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A frontier-based managerial approach for relative sustainability performance assessment of the world's airports

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Abstract

The sustainability impact of air transportation has become crucial to communities. Airports around the world are forced to be transparent with the society and to declare their sustainability results. As the sustainability goals and objectives and due to its multi-dimension aspects that are needed to be decided of and subsequently improved, the decision has been taken, and the parameters have been selected due to its significance in this field. This research presents a managerial approach combining the optimization-based frontier approach with the Global Report Initiative's comprehensive sustainability database for selected 30 major international airports based on data availability. In this regard, eco-efficiency analysis is carried out with four different models using input-oriented modeling with multiple undesirable environmental inputs (energy, carbon, water, and waste) and desirable outputs (revenue, passenger and employment) to compare efficiency and sustainability levels of airports in different contexts. Finally, performance improvement targets of each environmental indicators are presented for the airports. These comparative models reveal different frontier airports, which provide the opportunity to analyze diversified reference points for the same decision-making unit. The presented statistical study has shown that San Francisco, Hong Kong, Hamad International Airport are the most efficient airports in terms of overall sustainability performance based on collected data and selected indicators. The authors also concluded that there is a discrepancy in sustainability data reporting between airports, and there is a need for collecting complete, consistent and real-time social, environmental, economic, and governance data, to better compare and evaluate the performance of each airport from a sustainability perspective.

KEYWORDS

airports, environmental policy, frontier approach, statistical analysis, sustainability assessment, sustainability reporting and benchmarking, sustainable development

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1 | INTRODUCTION

Sustainable development is necessary for the well-being of society, and it can be achieved when humanity can meet its present needs without affecting the ability of the people in the future to meet their own needs (Bennbea, Wazwaz, Abujarbou, Abdella, & Musharavati, 2018; Halisçelik & Soytas, 2019; Kutty, Abdella, Kucukvar, Onat, & Bulu, 2020). Organizations are at the forefront of helping society to reach the goals of sustainable development (Wichaisri & Sopadang, 2018). With the current wave of globalization and technological advancements, companies have seized the emerging opportunities in helping society achieve a high quality of life as well as prosperity. Many people around the globe have been connected through technologies that have promoted information and knowledge sharing among different people (Onat & Kucukvar, 2020; Zhang et al., 2019).

Sustainable development has been faced with an ever-changing environment that demands a new way of thinking, as well as innovating ways of meeting those challenges (Baumgartner & Korhonen, 2010; Sen, Kucukvar, Onat, & Tatari, 2020; Shaikh, Kucukvar, Onat, & Kirkil, 2017). These challenges have called for new forms of interaction between companies, society, and the earth. The need to adapt to a new way of communication has forced companies to provide new opportunities and choices that affect the people, planet, and economies differently. There is a need to balance these impacts basing on economic, environmental, and social development (Gumus, Kucukvar, & Tatari, 2016; Kucukvar, Egilmez, & Tatari, 2016; Onat, Kucukvar, Aboushaqrah, & Jabbar, 2019). This has required that companies interact and communicate with all stakeholders openly and effectively (Onat, Kucukvar, Halog, & Cloutier, 2017). This transparency could be achieved if there is a common global language and metrics that all companies use to communicate their values and interactions with the economic, environmental, and social aspects that affect society.

Transportation is playing a significant role in achieving the goals of sustainable development (Walker & Cook, 2009). To solve the world's most significant issue in sustainability development, the United Nations (UNs) set up the Millennium Development Goals (MDGs) in 2000 (Halisçelik & Soytas, 2019; Kucukvar & Tatari, 2012; Sen, Onat, Kucukvar, & Tatari, 2019). In 2015, the global society worked to improve for the next 15 years (2000–2015) agreement to direct the improvement of economics, guarantee that it would not happen unless the environment is being sustained, and put poverty into an end. Daley (2009) raised a concern about the effectiveness of air transportation in achieving the MDGs and enhancing people's well-being in countries.

Due to the importance of airport and airline sustainability, communities around the world request for initiatives to be determined to achieve sustainability goals. Some airports and airlines around the world indicated and brought to their attention that there are seven initiatives concerned about sustainability that can lessen the environmental impact (Kaszewski & Sheate, 2004). Airlines and the airport industry play a huge role in affecting the environment significantly (Kurniawan & Khardi, 2011). As stated by the International Air Transport Association (IATA), there are several initiatives to reduce the waste and emission of carbon dioxide to save the ecological systems (Kousoulidou & Lonza, 2016). As a result, the airlines and airports came to the point that they will make considerable efforts to implement the initiatives. The seven initiatives as follow: firstly, to reduce the single-use of plastic waste. Secondly, some airlines closed the on plane duty-free to reduce the weights. Thirdly, some flights take the initiative of free single-use plastic. Fourthly, on some flights, they take the initiative of reducing the use of single-use plastic by 80%. Fifthly, raising awareness of recycling. Sixthly, zero waste flight. Seventhly, using Artificial intelligence to predict the patterns of consumption of customers (Future Travel Experience, 2019).

The sustainable development goals (SDGs), announced by the UN, consist of three main pillars. These are economic, social, and environmental (Nilsson, Griggs, & Visbeck, 2016). Airports are encountering critical challenges in accomplishing the SDGs. From the environmental aspect, the airports are facing challenges such as reducing the gas of greenhouse gas (GHG) emissions and endeavoring for the zero-carbon environment, whereas often dealing with insufficient funding and shortage in human resources. Hence, to achieve sustainability efficiently, airports need to set both strategical and tactical goals for sustainability, set performance indicators to those goals, construct lean in all processes to remove the wastes, and improve efficiency, thus achieving the sustainability goals (Carlucci, Cirà, & Coccorese, 2018).

In particular, the environmental aspect is the hottest topic among all, so airports throughout the world oblige their determination to improve the environmental performance by managing the growth of the environmental impact and do their best practice to reduce it. As mentioned above, among the elements that need to be monitored and controlled is the carbon dioxide (CO_2) emissions. It takes place at the highest priority. One more factor that the airports and airlines are working together to reduce or even eliminate it is the noise factor. There are many factors as well that IATA took into consideration to reduce the impact on the environment by airports and airlines, for instance, alternative fuels, carbon offset programs, environmental assessment, and FRED+. The FRED+ is a platform developed to help in reporting CO_2 emissions for the operator of the plane and the concerned entity (IATA, 2020).

2 | RESEARCH OBJECTIVES AND OUTLINE

This paper has three main research objectives to contribute to the body-of-knowledge such as; (a) enhance the transparency and awareness of sustainability indicators for air transportation by reviewing the initiatives of global sustainability and global reporting guidelines, (b) determine the parameters for the assessment by having the most critical indicators under the triple bottom goals such as environment, economy, and the society for the aviation industry, and (c) evaluate proposed frameworks to have a defined appraisal system that assesses the performance of airport sustainability.

The structure of the paper is organized as follows. The next section, after the introduction, presents a review on the Global Report Initiative (GRI) reporting and Data Envelopment Analysis (DEA). This part is followed by the method section that involves the process of how DEA is adopted and utilized in sustainability performance benchmarking for the airports. Furthermore, the data collection part presents information about how to gather a comprehensive sustainability data of world's airports around the world regarding data of proposed model variables. The results and discussion part take place, including an overview of the conducted analysis. The conclusion part completes the research with recommendations and further researches. To present the flow of the study, Figure 1 indicates the levels, which composes of three different phases.

3 | GLOBAL REPORTING INITIATIVE (GRI)

Sustainability reporting is critical to any corporation that may require operating in the global market as it provides accountability that makes the company gain a competitive advantage (Alazzani & Wan-Hussin,- 2013). Sustainability reporting includes a practice of disclosing and measuring as well as being accountable for both the external and internal stakeholders of the organization's performance in attaining sustainable development (Lu, Hsu, Liou, & Lo, 2018). Sustainability reporting aims to provide transparency to all stakeholders on how the organization's performance in achieving the triple bottom line that takes into consideration of economic, environmental, and social development aspects of development (Lozano & Huisingh, 2011).

GRI is a non-profitable, independent, international organization that is network-based with the primary objective of helping governments as well as individual businesses to report effectively and publicly disclose how their activities affect environmental, social, and governance sustainability issues (Kılkış & Kılkış, 2017, 2016). The GRI plays an essential role in sustainability reporting, and sustainable development as its sustainability reporting standards is highly regarded and can be widely comparable. Currently, the GRI is the leading global entity in corporate sustainability reporting. Beginning from the year 1999, the GRI has been able to provide a comprehensive framework for sustainability reporting that includes reporting guidelines, reporting principles and indicators (Del Mar Alonso-Almeida, Llach, & Marimon, 2014).

