviation fuel life cycle assessment model, “slacks-based measure data envelopment analysis (E-DEA)” and Framework for Strategic Sustainable Development (Pinheiro et al., 2020; Chao et al., 2019; Bertoni et al., 2015). This section will discuss three critical dimensions of sustainability concerning various tools and assessments presented in the literature.

2.1.1 Environmental Assessment

According to Pinheiro et al. (2020), a well-recognized and established framework used for environmental assessment is LCA, which lets the assessment of the systems' environmental impact throughout its whole L.C. LCA is an ISO typical technique and comprises of four stages: defining objective and scope, LCI, “Life Cycle Impact Assessment (LCIA),” and explanation. Specifically, for the aviation sector, Lopes performed a Life Cycle Assessment (LCA) research for Airbus A320-200 (Lopes, 2010). The researchers propose a detailed inventory for the jetliners’ industrial system. An identical study was conducted by Lewis, where a Life Cycle Assessment (LCA) was constructed for aircraft based on various flight situations (Lewis, 2013).

Chen (2013) clarified that Environmental Management System (EMS) is a significant methodology found on auditing measures and resemble the “Plan-Do-Check-Act model” of quality management, which consist of setting goals, quantifiable targets, a comprehensive program, and an assessment process to attain a firm’s persistent improvement of its environmental performance and behavior. Another well-known framework is "Fleet-level Environmental Evaluation (FLEE)," which evaluates the USA's commercial aviation operations' ecological routes. This model is used in the USA as it provides a detailed analysis of airline ticket prices, carriers' fleet configurations and sizes, and loads route through the airlines' networks using a system dynamics method (Chao et al., 2019). Chang et al. (2014) performed a study to analyze the economic sustainability and eco-efficiency of 27 international carriers. A comprehensive model, "Slacks-based measure data envelopment analysis model (SBM-DEA)," was developed to test the airline efficiency.

2.1.2 Economic Assessment

There are several practical approaches available for the computation of performance and costs (Finkbeiner et al., 2010). A well-organized framework for the economic assessment throughout the complete L.C. is “Life Cycle Costing (LCC)” by combining all costs and profits associated with the product under investigation (Pinheiro et al., 2020). Seemann et al. (2011) evaluated the economic sustainability dimensions with the support of “Life Cycle Costing (LCC)” for the protection and reconditioning of typical jet engines. The study shows that operation costs, which are mostly motivated by fuel consumption and propulsion system, are the maximum noteworthy cost factor throughout the L.C. Based on the LCC approach, Thokala et al. (2010) developed a decision support model to examine the connections between manufacture, operation, and decommissioning in the airline sector. Another critical model used in the U.S. aviation sector for the environment and economic assessment, but it was more helpful in economic assessment, is the “Sustainable Aviation Fuels (SAF)-LCA” model. This significant model sets an agent-based method to study the interconnections among air jets, agronomists, bio-refineries, air fleets, and policymakers. Airlines' objective is to fulfill passenger need and their stakeholders through producing profits—the choice to implement SAFs subject to the costs linked to aviation fuels and policy inducements. Bio-refineries will develop sites to satisfy SAF needs in case of a realistic view of profit reaps. The investment choice depends on some parameters, like the "Internal Rate of Return (IRR)" and "Present Net Value (NPV)" of the expenses in the production process to develop confident types of SAFs (Chao et al., 2019).

2.1.3 Social Assessment

A comprehensive framework for social sustainability assessment is "Social Life Cycle Assessment (S-LCA)" (Thies et al., 2019). The S-LCA tool permits the study of possible social shocks throughout the products' chain, considering some significant social attributes. All activities, including the extraction of raw materials to the final disposal phase in the life cycle of aviation, are all covered in this stage related to the social dimension. The social effects resulted are reflected as an infliction on the shareholders from the actions' perspective (Thies et al., 2019). The other assessment tool is "Corporate Social Responsibility (CSR)" reporting. CSR considers the airline industry's business obligation to protect and enhance society and business's welfare as a whole by implementing proper ethical, legal, and philanthropic actions (Anttila & Kretzschmar, 2010).

2.2 Airlines operations Eco-efficiency assessment

Eco-efficiency is such a philosophy that can help gain sustainability by encouraging businesses to explore such methods that can make the company more profitable and environmentally responsible. Eco-efficiency elaborates on the ratio of real resource effectiveness and their negative environmental impact (Sun et al., 2019). In this contemporary age, Eco-efficiency for the airline industry is most significant as the airline industry is a primary reason for global carbon emissions. The recent statistics revealed that the airline operation's CO_2 emissions were around 918 million tons in 2018, almost 2.4% of the total overall emissions, a considerable increase of 32% emissions in the world versus the last five years (ICCT, 2019). Airline efficiency explains the comparative capability of individual airlines to maximize their performance while reducing their resource utilization. There are numerous methods and frameworks applied by researchers to evaluate the performance of the airline industry, and one of the prominent radials is "Data Envelopment Analysis (DEA) models" are on top of this list (Wang et al., 2011).

Nevertheless, the radial approach would not show non-radial slacks impacts; thus, various non-radial frameworks are being used over the years where "Network Slacks-Based Measure (N-SBM) models" are significant for researchers (Chang and Yu, 2014). Some researchers believe that using collective structures of both the radial and non-radial approaches can help airline efficiency. In such cases, the Epsilon-Based Measure (EBM) is more suitable to adopt (Xu and Cui, 2017). The various researcher applied different combinations to evaluate the airline efficiencies so the environmental impact can be reduced and the company could achieve eco-efficiency such Li et al. (2015) had suggested an innovative model "Network Slack-Based Measure Data Envelopment Analysis (NSBM DEA) model" to assess the jetliners' efficiency. Chou et al. (2016) had created a new framework termed "Meta -Frontier Dynamic Network

Slack-Based Measure Data Envelopment Analysis (MDN-SBM-DEA)" for performance sustainability assessment. The framework combined the meta-frontiers concept to assist the decision-making unit's performance. The framework popularized dynamic and networked SBM models. Wang et al. (2011) suggested a "Dynamic Slack-Based Measure Data Envelopment Analysis (DSBM)," which can calculate the eco-efficiency of international airlines, and it is acknowledged well by aviation industry experts. Xu and Cui (2017) also suggested a unique incorporated "Network Epsilon-based Measure (NEBM)" and "Network Slacks-Based Measure (NSBM) Data Envelopment Analysis model" for evaluating the eco-efficiency of the aviation industry. Cui (2020) had assessed the effect of the "European Union Emissions Trading System" release privileges on aviation ecological effectiveness with the help of the "Network Environmental Slack-Based Measure (NSBM DEA) model" with fragile unwanted yields availability. The leading Indian and Chinese airline operators' efficiency performance have been assessed by Yu hang et al. (2019) using the "Dynamic Network DEA (DNDEA) model" considering a reflection of the jetliners' internal operations and connect the successive period that stands as a carry-over. The research reveals that India's SpiceJet and China's Spring are mainly useful operators from 2008 until 2015. The literature analysis reveals that many researchers examined the aviation sector's efficiency and applied DEA models widely. Still, they used SBM models rarely to examine the eco-efficiency of the aviation sector.

2.3 PCA approach for eco-efficiency assessment

PCA is the universal depiction of a method that utilizes complicated fundamental mathematical standards to convert the probably correlated variables to a small number of variables termed as principal components (Pereira et al., 2018). Duong and Duong (2008) provided another view as PCA converts the variables into new unrelated principle components and the first vital components retain the most significant variation in the original variables. Lever et al. (2017) believe that Principal component analysis (PCA) makes simpler the intricacy of high-dimensional data while keeping trends and patterns. This happens only by converting the data into smaller dimensions, which operate as an abstract of features. Nevertheless, PCA assists in interpreting data, but it will not always locate significant patterns. Han (2010) suggested that Principal Component Analysis (PCA) is the most frequently employed variety algorithm to reduce data size, eliminate noise, and pull out important information before further analysis. However, the PCA is quite an important tool but still receives less attention in the literature of aggregate indicator and eco-efficiency literature, where it is even not much utilized by the researcher. The utilization of Principal Component Analysis (PCA) provided significant benefits, such as it is a helpful method to elaborate maximum possible variations after merging main variables into linear components. PCA is a constructive instrument for enhancing the indicators' efficiency. Lastly, PCA is intended to decrease data sets' dimensionality. However, PCA is not a universal remedy but can still assist in evolving cumulative eco-efficiency (Jollands et al., 2004). As elaborated earlier that little attention is given to PCA in literature. However, its employees can be seen in various places, such as Onat et al. (2019) applied PCA and LCA in their research, which presented a novel incorporated framework to analyze the electric battery's eco-efficiency transportation USA states. Similarly, Park et al. (2015) researched on transportation concentrated on evaluating the performance of manufacturing sector sustainability in the U.S. through applying PCA methodology along with the "Economic Input-Output Life-Cycle Assessment (EIO-LCA)." The research reveals that both techniques help identify the least and most eco-efficiency in the respective sector. Jiang et al. (2018) also conducted a study to examine the engine manufacturing sector's corporate sustainable performance in China and offered a three-dimensional sustainability evaluation technique by using PCA methodology. This research first time used the PCA technique and matching units in the building of the "Corporate Sustainability Index (CSI)." Luca and Carlucci (2014) conducted a study aiming to develop several sustainable development indexes at the native dimension for Italy. Researchers took assistance from PCA, which was used to investigate the correlation between indicators and their involvement in the sustainability target. Paula and Kološta (2015) expanded their research instead of Europe's country to each of 27 European countries to develop an accumulated S.D. index and used PCA as an effective method. As per the countries' assessment by accumulated S.D. index, their research reveals that the countries' economic development appears to be comparatively sustainable compared to the remaining twenty-seven European countries. Denmark, Sweden, Netherlands, and Britain are considered as the best S.D. countries.

The principal component analysis is one of the most sophisticated frameworks 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.

CHAPTER 3: RESEARCH METHODOLOGY

This chapter presents the methodology and steps performed to assess the Eco-efficiency of airlines in Eastern Asia. It also highlights the methods/ techniques used in Chapter 4 for an in-depth analysis of eco-efficiency assessment results.

3.1 Methodology Overview

This research attempts to assess and analyze the eco-efficiency assessment applied to seven airlines in Eastern Asia using six sequential steps. Figure 4 presents the flow of the study. The methodology of eco-efficiency assessment of airlines started with identifying the airline sector's environmental and value-added indicators. Then, the published sustainability reports and annual reports were reviewed to collect the needed data. The collected data were normalized using the min-max technique. After that, the normalized data were weighted using the PCA approach and aggregated. The eco-efficiency score of each airline was calculated. Finally, Eco-efficiency assessment results were deeply analyzed.