The primary mission of the GRI is to ensure that sustainability-reporting standards are common practice standards that promote and manage the change that enhances sustainable development in a global economy (Pucheta-Martínez, Bel-Oms, & Nekhili, 2019). The GRI's primary purpose is to encourage the use of sustainability reporting to drive organizations to become more sustainable as well as enhancing their contribution to sustainable development (KPMG, 2017). Through the GRI reporting framework, many organizations and companies have been motivated to measure and understand their sustainable development while at the same time being able to clearly and effectively communicate their durable development performance to all their stakeholders. Through the GRI, organizations can provide sustainability reporting on governance, economic, social, and environmental performance. GRI standards involve a collection that contains 36 modular standards. The three universal standards, which include GRI 101, GRI 102, and GRI 103, apply to all reporting organizations (Pucheta-Martínez et al., 2019).

The GRI functions are achieved through the G4 sustainability reporting guidelines, which were released in the year 2013. These guidelines have been widely adopted by many governments and organizations (Antonini & Larrinaga, 2017). The GRI has released global best practice sustainability reporting standards for organizations in the year 2016 and has been focused mainly on updating the G4 guidelines. Through standardized, voluntary sustainability reporting, the GRI 4 has been useful in allowing for comparability across sectors and organizations, thus making sustainability reporting as a routine just like the financial reporting has been over the years (Habek & Wolniak, 2016). Overall, the GRI standards are designed in such a way that disclosures on material sustainability topics about the organization are done "in accordance" to help the organization meet its non-financial information requirements of its investors as well as stakeholders (GRI, 2016).

4 | DATA ENVELOPMENT ANALYSIS AND AIRPORTS

DEA is a mathematical programming method used to measure and analyze the productive efficiency of decision-making units (DMUs) (Park, Egilmez, & Kucukvar, 2016). The DEA has an advantage over several of the existing methods in that there is no need for a specific

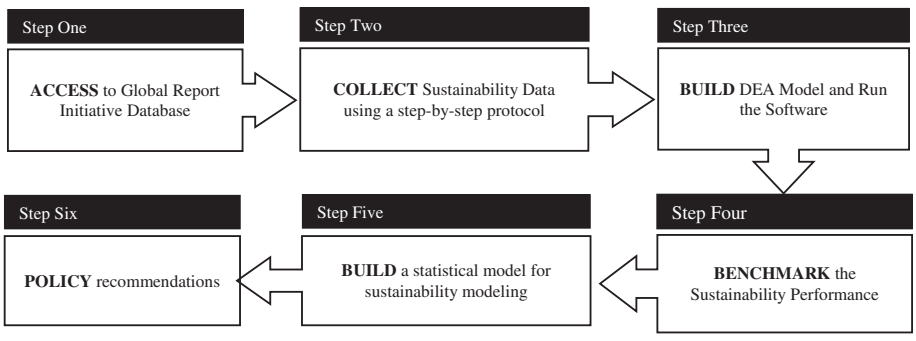


FIGURE 1 Flowchart illustrating the main phases of this research

mathematical formulation for the production function (Egilmez, Kucukvar, Tatari, & Bhutta, 2014). Moreover, DEA is a frequently used method which attracts the attention of the researcher by measuring the relative efficiency of several DMUs including multiple input–output variables. (Cooper, Seiford, & Zhu, 2011). Since, our study includes 30 different airports by involving complex structure of the relationships between multiple process inputs and outputs, DEA methodology is used to evaluate eco-efficiency of the airports in holistic view.

In the past studies, many scholars focused merely on financial and economic perspectives of airlines and have not paid enough attention to productivity and performance measures of airports, including social, environmental, and economic dimensions. Gillen and Lall (1997) used the DEA to evaluate the sustainability performance of 21 airports in the United States between 1989 and 1993. The study involved multiple indicators that belong to terminals and airside operations regarding productivity measurement. The study revealed that possessing hub airlines and broadening gate capacity is significant to the enhancement of airport efficiency. On the other hand, terminal efficiency is enhanced by broadening the number of gates and applying effective management strategies.

Technical and allocative efficiency analysis of Portuguese airports were carried out with DEA approach to determine least performed airports by considering their efficiency scores (Barros & Sampaio, 2004). They ranked the airports based on their total productivity between the years 1990 and 2000. The economic policies are also developed for the considered airports.

The relative efficiency of airports was taken into consideration to reveal the quality level of airlines by Adler and Berechman (2001). In contrast to past studies that used subjective passenger data to identify quality level, they defined the quality from the airlines' viewpoint. DEA was used as the main methodology to find out relative quality levels of European and non-European airports to the place of each airport relative to an efficient frontier, portrayed by considered airports. The results showed that West European airports such as Geneva and Milan are founded to be efficient frontiers, whereas Charles de Gaulle, Athens, and Manchester airports were reported at the low level in the rankings. Lin and Hong (2006) utilized DEA to measure the operational performance level of 20 significant airports all around the world. They pointed out that a higher frequency of flights and improved international business activities should be ensured to reach an efficiency level of operational performance. Considering the location, airports in North America and Europe have supreme efficiencies compared to airports in Asia and Australia.

DEA is utilized to benchmark airports regarding cost and revenue perspectives by Adler, Ulku, and Yazhemsky (2013). In this study, they involved factors under partial managerial control and non-discretionary variables and determined suitable reference set for a European example utilizing best practice airports.

Three different DEA models were developed to help managers of the airports to provide efficient growth in passenger and aircraft movements by considering undesirable outputs and environmental categories (Yu, 2004). This study resulted that the number of passengers and aircraft movements can be increased compared to previous years in Taiwan airports. Also, it is stated that expanding facilities may not be so crucial for some of the domestic airports.

On the other hand, the form of ownership and size are not found as critical indicators for the operational performance of airports. Furthermore, these airports are grouped into four different efficiency classes considering their performance efficiency scores for benchmarking purposes. Suzuki, Nijkamp, Rietveld, and Pels (2010) introduced a distinguished methodology called distance friction minimization (DFM) as a joint application with DEA to reveal applicable efficiency-enhancing projection concept which aiming to reach operational efficiency in airports by minimum input and maximum output levels. This presented DFM model is applied to 30 European airports to conduct a comparative analysis of the efficiency of performance management for the considered airports. This model provides an advantage in which efficiency is defined by minimizing the distance to frontier, with utilizing a balanced and lean instruction to compare a decision-making unit with other DMUs of similar structure. Moreover, the analysis also indicated slacks of input and output variables belong to each airport.

Ripoll Zarraga and Lozano (2019) utilized a non-oriented Slack-based inefficiency DEA approach to reallocate two different inputs as labor costs and operating costs in between the airports. This study revealed the strategy to increase the total number of passengers, Cargo and number of aircraft movements while keeping the inputs at the same level with reallocating the inputs in an efficient approach. The proposed model also determined airports that suffer from overcapacity by providing specified targets for each input and output indicators to reach efficiency level.

To assist airport managers to find out significant factors for improving the airport operational efficiency and capability of competing with its rivals, Ahn and Min (2014) used DEA as a benchmarking tool and Malmquist productivity index to compare efficiencies of international airports between 2006 and 2011. This study showed that shifts in government policies and technological innovations have a critical impact on the productivity of an airport, whereas the technical efficiency alteration is affected by an operational alteration of the airport itself. The study stated that the productivity of major international airports has declined with 1.7% during the period between 2006 and 2011. This finding was attributed to government policy changes and technological innovations instead of critical enhancements in managerial implications. The study reported that more enhancements could be carried out in terms of airport performance through managerial implications, for instance, improving privatization and public-private partnerships for airport finances and operations.

Olfat, Amiri, Bamdad, and Pishdar (2016) considered the internal functions of airports as its environmental and economic factors in both normal time and during New Year holidays. This approach allows to observe broadening vision of current sustainability performance of airports with the support of proposing and assessing fuzzy dynamic network DEA model.

The productivity assessment of 21 Turkey airports was carried out with consideration from 2009 to 2014 by using DEA and Malmquist productivity index (Orkcu, Balıkçı, Dogan, & Genç, 2016). The results showed that the efficiency and productivity of the airports

increased through the considered period. On the other hand, decreasing efficiency points were recorded during the years 2011 and 2012. The reason behind this decline is the important enlargement of the physical capacity of the airports in 2011. Also, a low level of passenger and cargo traffic were the main reasons for the inefficiency of airports in 2012. This study concluded that the majority of Turkish airports faced declining productivity issues, but they followed up with technological advances. Finally, operating hours and the percentage of international traffic were determined as exploratory variations in airport efficiency. The researches, which are captured from the most recent literature to address sustainability aspect of airports, are demonstrated in below Table 1.