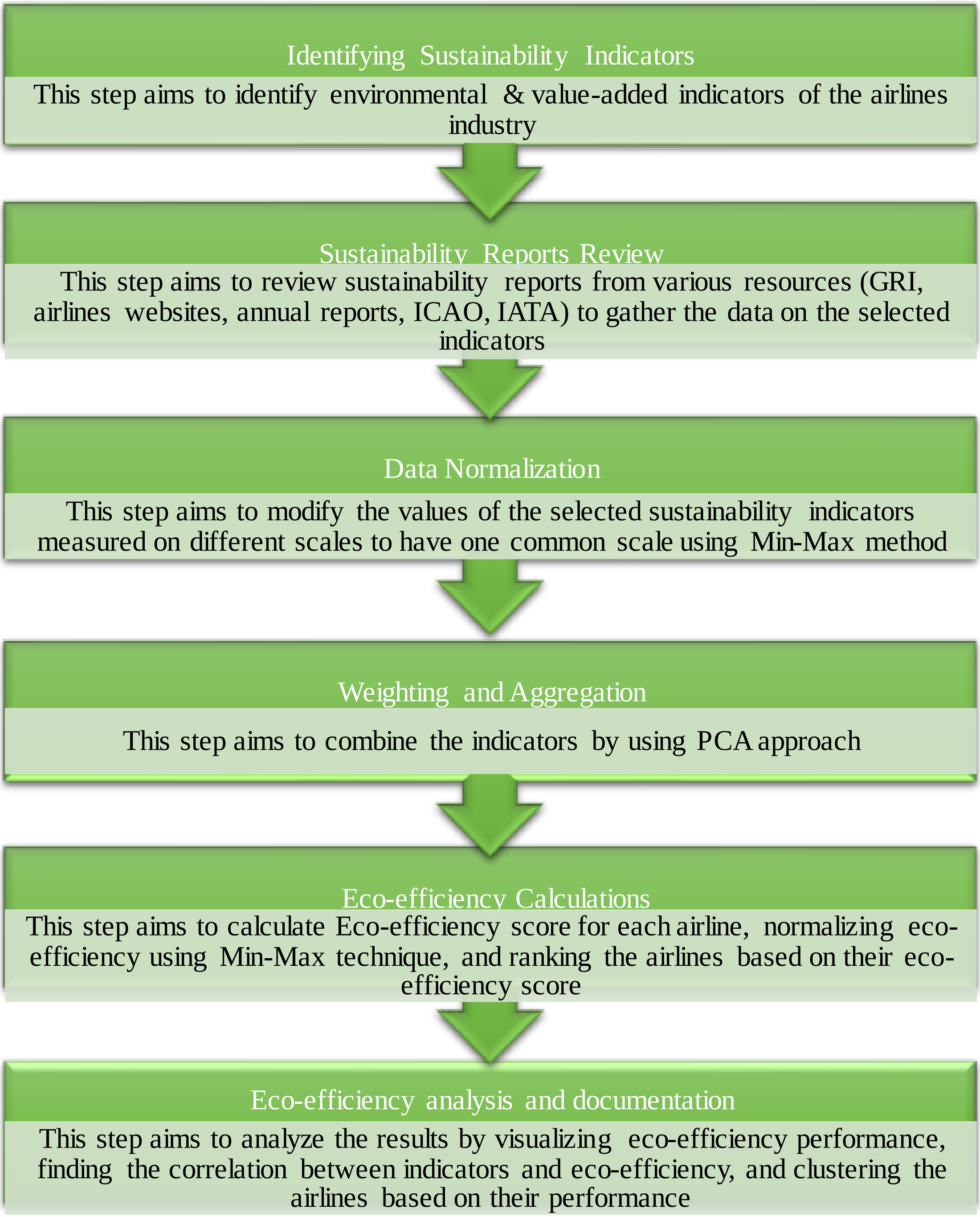

Figure 4. The flow of the study

3.2 Identifying Sustainability indicators

There are several environmental impacts during the airline operation stage and other airline life cycle operations phases. This can be measured by some indicators such as energy resources consumption (electricity and jet fuels), Greenhouse Gas emissions (GHG), water consumption, and waste generated.

However, the aviation sector is considered a significant key driver of society's economic contribution growth in terms of GDP. The sector also enhanced passengers and goods (cargo) movement faster with connectivity across the world. Moreover, supporting the employment of large and different groups of employees in the sector.

In this research, based on the airline industry's reality and the previous literature reviews, five environmental indicators were selected for assessing the impact of airlines on the environment, and four indicators were selected as value-added from the airline industry to evaluate the eco-efficiency of airlines. Table 1 highlights the selected indicators for the assessment.

Table 1. Sustainability indicators of airlines

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)	

3.3 Sustainability Reports review

Airlines Sustainability reports in the Global Reporting Initiative (GRI) database, airline websites, ICAO, and IATA were reviewed to gather environmental indicators' data. Airlines' annual reports were reviewed to collect data regarding revenue, passengers, cargo carried, and employees as that information is not available in most of the sustainability reports.

A search on the GRI database regarding airlines between 2015 and 2019 was performed considering Asia only, and the research provided only ten organizations. Additional search on airline websites, IATA and ICAO, was performed to gather sustainability and annual reports. By reviewing the reports, it was observed that the reports' completed system is in 2018 for seven selected airlines in the Eastern Asia zone with all the data of indicators required for the sustainability assessment, as identified in section 3.2.

We have noticed a lack of information on some indicators; hence some airlines were excluded. The collected data are available in Table 12 of appendix A. Table 2 provides the descriptive statistics of the selected indicators in the research study. Figures 5 and 6 show the data of all indicators for the seven airlines.

Table 2. The statistics of the selected airlines' 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

The impact of airlines on environmental indicators varies among the airlines, as presented in Figure 5. It has been observed that China Southern Airlines have the highest GHG emissions, followed by China Eastern Airlines due to high jet fuel consumption. In contrast, China Airlines have the lowest GHG emissions due to low fuel consumption. In terms of energy consumption, Korean Airlines are the largest consumer of electricity. China Southern Airlines is the largest Jet fuel consumer among the airlines, while ANA airlines are considered the lowest Jet fuel consumption airlines. In terms of water consumption, China Southern, Cathay Pacific, and China Eastem airlines consumed high water. All Nippon Airlines are the highest airlines that generated wastes.

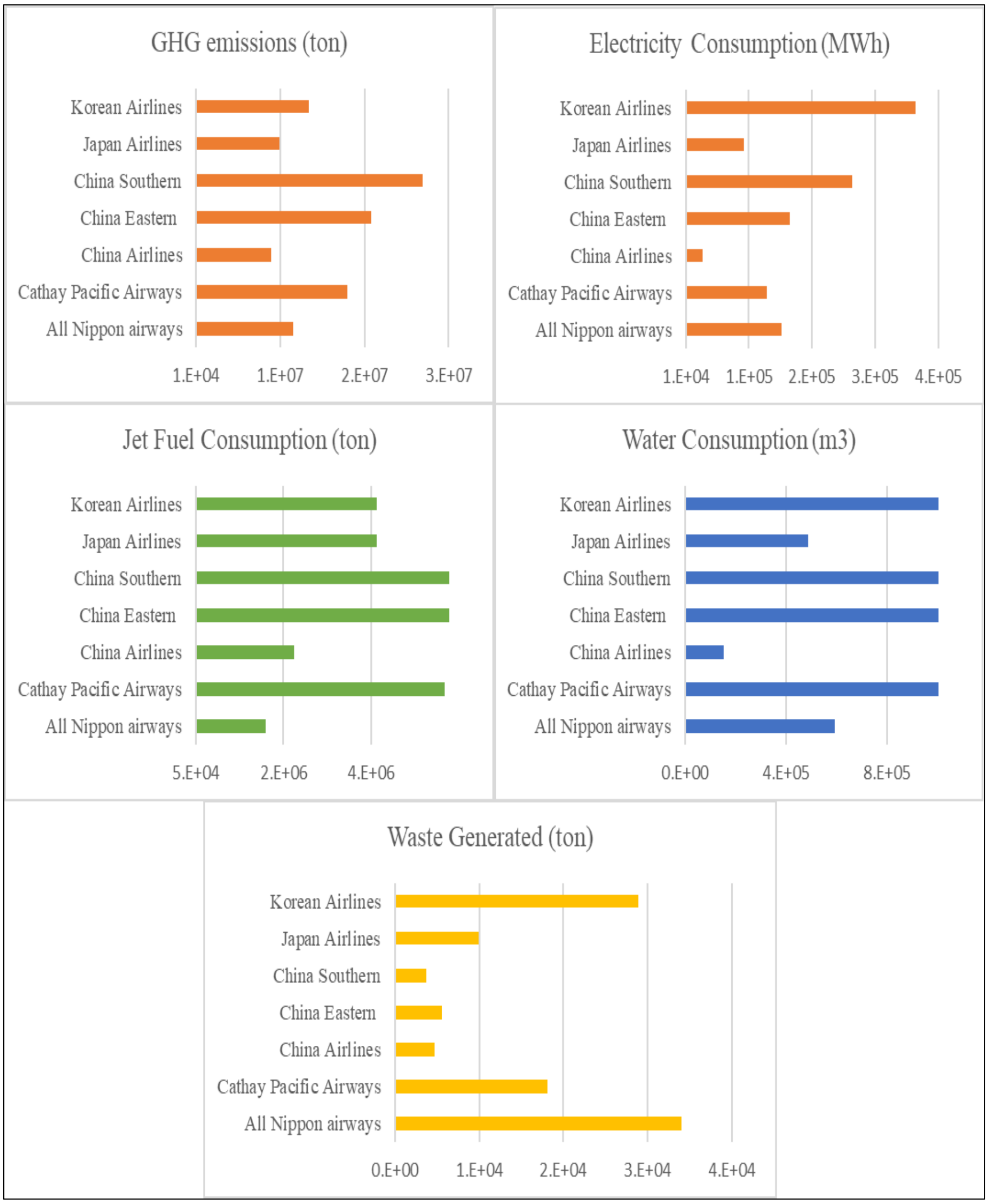

Figure 5. Data for environmental indicators

The data above shows a discrepancy in the data due to the diversity in reporting between airlines in terms of units and boundaries/definition of each indicator, impacting the calculations.

In terms of value-added indicators, airlines have different contributions to the value-added indicators, as shown in Figure 6. China Airlines have the highest revenue generated in the year 2018. China Southern and Eastern carried the largest number of passengers. In contrast, Cathay Pacific Airlines carried the most massive cargo. Since China Southern airlines provide the service to many passengers, they have a high number of employees.