Airports are expected to provide best service level and concern environmental issues with an economically efficient point of view. This can be merely concrete with an integrated approach by including multiple categories such as economic, social, and environmental views. In current literature, there is still need of sustainability performance measurement models to provide a guideline for airports to reach eco-efficiency levels. In this context, this study introduces and practices multifactor models to compare and contribute eco-efficiencies of airports regarding sustainable development of environmental impact categories such as carbon, energy, water, and waste to fill this gap in the literature. In addition to that, total revenue as a financial indicator, number of passengers, and total number of employees are determined as outcomes while preserving the desired level of inputs for the proposed models.

5 | METHODS AND DATA

5.1 | Data envelopment analysis

DEA is widely applied for evaluating the environmental performance of DMUs with multiple performance measures that are termed as

TABLE 1 Studies on sustainability aspects of airports

Authors	Goals and findings
Carlucci et al. (2018)	They analyzed overall technical, pure technical, and scale efficiency of 34 Italian airports in the period 2006–2016 to understand effect of the indicators on the efficiency and economic sustainability of regional airports. The results showed that airport size, presence of low-cost carriers and cargo traffic have an important effect on the technical and scale efficiency of Italian airports.
Adler et al. (2013)	To find out how small and regional airports can be operated to survive efficiently; 85 European regional airports were taken into consideration for benchmarking in terms of their sustainability performances.
Janic (2010)	In this study, an indicator system for monitoring, analyzing, and assessing sustainability of airports is developed. The indicator system involves the indicators and their measures indicating the airport performance with respect to operational, economic, social, and environmental aspects. By implying, the developed indicator system revealed that proposed methodology can be considered as an initial step for measuring current and prospective level of airport sustainable development.
Karagiannis et al. (2019)	193 international reports were considered including 33 reports and 903 materials issues and a benchmarking framework for the liability level of best reporting airport operators was proposed. This study revealed that corporate responsibility, economic vitality, contribution to local communities, and climate change adaptation are the most significant factors for airport operators in sustainability reporting.
Lu et al. (2018)	A hybrid multicriteria decision-making and balance score card model was developed to investigate key indicators of airport sustainability. They used three international airports in Taiwan for applying the proposed integrated model. The results revealed that airport image is most critical factor and social view possess the maximum level of net effect.
Wan, Peng, Wang, Tian, and Xu (2020)	By considering the Guangzhou Baiyun International Airport as a case study, the airport sustainability was assessed and defined regarding China's national conditions and airport properties.
Durrani and Forbes (2004)	The research demonstrates indicators that indicates the growth lines for regional airports, provides an evaluation of the related properties that has impact on sustainability of operations, and long term strategic growth that involves innovative use of facilities, technologies, and the influence of the related regulatory environment.
Baxter, Srisaeng, and Wild (2019)	The goal of this research was to investigate Copenhagen Airport's sustainable water management strategies and systems including the years between 2006 and 2016. The strategies, systems, and the water-saving initiatives were provided for sustainable water management in Copenhagen Airport.
Monsalud, Ho, and Rakas (2015)	This study introduces an assessment stages with the utilization of an influence matrix through which to define effective sustainable practices at U.S. airports. This assessment model aims to quantify and hence enhance decision-making in airport sustainability.
Koc and Durmaz (2015)	Airports are the most important basic of the air transportation industry the factors for the sustainability of airport management. This research aimed to provide a benchmark of the world's best 10 airports, relied on the results which were brought from annually by passenger surveys.
Sarrah, Ajmal, and Mertzanis (2020)	The aim of this study is to provide definition of significant sustainability factors in the civil aviation industry in Dubai. The outcomes of this study indicate that stakeholders emphasize the importance of social sustainability factors that merit equal growth in the setting of business objectives.

inputs and outputs. DEA is a novel data-driven decision-making method to assess the activity of several peer objects named DMUs that change several inputs into outputs (Mardani, Zavadskas, Streimikiene, Jusoh, & Khoshnoudi, 2017). In the literature, Charnes, Cooper, and Rhodes (1978) generalized Farrell's measure to multiple input multiple output situations and operationalized it using a linear programming model. According to reviews conducted by Martín-Gamboa, Iribarren, García-Gusano, and Dufour (2017) and Zhou, Yang, Chen, and Zhu (2018), The DEA is widely used for analyzing the sustainability performance of airports sector considering various environmental and economic metrics (Adler & Berechman, 2001; Barros & Dieke, 2007; Gillen & Lall, 1997; Martín & Roman, 2001; Suzuki et al., 2010). The DEA methodology has also been applied to evaluate the environmental efficiencies of DMUs, and eco-efficiency has been introduced as a proxy for measuring the economic and environmental performance of DMUs (Egilmez et al., 2014; Mahmoudi, Emrouznejad, Shetab-Boushehri, & Hejazi, 2020). Many studies used DEA as eco-efficiency analysis and benchmarking method for manufacturing (Egilmez, Kucukvar, & Tatari, 2013), construction (Tatari & Kucukvar, 2012), food production (Egilmez, Gumus, Kucukvar, & Tatari, 2016; Egilmez, Kucukvar, & Park, 2016), electric vehicle technologies (Onat, Kucukvar, Aboushaqrah, & Jabbar, 2019; Onat, Kucukvar, & Afshar, 2019), energy (Li, Xie, & Wang, 2019), and industrial sectors (Goto & Sueyoshi, 2020).

There are severeal specific model options in DEA that vary according to the purpose and scope of the study to be carried out (Cook & Seiford, 2009). Two of the most used and traditional methods are CCR and BCC models. If it is desired to reach the total efficiency of the DMUs and there is an assumption that they will produce a fixed return according to the scale, CCR or non-oriented models are used (Supciller & Bulak, 2020). On the other hand, if the technical efficiency of the DMUs is desired to be evaluated and there is an assumption that it will produce a variable return according to the scale, the BCC model is preferred (Ozden, 2008). BCC model is a more flexible model and produces variable results according to the scale (Banker, Charnes, & Cooper, 1984). This model was developed by adding the convexity constraint to the CCR model. This constraint enables the efficiency boundary in the BCC model to envelop the decision units more closely and tightly. Therefore, there is a higher possibility for a decision-making unit to be effective in BCC than CCR model (Romano & Guerrini, 2011). Therefore, a DMU that is found to be efficient in the CCR model is also efficient in the BCC model. However, it is not possible for a decision-making unit which is efficient in the BCC model to be efficient in the CCR in all cases. In addition, due to the location of the effective boundaries in other models, it is high to obtain an efficient result. This causes the reliability of the established model to be questioned. The CCR model was preferred in this study because the CCR model performs the most precise efficiency measurement by producing realistic results among DEA models (Lombardi et al., 2019).

To estimate the efficiency of a specific DMU, we first define x_i and y_j as the ith input and jth output of the corresponding DMU and calculate the virtual input (VI) and output (VO) as follows (Onat et al., 2017; Onat, Kucukvar, et al., 2017):

$$\mathrm{VI} = \sum_{i=1}^{M} u_i x_i; \mathrm{VO} = \sum_{j=1}^{S} v_j y_j, \tag{1}$$

where M and S are the numbers of DMU's inputs and outputs, $u_i \geq 0$ and $v_j \geq 0$ are the weights associated with the ith and jth DMU input and output, respectively. The eco-efficiency of the DMU can be estimated as the ratio between the DMU virtual outputs and inputs:

$$\text{Efficiency} = \xi = \frac{\mathrm{VO}}{\mathrm{VI}} = \frac{\sum_{i=1}^{S} v_j y_j}{\sum_{i=1}^{M} u_i x_i}. \tag{2}$$

The DMU's weights, u_i and v_j are explicitly assigned for each DMU by using mathematical programming and. Equations (3)–(5) represent the DEA model used in this paper:

Objective Function

$$\text{Maximize} \xi = \frac{\sum_{j=1}^{S} u_j y_{jk}}{\sum_{i=1}^{M} v_i x_{ik}}. \tag{3}$$

Subject to

$$\frac{\sum_{j=1}^{S} u_j y_{jk}}{\sum_{i=1}^{M} v_i x_{ik}} \leq 1, k = 1, 2, \ldots, N, \tag{4}$$

$$u_j \geq 0, v_i \geq 0, i = 1, 2, \ldots S; j = 1, 2, \ldots M, \tag{5}$$

where x_{ik} and y_{jk} are the ith input and jth output of the kth DMU, and N is the total number of the DMUs. In what follows, we use IP and OP to refer to the inputs and outputs of a specific DMU. The decision to increase the IP or decreasing the OP is critical to the desired efficiency (Park, Egilmez, & Kucukvar, 2015). The aim of this study is mainly about minimizing the inputs and the undesired outputs for the triple bottom lines for the airport to be efficient and sustained. For that reason, the input-based DEA multiplier model was used. It is crucial here to mention that the input-oriented DEA models can take many shapes of the undesired inputs or outputs. As several scholars have suggested (Lozano, Gutiérrez, & Moreno, 2013; Tatari & Kucukvar, 2012), undesired outputs like CO_2, wastes, toxic release, and other environmental impacts are used as inputs of the DEA model.

TABLE 2 IP and OP of the proposed DEA models

Model	Inputs	Outputs
Model 1	CO_2 Emission (ton) Total Energy Consumption (MWh) Water Use (ton) Waste Generation (ton)	Total Revenue ($)
Model 2		Passenger
Model 3		Total Employees
Model 4		Total Revenue ($) Passenger Total Employees

5.2 | Data collection

The selection of the proper performance measures (IP and OP) is critical to the DEA optimization model, shown in Equations (3)–(5). Four different DEA models developed to find out the impacts of IP variables on the eco-efficiency measure of each airport; see Table 2.

Figure 2 shows the structured GRI report review process, and the number of reports revealed in each step toward narrowing down the reports for the scope of this research work.

Step one reports the results of searching 165 of the GRI reports between 2015 and 2019. The reports included only the best 10 airports and continents, which involve Europe, America, Asia, and Oceania. Step 2 reports the results of the restricted search of the GRI, considering only the completed GRI. In this step, 15 sustainability, under the three sustainability pillars, indicators are considered, as shown in Table 3.

The corresponding sustainability indicators were examined across the period of the study, and the completed form of reports was found to be in the year 2018 with the number of 58 different airport sustainability reports. In step 3, these reports were analyzed and filtered in detail. Through this step, the number of airports sustainability GRI, including most common indicators, was narrowed down to 30 airports. The collected data and their sources are provided in Tables 2 and 3 of the Appendix. Table 4 reports the descriptive statistics of the sustainability indicators included in this study.

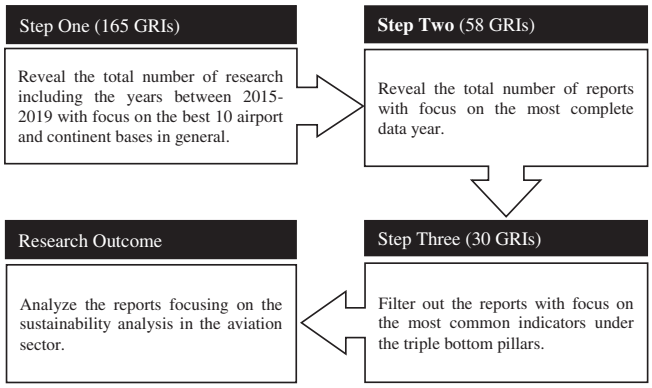


FIGURE 2 GRI airport sustainability report review analysis/filtering flow

6 | RESULTS AND DISCUSSION

6.1 | Efficiency assessment

The DEA is often defined as a weighted sum of IP divided by a weighted sum of IPs. It has been one of the most popular measures of efficiency. It is conventional in the DEA practices to use the presence of high levels of multicollinearity between the pairs of the DEA-IP or OP as a justification for omitting the correlated IPs or OPs. The multicollinearity under the DEA context refers to the situation when two or more of the model IPs are highly linearly related to each other. Several methods are available in the literature for multicollinearity assessment. The most common among these are the sample-based correlation of determination (R^2) and Pearson correlation coefficient (R) (Abdella, Al-Khalifa, Maha, and Hamouda (2019).

To continue, we calculated the correlation of determination (R^2) for all the potential pairs of IPs and OPs and reported the results below:

	Emissions	Energy	Water	Waste	Revenue	Passenger	Employees
Emissions	1.00	0.00	0.00	0.01	0.00	0.00	0.04
Energy	0.00	1.00	0.04	0.09	0.00	0.01	0.09
Water	0.00	0.04	1.00	0.00	0.49	0.00	0.36
Waste	0.01	0.09	0.00	1.00	0.16	0.01	0.00
Revenue	0.00	0.00	0.49	0.16	1.00	0.00	0.36
Passenger	0.00	0.01	0.00	0.01	0.00	1.00	0.00
Employees	0.04	0.09	0.36	0.00	0.36	0.00	1.00

The results above show low correlation levels among all the IPs and Ops ranging from $0.00 \le R^2 \le 0.49$. Water and Emissions are the highest correlated pair of indicators ($R^2 = 0.49$), while the Energy and Passenger are the lowest correlated pair with $R^2 = 0.00$. However, since there is no evidence of multicollinearity among the IPs and OPs, none of them is omitted in this study.

In what follows, we calculate the ξ values of the DEA models using the corresponding IPs and OPs. Figure 3 shows the rank of the ξ values, estimated using Model 1, of the 30 airports involved in this study. Note that the Y-axis shows the rank of the E-values of these airports. Figure 3 reveals that among the 30 DMU's, Ljubljana airport is ranked at the bottom of the lowest among the others ($\xi = 0.017$). While San Francisco ($\xi = 1.00$), DFW ($\xi = 1.00$), Hamad ($\xi = 1.00$), and Brisbane ($\xi = 1.00$) airports are ranked at the top of the list with ξ value equals to one. Figure 4 reports the ξ values of Model 2. One can easily notice that Francisco airport has lost the advantage of being the most efficient airport once the number of passengers replaces the Revenue or profit. Hamad airport has shown stability in the ξ performance in the sense the rank is the second-best efficient performance was maintained in both Model 1 and 2. Moreover, when the results of Model 1 and Model 2 are compared, we can easily notice that the

TABLE 3 Economic, environmental, and social indicators of airports

Indicators	Economic	Environmental	Social
Total revenue	✓		
Number of total passengers	✓		
Total amount of indirect economic impacts	✓		
Number of total employees	✓		
Material		✓	
CO_2		✓	
Total energy consumption		✓	
Electricity consumption		✓	
Water consumption		✓	
Waste volume		✓	
Average number of training			✓
Number of accidents			✓
Injury rate			✓
Occupational disease			✓
Absence rate			✓

TABLE 4 Descriptive statistics of the sustainability indicators

	Sustainability indicator						
Statistic	Emissions	Energy	Water	Waste	Revenue	Passenger	Employees
Max	9E+06	1E+06	2E+07	2E+05	6E+10	7E+08	4E+04
Min	5E+03	1E+03	3E+04	1E+03	5E+07	2E+06	3E+02
Average	7E+05	3E+05	2E+06	3E+04	5E+09	6E+07	5E+03
Standard Deviation	2E+06	3E+05	4E+06	3E+04	1E+10	1E+08	9E+03

Frankfurt airport has lost its position from the medium-zone to the low-zone of ranking.

Figure 5 shows the ξ values estimated using Model 3. The results show that Seoul is the lowest efficient airport (ξ = 0.058), while Dublin, Manchester, Zurich, Vienna, Frankfurt, Hamad, and San Francisco are the most efficient airport (ξ = 1.00) among the others. Note that Dublin airport has never be ranked at the top of the list under Model 1 and Model 2. Figure 5 shows that Seoul is the lowest efficient (ξ = 1.00), while Dublin, Frankfurt, Hamad, Manchester, San Francisco, Vienna, and Zurich are at the top of the sustainability performances with ξ = 1.00. The enhancement in the efficiency of Dublin (ξ = 1.00) and Frankfort (ξ = 1.00) is the most notable finding. Figure 6 shows the rank of the ξ values estimated using Model 4. The results of Model 4 show a significant enhancement in the sustainability performance of several of the airports, specifically Brisbane, DFW, and El Dorado. The results have also shown that more enhancement is achieved when more OPs are added to the model.

6.2 | Efficiency performance grouping

This section is dedicated to grouping the DMUs concerning their efficiency performance. One of the well-known methods that can be utilized for this purpose is the "*Quartiles*" method. This method is used to create three threshold points that split a data stream into four equally spaced intervals. In this study, these intervals are named as "Poor," "Fair," "Good," and "Excellent." The grouping would provide an insight into the impact of the inclusion of the OPs on the efficiency performance estimation. However, once the threshold of the groups is determined, we assign each DMU to one of these groups following its ξ value.

Figure 7 shows the color code of the group distribution of each of the DEA models considered in this study. The consistency of the color code shows the stability in the efficiency performance of an airport over the four examined models. The results show that Dublin and Hamad's airports have maintained an "Excellent" performance' under all the examined models. Paris CDG has shown a "Poor" performance and continued this performance under all the models. Brisbane and Hong Kong airports have shown a drop in their performance under Model 3, but they return to show an "Excellent" performance under Model 4.