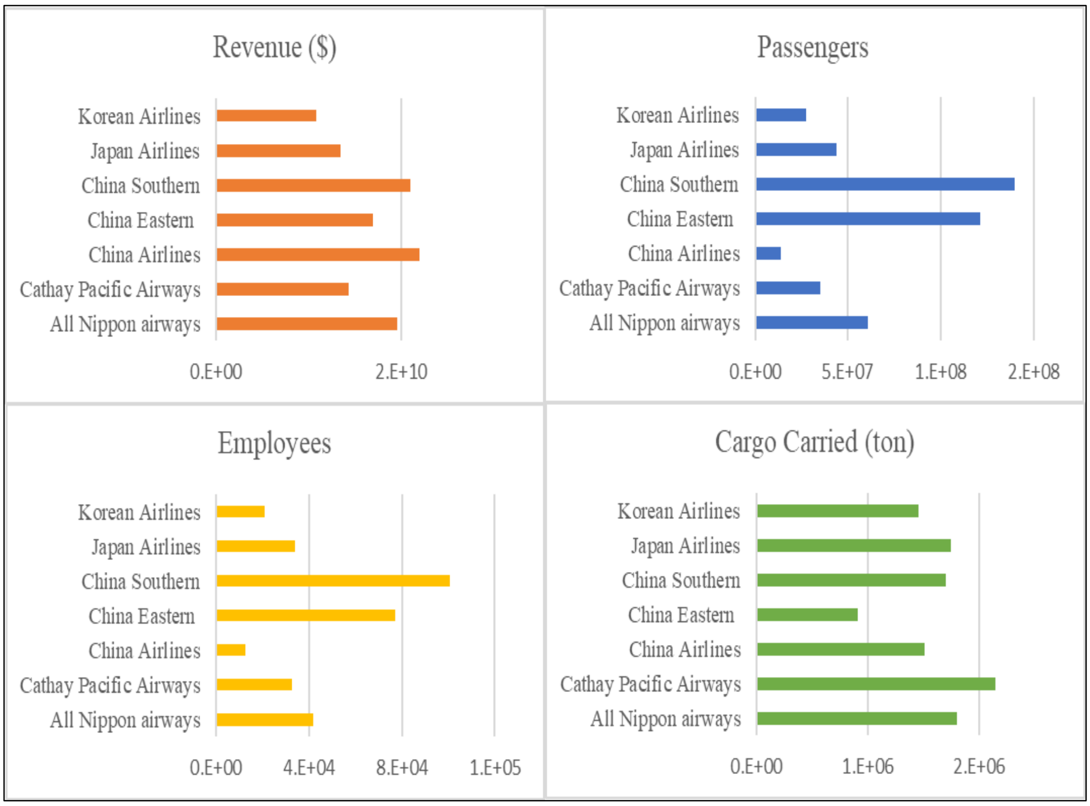

Figure 6. Data of value-added indicators

3.4 Data Normalization

The results were collected into a matrix to be used as the subsequent analysis and calculations. The matrix consists of seven airlines in Eastern Asia (rows) and five environmental indicators, and four value-added indicators (columns).

Since the data has different measuring units, normalization must form dimensionless and meaningful data to aggregate them. Several data normalization methods are available in the literature. In this study, we use the Min-Max technique, Equation 1, for simplicity and ease of use.

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

X_i^* is the normalized data for each airline i, and X_i is the collected data of each indicator for the country i. (a) is equal to1 and (b) is equal to 2 for ranges from 1 to 2 intervals. The $X_{i,min}$ and $X_{i,max}$ represent each indicator has collected data's minimum and maximum value. The normalized data for all indicators are presented in table 13 of appendix B.

3.5 Weighting and aggregation of sustainability indicators

The composite environmental index (CEI) was obtained using the PCA approach to combine the five environmental indicators. The 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 PCA components obtained using XLSTAT for environmental and value-added indicators separately. The eigenvalue measures the obtained principal component covered the variability within the data.

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

Where F1, F2,..., F5 are the obtained principal components.

Some rules were chosen and followed in selecting the components that work well and finding the smallest number of components required to obtain a good representation of the data, following Kaiser's stopping rule, based on selecting the components whose eigenvalues are more extensive than 1. The first component has been selected whose eigenvalue is larger than one for environmental, and the first component for value-added indicators has been selected, while the remaining components were omitted as they do not have remarkable impacts on the results. Table 4 presents the eigenvectors for the selected components.

Table 4. Eigenvectors of the selected 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		

PCA value for each airline can be computed used Equation (2)

$$PCA\ value = C_1 Z_1 + C_2 Z_2 + C_3 Z_3 + C_4 Z_4 + C_5 Z_5 \qquad (2)$$

The correlation between the indicators and the first principal component are shown in Table 5. There is a positive correlation between all the environmental indicators values and the principal component except the waste indicator; there is a negative correlation with the component. Therefore, the PCA score increases by increasing all environmental indicators' values except waste, whereas PCA is increasing with decreasing the value of waste. On the other hand, there is a positive correlation between all the value-added indicators and the principal component except the cargo indicator; 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 7 displays the variables factor map, which shows the environmental indicators' vector by presenting the variance' percentage of the first and the second PCA. Their opposite directions express the negative correlations between waste and the remaining indicators.