6.3 | Model-based variability analysis

In this section, we conduct a test of the hypothesis for examining the equality of ξ score means of the four DEA models using the Kruskal-Wallis test. The Kruskal-Wallis is a non-parametric test for comparing

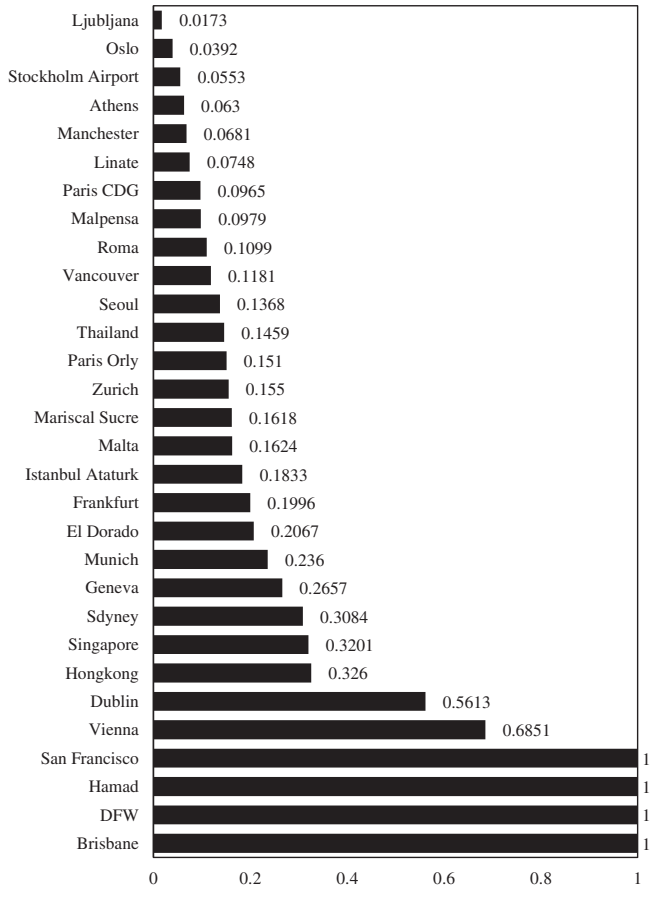


FIGURE 3 Eco-efficiency scores ranking using the DEA-Model 1

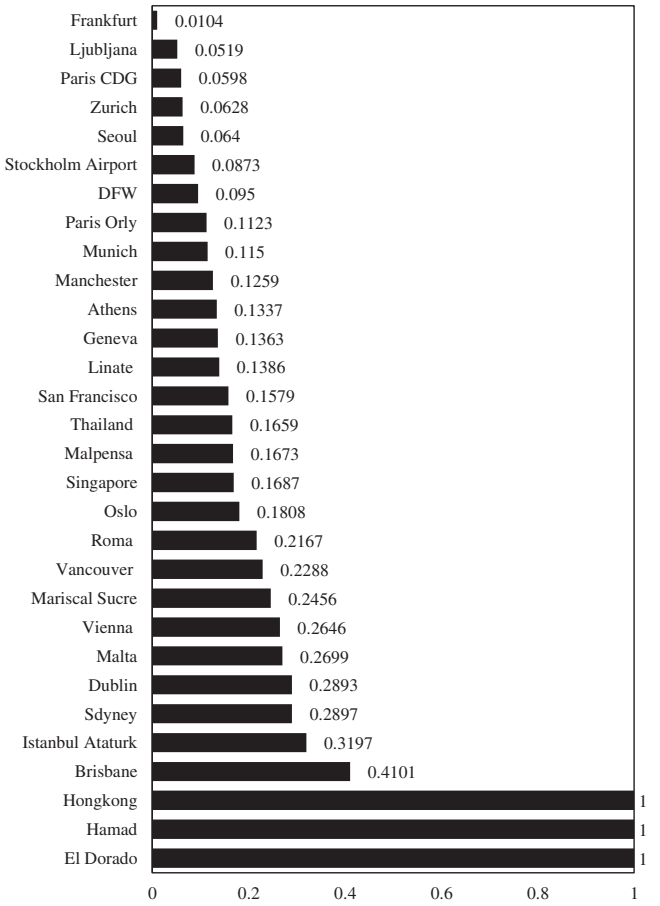


FIGURE 4 Eco-efficiency scores ranking using the DEA-Model 2

two or more groups of observations. Since it is a non-parametric method, the Kruskal Wallis test does not assume a normal distribution of the group residuals. This paper test the null hypothesis $H_0 = \mu_{\xi(1)} = \mu_{\xi(2)} = \mu_{\xi(3)} = \mu_{\xi(4)}$ versus the alternative hypothesis $H_1 = \mu_{\xi(1)} = \mu_{\xi(2)} = \mu_{\xi(3)} = \mu_{\xi(4)}$; where $\mu_{\xi(i)}$ represents the ξ mean score of the ith DEA model. The test statistic of the Kruskal-Wallis test is calculated using:

$$K = \frac{\sum_{all\, i} \left(\bar{R}_i - \bar{R}\right)(N-1)}{\sum_{all\, i} \sum_{j=1}^{n_i} \left(R_{ij} - \bar{R}\right)^2}; i = 1,2,3,4, \quad (6)$$

where n_i is the number of DMUs tested under the ith DEA model, N is the total number of DMUs across all the DEA groups, R_{ij} is the rank of the jth observation in the ith DEA model, $\bar{R}_i$ is the average rank of the ith DEA model, and $\bar{R}$ is the average rank of all the DEA groups.

The decision is made by comparing the test statistic K, obtained from Equation (6) to a critical value at a given significance level (α). In this study, the value of α is set at its customary value of 0.05. To examine the significance of the test statistic K, we compare the resulted p-value with the value of α. However, if p-value $>\alpha$, that means the K statistic is not significant (do not reject H_0). In other words, there is no evidence of differences between the means of the ξ scores of the DEA models. If p-value $\leq \alpha$, then at least one of the DEA models dominates the other models. The K value of the Kruskal-Wallis test and p-value is calculated and found to be 32.22 and 0.00001, respectively. Considering that the value of α is 0.05, we conclude that at least one of the examined DEA models dominates the other three models (H_0 should be rejected).

For better understanding the effect of the inclusion of the IPs and OPs on the ξ scores, we conducted a pairwise Kruskal-Wallis comparison. The primary purpose of this step is to identify the DEA models providing approximately similar ξ scores. The number of possible combination of DEA model is calculated as a combination $C_r^n = C_2^4$; where $n = 4$ is the number of DEA models and $r = 2$ the number of compared models in each pair. Table 5 shows the results of the comparison using $\alpha = 0.05$.

The "Decision" column refers to the significance of differences between the ξ scores of the corresponding pair of DEA models. However, the results in Table 4 show there is no significant difference between the ξ scores of Model 1 and 2. The same finding is valid when Model 3 and 4 are compared. In conclusion, the ξ scores data support a difference in the four DEA models means. Such a finding would provide the authority with guild lines for future sustainability assessment and development. However, the results revealed that the DEA is sensitive to the selected subset of IPs and OPs. For better stability of the outcome, one can start by selecting the most appropriate

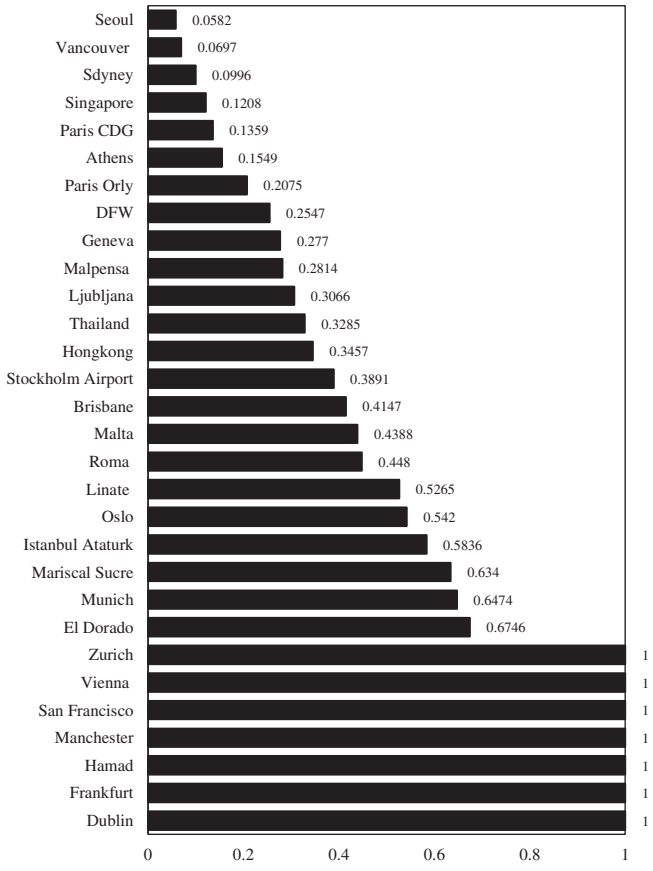


FIGURE 5 Eco-efficiency scores ranking using the DEA-Model 3

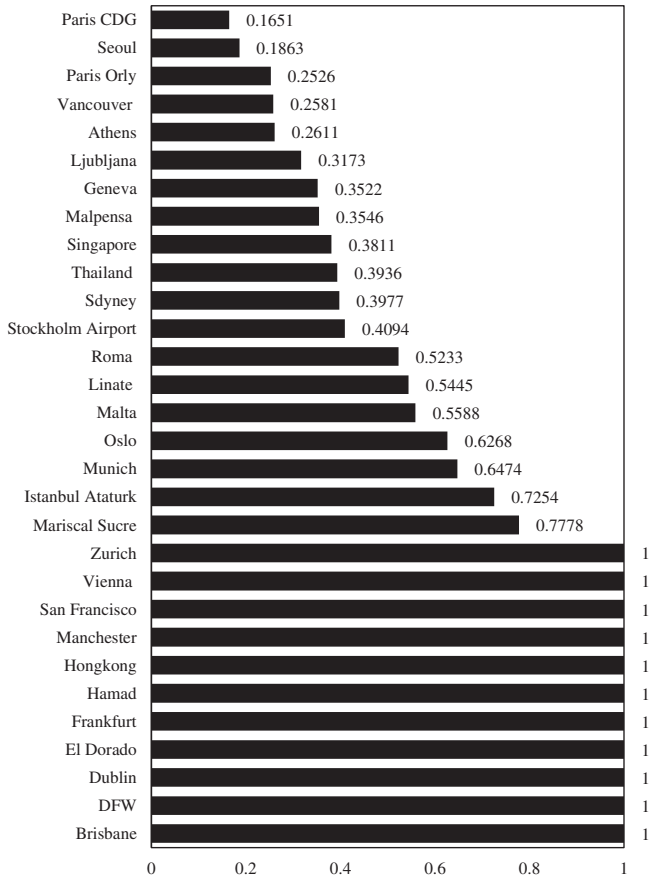


FIGURE 6 Eco-efficiency scores ranking using the DEA-Model 4

IPs and OPs as an initial step. For this purpose, methods such as multiple regressions, principle component analysis (PCA), and factor analysis (FA) might be used to find the most appropriate set of IPs, and OPs should be involved. This selection of the IPs and OPs would provide the opportunity to both reduce the dimensionality and high-correlation impact. Examples of the applications of these methods under the sustainability context can be found in Park et al. (2015), Kucukvar, Onat, Abdella, and Tatari (2019), and Abdella, Kucukvar, Onat, Al-Yafay, and Bulak (2020).

6.4 | Projection level analysis

In this analysis, the projection level analysis is carried out for four different types of models. The proposed percentage reductions explain how much each of the environmental impact categories should be reduced to make the airport 100% efficient. In other words, it's about estimating the action to be taken in the future to improve the sustainability performance of each airport. Therefore, Figure 9 presents the proper activities illustrated with numbers to enhance the sustainability performances for every DMU from all environmental aspects. Figure 8a shows the projection for model 1 that the concerned airport would take into consideration to improve the airport performance. Analyses

Airport Name	Model 1	Model 2	Model 3	Model 4
Athens	1	2	1	1
Brisbane	4	4	2	4
DFW	4	1	2	4
Dublin	4	4	4	4
El Dorado	3	4	4	4
Frankfurt	3	1	4	4
Geneva	3	2	2	1
Hamad	4	4	4	4
Hong Kong	4	4	2	4
Istanbul Ataturk	3	4	3	3
Linate	1	2	3	2
Ljubljana	1	1	2	1
Malpensa	2	3	2	2
Malta	3	4	3	2
Manchester	1	2	4	4
Mariscal Sucre	2	3	3	3
Munich	3	2	3	3
Oslo	1	3	3	3
Paris CDG	1	1	1	1
Paris Orly	2	2	1	1
Roma	2	3	3	2
San Francisco	4	2	4	4
Sydney	3	4	1	2
Seoul	2	1	1	1
Singapore	4	3	1	2
Stockholm Airport	1	1	2	2
Thailand	2	2	2	2
Vancouver	2	3	1	1
Vienna	4	3	4	4
Zurich	2	1	4	4

Color Code Key: Poor | Fair | Good | Excellent

FIGURE 7 Group-based efficiency performance comparison

of DEA resulted that Ljubljana airport is observed to be least efficient with an efficiency score of 0.0173 among 30 airports. This airport has benchmarked with Hamad Airport in its reference set, which indicates that the frontier airport should be analyzed for the targeted level. Benchmarking airports form the baseline for transforming an efficient airport in the analysis.

In detail, to become an efficient airport, inputs of the Ljubljana airport should be assessed. The weight assigned to the input variables of Hamad Airport is 0.003. Therefore, each input variable of Hamad Airport should be multiplied with the assigned weight to assist Ljubljana airport for becoming an efficient unit as given values in Table 6. Ljubljana airport should reduce emissions by 99.03%, energy consumption by 98.27%, water consumption by 98.27%, and finally waste by 98.96%, to improve the efficiency or the sustainability performance of the airport; otherwise, the airport will remain as insufficient.

Furthermore, as the environmental indicators decrease and enhanced by airport management, in model 2, the output indicator (the passengers) will increase to improve sustainability performance as well. Based on DEA results, Frankfurt airport is evaluated to be the least efficient airport with a score of 0.0104, and its reference set is composed of Hong Kong airport. The weight that is assigned to benchmark airport is 0.009 for the Frankfurt airport. Therefore, multiplying the input variables of Hong Kong airport with the assigned weight will help Frankfurt airport to become an efficient unit as given values in Table 7.

Moreover, for Model 3, Seoul airport seemed to be the least efficient airport with a score of 0.0582, and Dublin and Frankfurt airports were placed at the reference set. The inputs of these two airports should be multiplied with the weights of 0.187 and 0.041, respectively, and the values to reach efficiency level are represented in Table 8. Besides, Seoul airport should decline emissions by 94.18%, energy consumption by 96.36%, water consumption by 94.18%, and finally waste by 95.5%, to enhance the sustainability performance as a resource usage perspective (Figure 8c). On the other hand, the airport of Ljubljana most decreases the emissions, energy consumptions, water consumption, and waste by the percentage at this model. This is by increasing the number of employees against the environmental indicators, which in return, improve the sustainability performances. As has been discussed earlier regarding the correlations between variables, it is important to mention that not all indicators should be decreased for the output indicator to be increased. Sometimes the relationships are positive, so as one environmental indicator increases, it may result in increasing the output indicators.

Finally, model 4 combines the three output indicators with the four input indicators in one model and against each other. The DEA results showed that Paris CDG airport turned out to be the least efficient unit with the 0.1651 efficiency score for this model.

TABLE 5 Pairwise comparison of the ξ scores of the DEA models

DEA models	Kruskal-Wallis	*p*-value	Decision
Model 1 vs. Model 2	0.071	.0708	Insignificant
Model 1 vs. Model 3	7.808	.0052	Significant
Model 1 vs. Model 4	18.51	.0000	Significant
Model 2 vs. Model 3	11.31	.0008	Significant
Model 2 vs. Model 4	23.59	.0000	Significant
Model 3 vs. Model 4	2.693	.1008	Insignificant

TABLE 6 Reference set and average projection level for Ljubljana Airport in Model 1

Inputs	Ljubljana Airport best level	Reference set	Average projection level (%)
CO_2 emission (ton)	599.335	Hamad Airport	98.63
Total energy consumption (MWh)	217.695		
Water use (ton)	13,422.42		
Waste generation (ton)	207.693		

TABLE 7 Reference set and average projection level for Frankfurt Airport in Model 2

Inputs	Frankfurt Airport best level	Reference set	Average projection level (%)
CO_2 Emission (ton)	1,518.99	Hong Kong Airport	99.42
Total Energy Consumption (MWh)	2,884.28		
Water Use (ton)	3,616.64		
Waste Generation (ton)	294.232		

TABLE 8 Reference set and average projection level for Seoul Airport in Model 3

Inputs	Seoul Airport best level	Reference set	Average projection level (%)
CO_2 emission (ton)	15,139	Dublin Airport, Frankfurt Airport	95.05
Total energy consumption (MWh)	41,459		
Water use (ton)	139,874.3		
Waste generation (ton)	2,030.69		