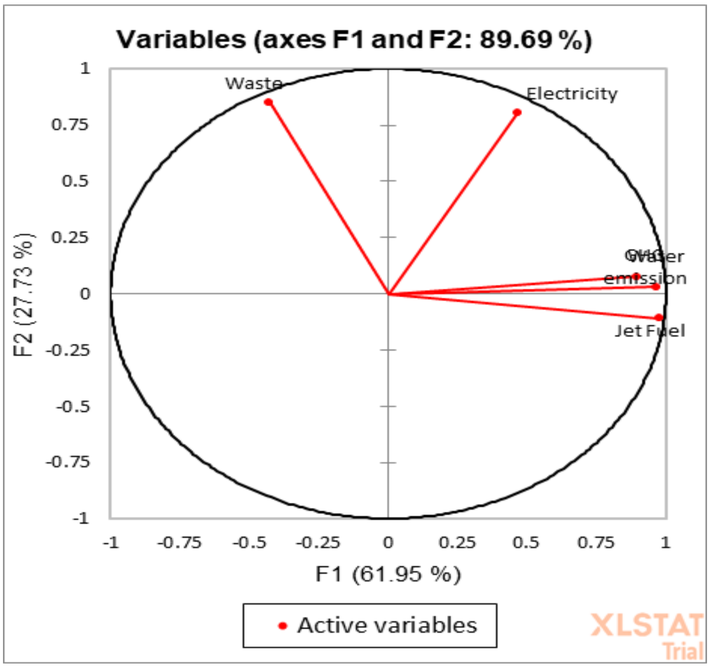

Figure 7. Variables factor map for environmental indicators

Figure 8 displays the variables factor map for the value-added indicators' vector, where all indicators have a positive direction except the cargo indicator.

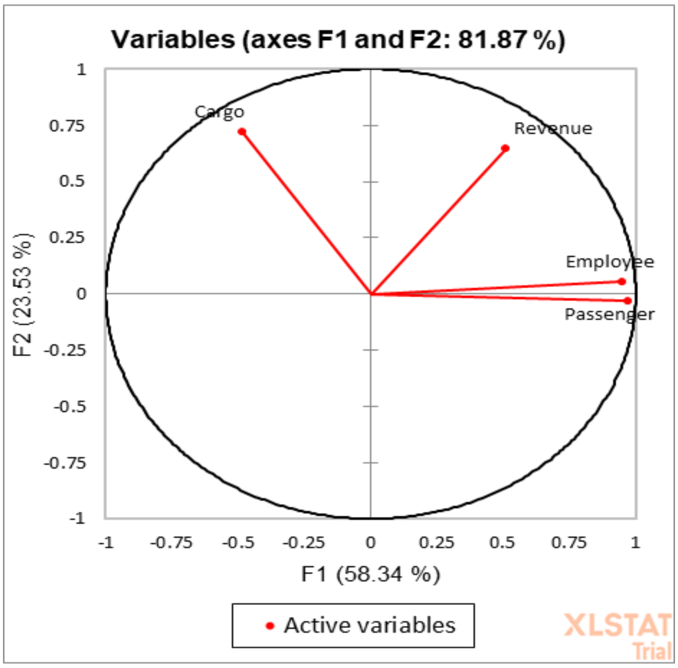

Figure 8. Variables factor map for value-added indicators

The first 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%, 58.342% for environmental and value-added indicators, respectively) and cover most of the dataset's information. CEI and CVI were computed using Equations (3) and (4).

$$CEI = (0.465\, X_1^* + 0.979X_2^* + 0.968X_3^* + (-0.429X_4^*) + 0.895X_5^*) \qquad (3)$$

$$CVI = (0.511X_1^* + 0.970X_2^* + 0.948X_3^* + (-0.484X_4^*)) \qquad (4)$$

Where X_i^* in Equation (3) is the corresponding environmental indicator, and X_i^* in Equation (4) is the corresponding value-added indicator.

3.6 Eco-efficiency calculations

In this step, eco-efficiency calculations have been performed, as shown in Figure 9.

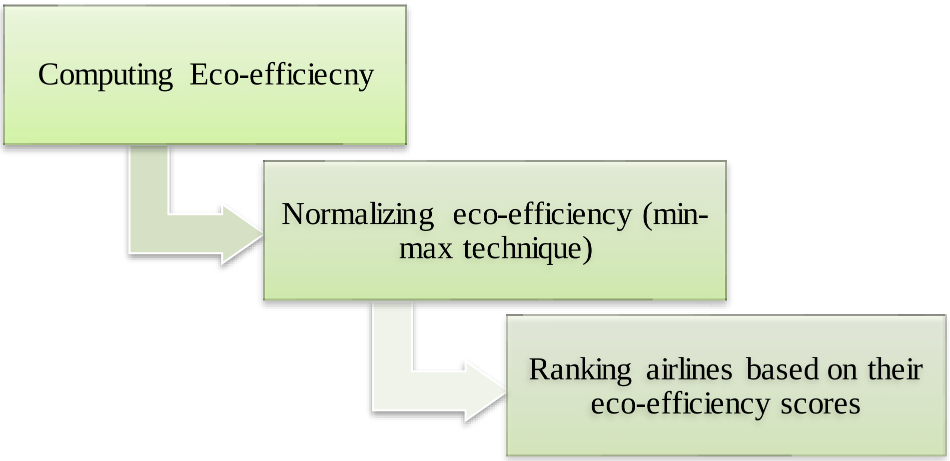

Figure 9. Steps to calculate eco-efficiency

The eco-efficiency score for each airline as a ratio of the value-added index over the environmental index is computed as displayed in Equation (5).

$$Eco - efficiecny = \frac{CVI}{CEI} \quad (5)$$

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.

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

Where (a) is equal to 1 and (b) is equal to 2. E_i is the raw eco-efficiency score for airline i, and E_{max} and E_{min} are the maximum and minimum scores of eco-efficiency among all the airlines, respectively.

After that, the airlines are ranked based on their eco-efficiency scores, as presented in table 6 in Chapter 4.