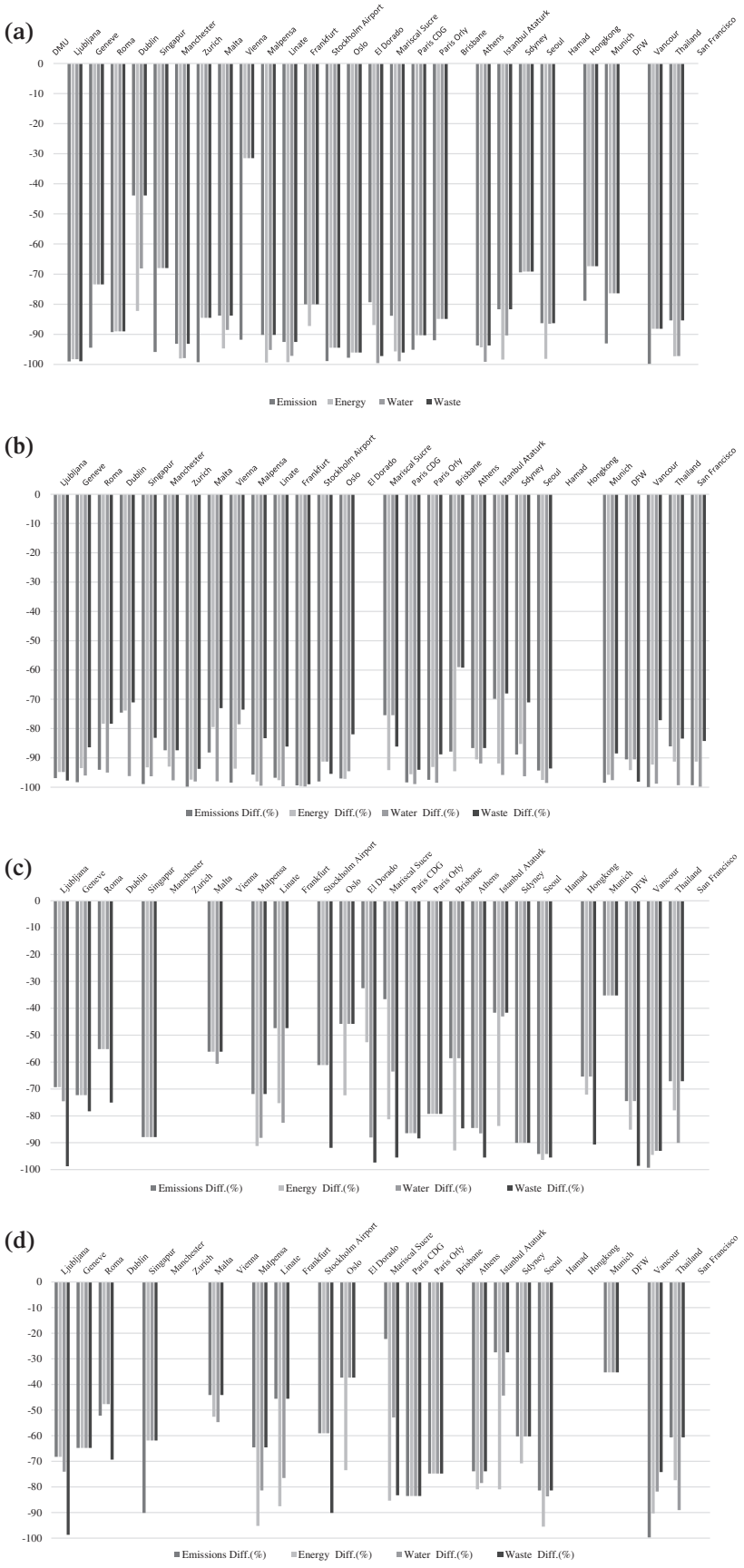


FIGURE 8 Projection levels by the percentage of reduction in environmental impact categories (a) Model 1 (b) Model 2 (c) Model 3 (d) Model 4

TABLE 9 Reference set and average projection level for Paris CDG in Model 4

Inputs	Paris CDG Airport best level	Reference set	Average projection level (%)
CO_2 emission (ton)	160,392	Dublin Airport, Zurich Airport, Vienna Airport, Hong Kong Airport, DFW Airport, San Francisco Airport	83.48
Total energy consumption (MWh)	112,227		
Water use (ton)	587,987		
Waste generation (ton)	8,437.56		

This incompetent airport is benchmarked to Dublin, Zurich, Vienna, Hong Kong, DFW, and San Francisco airports, which means these six frontier airports should consider achieving the desired level. The weights assigned to benchmark airports are 0.814, 0.002, 0.052, 0.01 and 0.011, respectively. Also, this airport should decrease the input variables by 83.48 as an average to reach a satisfactory sustainability performance level (Table 9). In summary, the suggested levels of each input variable are indicated in Figure 8d. By considering the above models with each airport and taking the recommendation of enhancing the performance of each indicator, the airports can achieve the enhancement of their sustainability performances to be the lead in their industry.

7 | CONCLUSION AND RECOMMENDATIONS

The DEA method is gainful, meaning it is a tool that is used to empirically measure the efficiency of, in this research, of the airports. The data has been collected from their authentic sources that are used in the DEA model to evaluate the sustainability performances for all 30 airports. The results had been obtained and recorded. Four models have been performed in this research; each model produces or results with different efficient and sustained airports, as indicated in the analysis. Besides, the projection has been introduced for all airports in what they should enhance to improve their sustainability performances. Last but not least, the recommendation is to call all the regarded airports to utilize the data and information that has been used in this research as it is authentic information and to improve their airport performances by enhancing the results of the environmental indicators.

In this research, the environmental, social, and economic data that are used for the sake of evaluation using the DEA model are limited to some extent. Hence, to make these results more efficient and sufficient for the companies to be satisfied in using it, we can collect more sustainability data from the published GRI reports. Further, the sustainability data that has been extracted from GRI reports and presented here in this report are somehow an old data of 2018. If a time-series of data between 2010 and 2019 is available, the DEA model used in this research can show the sustainability performance of all 30 airports mentioned above over that period.

Therefore, the recommendation that this research can deliver is that the airport's management can compare their performances dynamically. Another opportunity is that the diversity of tools that can be utilized in addition to the proposed DEA model. An example of the tools that can be used here is stochastic DEA, Malmquist Index, and fuzzy DEA methods to tackle issues related to uncertain and time-variant datasets.

Finally, the recommendation to improve the user data analysis tool is to further analysis with more data collections and diversify more in importing more airports for the sake of more accuracy and applicability of our method. The number of airports that we had extracted the data from them is limited to only 30 airports. It is worth mentioning that data collection was one of the most challenging parts of this paper. Most of the sustainability reports used different formats and presented different types of environmental and socioeconomic data, and most of the datasets were not complete. Furthermore, it was challenging to reach out to the most recent data, which was not provided by the airport's sustainability reports. Therefore, the authors recommend the use of the latest and consistent GRI version by each airport authorities and have a consensus on disclosing the complete dataset for environmental, economic, social, and governance-related indicators.

In terms of sustainable development, which has been paid attention since the 1980s from policymakers, the airports are one of the most important service providers regarding economic revenues all around the world. The aviation sector employs thousands of employees and provide transportation services for both domestic and international passengers. Therefore, managers and decision makers need to be careful about managing the resources in a right way. Sustainable and efficient airport management are essential to reduce the utilization of natural resources, and mitigate the environmental affects generated by its service system. While evaluating the eco-efficiency of airports, it is so important to underline the need of developing and establishing new methodologies. These methodologies would lead airports to decide how to deal with new techniques, since the both environmental and economic views would be taken into consideration. In addition, extending the scenarios to consider other stages of the life cycle, such as water and energy use, and waste management, would possibly enhance the process by reaching the eco-efficiency level of airports. In this context, to be able to perform outreaching sustainability performance, managers should propose policies, which lead to sustaining the existing resources and generating new ones. Managers also should be aware of managing the value of the human resources, which can be considered as one of the most significant assets of all service providers.

On the other hand, the spread of the Industry 4.0 will bring several issues related environmental concerns for the airports. An adaptation process to this new trend by purchasing new machinery, the involvement of sensors and software, and high computing capacities require new developed infrastructure to feed digital transformation that solely depends on natural and human-made resources. Hence, implication of new devices and methods will generate negative impacts on environmental sustainability of the airports. In addition, landfill demand will be emergent subject because of the new skill requirements while recycling becomes to be an outdated issue. In this context, airports should adopt cleaner automation in their service processes to mitigate environmental burdens while adopting the new technology trends.