3.7 Eco-efficiency analysis and documentation

Eco-efficiency results will be deeply analyzed in chapter 4 and the airlines will be compared and grouped based on their eco-efficiency performance by visualizing the performance. The correlation of determination will also be used to analyze the correlation between the indicators and the eco-efficiency. Also, the quartiles method will be utilized 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 the calculations of eco-efficiency results are organized to share and access easily.

CHAPTER 4: RESULTS & DISCUSSION

This chapter aims to visualize the results of airlines' eco-efficiency performance and compare the airlines' performance based on their eco-efficiency scores. Also, the correlation of determination is used to investigate the correlation between indicators and eco-efficiency. Furthermore, the airlines are clustered based on their eco-efficiency scores using the quartiles method.

4.1 Visualizing eco-efficiency performance

Airlines' eco-efficiency scores were calculated by following the steps presented in Chapter 3. Table 6 presents the eco-efficiency results for the selected seven airlines in Eastern Asia.

Table 6. CEI, CVI, and normalized eco-efficiency results of airlines.

	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

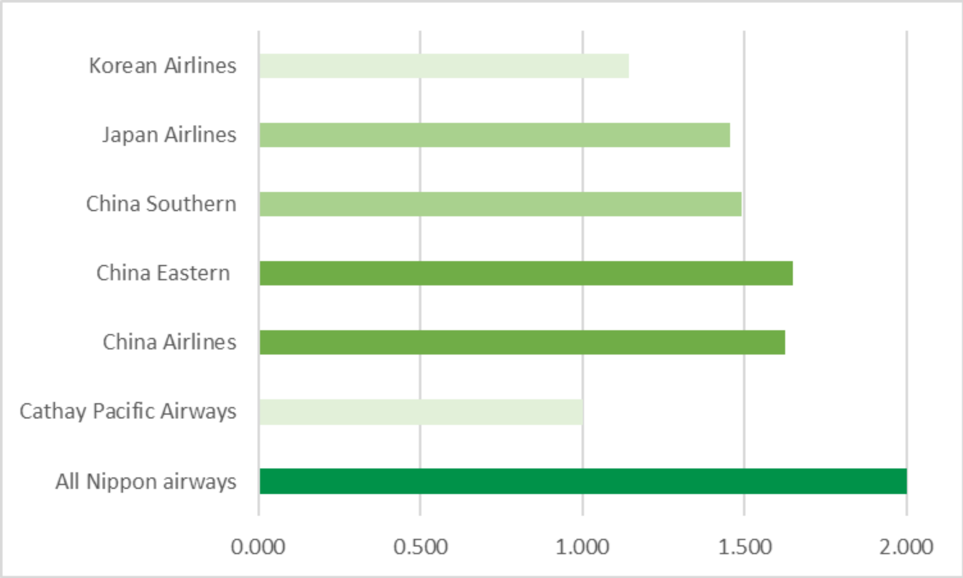

Figure 10. Eco-efficiency scores for airlines in Asia

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 are the highest eco-efficient airlines in Eastern Asia as they have the lowest CEI among the airlines due to low GHG emissions and Jet fuel consumption. The second highest eco-efficient airline is China Eastern Airlines since they have a high value of CVI. China Airlines are the third-highest eco-efficient airlines in Eastern Asia.

Three airlines in China were included in this study (China airlines, China Eastern, and China Southern airlines). Two of them (China Airlines and China Eastern) are on the top three eco-efficient airlines in Eastern Asia. At the same time, China Southern airlines are the fourth-highest eco-efficient airlines with Japan airlines. Although China Southern has the maximum CVI, CEI's highest value makes the airlines the fourth eco-efficient airline.

In contrast, Cathay Pacific airlines are the lowest eco-efficient airlines in Eastern Asia since they hold a high CEI value as Cathay consumed high water and jet fuel. Thus, airlines with higher CEI values lead to marking them as the least eco-efficiency airlines.

4.2 Correlation Analysis

There are several methods available in the literature for correlation analysis. The most common methods are the Pearson correlation coefficient (R) and determination (R^2). Correlation of determination (R^2) is selected in this study to analyze the correlation between the selected five 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 of environmental indicators and eco-efficiency

	Electricity	Jet-Fuel	GHG emission	Waste	Water	Eco-efficiency
Electricity	1	0.161	0.203	0.137	0.117	0.109
Jet fuel	0.161	1	0.858	0.289	0.680	0.152
GHG	0.203	0.858	1	0.135	0.717	0.032
Waste	0.137	0.289	0.135	1	0.046	0.001
Water	0.117	0.680	0.717	0.046	1	0.321
Eco-efficiency	0.109	0.152	0.032	0.001	0.321	1

As presented in the above table, the correlation between environmental indicators and eco-efficiency ranging from $0.001 \leq R2 \leq 0.321$. Eco-efficiency has the highest correlation with water and the lowest correlation with waste indicator.

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

	Revenue	Passenger	Employee	Cargo	Eco-efficiency
Revenue	1	0.115	0.116	0.004	0.431
Passenger	0.115	1	0.983	0.140	0.085
Employee	0.116	0.983	1	0.070	0.049
Cargo	0.004	0.140	0.070	1	0.103
Eco-efficiency	0.431	0.085	0.049	0.103	1

The correlation between value-added indicators and eco-efficiency, ranging from $0.049 \leq R2 \leq 0.431$. 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.

4.3 Eco-efficiency performance clustering

In this section, the airlines in Eastern Asia have been clustered into groups based on their efficiency performance. Quartiles method is utilized as it is considered the most common method for this purpose. 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 the below table.

Table 9. Quartiles definition and values

		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

In this project, the four quarters are named as “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

		Definition
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 are maintained an excellent performance.

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

	Definition
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

CHAPTER 5: CONCLUSION & RECOMMENDATIONS

This chapter summarizes the main finding of the research, recommendation, and possible future works.

5.1 Research Summary and Findings

The aviation industry has played a dynamic character in the global development process. Significant growth can be realized in the aviation sector in the past couple of decades. Industry experts have fully recognized the need for sustainability assessment within this industry in a more incorporated manner. This research conducted a small-scale literature review covering all the prominent tools and methods used for sustainability and eco-efficiency assessment in the aviation industry. Furthermore, the eco-efficiency of the selected seven airlines in Eastern Asia were 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 Eastern Asia. The sustainability reports of the year 2018 were reviewed to gather the needed data. PCA approach was used as a weighting strategy to compute the efficiency of airlines. The results show that All Nippon Airlines are the most efficient airline in Eastern Asia, while Cathay Pacific airlines are the least efficient airline.
The outcomes of this research can support creating sustainable aviation policies and offer a direction for decision making.

5.2 Recommendations

After implementing this research, it is recommended that the aviation industry must achieve environmental sustainability. For this reason, the aviation industry needs to switch to more fuel-efficient airplanes for their movements. This would significantly decrease carbon emission and assist in sustainably improving the environment. Similarly, fuel-efficient planes consume less fuel and create a better impact on the economic side of sustainability as well. It is also recommended that the aviation industry introduce new technologies and initiatives to reduce ecological effects.

As stated before, this paper's scope was subject to the availability of the data 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.

5.3 Future Work

The study can be further extended to analyze the eco-efficiency performance universally and benchmark the level of eco-efficiency. Future works can also comprise more sustainability indicators covering all the sustainability dimensions (socio-economic, environmental). During specific years, the airline's performance can be derived by implementing a time series analysis for annual sustainability performance to measure the improvements or deviations. More research can be carried out to identify inefficient airlines' causes, which show low eco-efficiency performance.

Furthermore, research can be carried out to study the impact of the COVID-19 pandemic on the aviation sector in terms of sustainability concerning the three pillars dimensions of sustainability (environment, economy, and society) compared to the performance pre and post- COVID-19 recovery.

Integrating empirical methods with sustainability assessment tools can deliver promising results to support decision making. For future research, it is recommended to use an integrated LCSA approach (Kucukvar et al., 2018); “material footprint analysis” (Kucukvar et al., 2019-A); and “Economic input-output (EIO) analysis” (Egilmez et al., 2013), merged with other D.M. models, for instance like the Fuzzy-MCDM model (Onat et al., 2016-A) covering the three pillars of sustainability. Additionally, multivariate regression models such as stepwise regression, LASSO regression, and ridge can be used for selecting response variables to assist the aggregation step while analyzing sustainability (Abdella et al., 2016). To better understand statistical computation models and sustainability applications, the readers can refer Abdur-Rouf et al. (2018); Abdella et al. (2020).

There are enormous opportunities for further research and analysis of this sector due to its benefits, expansion, and impact on the environment.

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APPENDIX

Appendix A: Preliminary Data Collection

Table 12. The collected data of airlines

Airline	Electricity Consumption (MWh)	Jet fuel (ton)	GHG (ton)	Waste (ton)	Water (m3)	Revenue ($)	Passengers	Employee	Cargo (ton)
All Nippon airways	1.61E+5	1.63E+6	1.15E+7	3.40E+4	5.91E+5	1.94E+10	6.10E+7	4.19E+4	1.80E+6
Cathay Pacific Airways	1.38E+05	5.713E+06	1.80E+7	1.81E+4	9.17E+6	1.43E+10	3.50E+7	3.25E+4	2.15E+6
China Airlines	3.60E+4	2.285E+06	8.89E+6	4.68E+3	1.50E+5	2.19E+10	1.37E+7	1.24E+4	1.51E+6
China Eastern	1.74E+5	6.60E+6	2.08E+7	5.54E+3	5.24E+6	1.68E+10	1.21E+8	7.70E+4	9.15E+5
China Southern	2.74E+05	8.540E+6	2.69E+7	3.66E+3	7.79E+6	2.1E+10	1.40E+8	1.00E+5	1.70E+6
Japan Airlines	1.02E+05	4.17E+6	9.86E+6	9.88E+3	4.85E+5	1.3E+10	4.40E+7	3.40E+4	1.75E+6
Korean Airlines	3.74E+5	4.16E+6	1.33E+7	2.88E+4	3.08E+6	1.1E+10	2.73E+7	2.06E+4	1.46E+6

Appendix B: The Normalized Data

Table 13. The normalized data

	Electricity	Jet Fuel	GHG	Waste	Water	Revenue	Passenger	Employee	Cargo
All Nippon	1.36	1.00	1.14	2.00	1.04	1.77	1.37	1.33	1.71
Cathay Pacific	1.30	1.59	1.50	1.47	2.00	1.31	1.16	1.22	2.00
China Airlines	1.00	1.09	1.00	1.03	1.00	2.00	1.00	1.00	1.48
China Eastern	1.41	1.72	1.66	1.06	1.56	1.54	1.85	1.73	1.00
China Southern	1.70	2.00	2.00	1.00	1.84	1.90	2.00	2.00	1.63
Japan Airlines	1.19	1.36	1.05	1.20	1.03	1.23	1.24	1.24	1.67
Korean Airlines	2.00	1.36	1.24	1.83	1.32	1.00	1.10	1.09	1.44