One of the limitations of for this study is that the eco-efficiency of airports is determined based on relative comparison approach that can lead to misinterpret the importance of the different issues behind eco-inefficiency. Therefore, more detailed research should be carried out to find out the causes of inefficiency for the airports, which show low sustainability performance. In addition, the model used in this study is constant return to scale, which limits the number of efficient units compared to other models. Hence, variable return to scale or BCC model can be included for the further analysis to observe other possible efficient airports. For further benefit of the proposed DEA-based method, we recommend increasing the pool of DMUs, the matter that will provide the decision-makers with a data-based tool for developing reliable airport sustainability indices. Moreover, beside to unrestricted DEA, weight restricted models can be taken into consideration to observe and compare eco-efficiency points of the airports relied on determined weights to environmental indicators. Economic Input–output Life Cycle Assessment and DEA can be combined to assess environmental impacts and eco-efficiency of the airports for the further analysis (Onat, Kucukvar, & Tatari, 2016; Onat, Kucukvar, & Tatari, 2018; Onat, Kucukvar, Tatari, & Egilmez, 2016). Finally, Life-cycle assessment (LCA) and life-cycle cost (LCC) can be jointly used to derive the eco-efficiency ratios (Onat, Kucukvar, & Afshar, 2019).

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APPENDIX A

TABLE A1 Airports sustainability data

Airport	CO_2 emission (tons)	Total energy consumption (MWh)	Water (tons)	Waste (tons)	Total revenue ($)	Passenger	Total employees
Ljubljana	6E+04	1E+04	8E+05	2E+04	5E+07	2E+06	5E+02
Geneva	2E+05	1E+05	2E+05	5E+03	5E+08	2E+07	1E+03
Roma	2E+05	9E+04	2E+06	1E+04	1E+09	5E+07	3E+03
Dublin	3E+04	5E+04	4E+05	5E+03	1E+09	3E+07	3E+03
Singapore	1E+06	4E+05	9E+05	2E+04	2E+09	7E+07	2E+03
Manchester	5E+04	2E+05	1E+06	2E+04	3E+08	3E+07	6E+03
Zurich	4E+06	5E+05	8E+05	2E+04	1E+09	3E+07	3E+04
Malta	1E+04	1E+04	2E+05	1E+03	1E+08	7E+06	4E+02
Vienna	4E+05	2E+05	7E+04	4E+03	9E+08	3E+07	5E+03
Malpensa	1E+05	5E+05	3E+06	6E+03	5E+08	2E+07	2E+03
Linate	6E+04	2E+05	2E+06	3E+03	2E+08	9E+06	1E+03
Frankfurt	2E+05	8E+05	1E+06	3E+04	2E+09	7E+06	2E+04
Stockholm Airport	5E+05	2E+05	6E+05	5E+04	6E+08	4E+07	3E+03
Oslo	2E+05	4E+05	3E+05	7E+03	1E+08	3E+07	3E+03
El Dorado	6E+03	3E+04	1E+06	5E+04	3E+08	3E+07	5E+02
Mariscal Sucre	5E+03	5E+04	2E+05	2E+04	2E+08	5E+06	4E+02
Paris CDG	1E+06	7E+05	4E+06	5E+04	2E+09	7E+07	4E+03
Paris Orly	3E+05	2E+05	1E+06	1E+04	1E+09	3E+07	2E+03
Brisbane	4E+04	2E+05	3E+04	2E+03	8E+08	2E+07	3E+02
Athens	4E+04	1E+05	1E+06	4E+04	5E+08	2E+07	7E+02
Istanbul Ataturk	5E+04	3E+05	8E+05	8E+03	6E+08	6E+07	3E+03
Sydney	9E+04	1E+05	6E+05	6E+03	1E+09	4E+07	5E+02
Seoul	3E+05	1E+06	2E+06	5E+04	2E+09	7E+07	1E+03
Hamad	2E+05	1E+03	5E+06	5E+04	1E+10	3E+07	1E+03
Hong Kong	2E+05	3E+05	4E+05	3E+04	2E+09	7E+08	2E+03
Munich	7E+05	5E+05	1E+06	2E+04	2E+09	5E+07	1E+04
DFW	2E+05	5E+05	5E+05	2E+05	4E+10	7E+07	2E+03
Vancouver	9E+03	1E+05	1E+06	5E+03	6E+08	3E+07	5E+02
Thailand	2E+05	7E+05	1E+07	4E+04	2E+09	1E+08	8E+03
San Francisco	2E+06	3E+05	2E+07	2E+04	6E+10	6E+07	4E+04

TABLE A2 Data sources

Airport name	Source of data	GRI version
Vienna Airport	https://www.viennaairport.com/jart/prj3/va/uploads/data-uploads/Konzern/Investor%20Relations/Geschaeftsberichte/GB_2018_EN.pdf	GRI-Std.
Amsterdam Schiphol	https://www.annualreportschiphol.com/pdfondemand/printpdf?docId=192807	GRI-Std.
Manchester	https://www.magairports.com/media/1433/mag-2017-csr-report-final.pdf	GRI-Std. GRI 4
Krakow	https://issuu.com/yoho96/docs/krakowairport_raport2018_en_flipboo	GRI-Std. GRI G4
Milano	http://www.seamilano.eu/sites/sea14.message-asp.com/files/docs/sea_csr_report_2018_eng.pdf	GRI-Std.
Frankfurt	https://www.fraport.com/en/misc/binaer/fraport-group/responsibility/publications/sustainability-reports/2018/sustainability-report-and-gri/gri-report-2018/_jcr_content.file/gri-report-2018_final_.pdf	GRI-Std.
Stockholm	https://www.swedavia.com/globalassets/om-swedavia/roll-och-uppdrag/swedavias-annual-and-sustainability-report-2018.pdf	GRI G4
Dublin	https://www.bitc.ie/wp-content/uploads/2015/10/Sustainability-Report-2012-Final-Version.pdf https://www.daa.ie/wp-content/uploads/2019/04/Sustainability-Update-20162017.pdf	GRI-Std.
Oslo	https://avinor.no/globalassets/_konsern/om-oss/rapporter/en/annual-report-2018.pdf	GRI-Std.
Eldorado	https://pbwebpgaqa01.azurewebsites.net/Portals/0/Images/Inversionistas/reporteintegrado/INFORME-ODINSA-2018_Final-en-ingle%CC%81s-.pdf?ver=2019-11-19-224619-697	GRI-Std.
Sao Paulo	http://ri.ccr.com.br/wp-content/uploads/sites/28/2017/11/CCR-RAS-2016-ingl%C3%AAs-final.pdf	GRI-G4
Mexico City	http://ri.ccr.com.br/wp-content/uploads/sites/28/2017/11/CCR-RAS-2016-ingl%C3%AAs-final.pdf	GRI-G4
Peru	airport.com/eng/Documents/Sustainability%20and%E2%80%8B%20Annual%20Report%202017.pdf	GRI-Std.
Brazil	http://ri.voegol.com.br/download_arquivos.asp?id_arquivo=A57114C7-3B82-4F0E-BB8B-5D65E693809D	GRI-Std.
Zurich	https://www.yumpu.com/en/document/read/36882683/2008-sustainability-report-zurich-airport	Non-GRI
Puerto Rico	https://www.copaair.com/documents/20182/2663363/COPA+AIRLINES_-_Informe+Sostenibilidad+2017+ENG_BAJA.pdf/697d3bd9-6268-649b-d256-e55b5b681c71 https://www.dpdhl.com/content/dam/dpdhl/en/media-center/responsibility/dpdhl-corporate-responsibility-report-2018.pdf	GRI-G4
Malta	https://mia-prod-s3-cdn.s3.amazonaws.com/wp-content/uploads/2019/06/J19_4227-MIA-Sustainability-Report-2018-v1.11-WEB-OUTPUT-Spreads_2.pdf	GRI-Std.
Singapore	http://sustainability.changiairport.com/	GRI-Std.
Paris CDG	https://www.parisaeroport.fr/docs/default-source/groupe-fichiers/finance/information-r%C3%A9glement%C3%A9e-amf/documents-de-r%C3%A9f%C3%A9rence/2018/ddr-2018-va-vdef.pdf?	GRI-Std. GRI 4
Australia	https://www.bne.com.au/sites/default/files/docs/2018-Sustainability-Report.pdf	GRI-Std.
Sweden	https://www.swedavia.com/globalassets/om-swedavia/roll-och-uppdrag/swedavias-annual-and-sustainability-report-2018.pdf	GRI-Std. GRI-G4
Athens	https://www.avialliance.de/avia_de/data/pdf/AIA_Annual_Report_2018.pdf	GRI-Std. GRI-G4
İstanbul Atatürk	http://www.tavhavalimanlari.com.tr/tr-TR/basin-odasi/kurumsal-yayinlar/pages/surdurulebilirlik-raporu	GRI-Std.
Sydney	https://assets.ctfassets.net/v228i5y5k0x4/4601gBqOhHbkmYhkfleZPL/db41f43b16c6111b17c4c3c6ff4ee00d/Sydney_Airport_Sustainability_Report_2018.pdf https://www.sydneyairport.com.au/investor/investors-centre/reports/annual-reports and https://assets.ctfassets.net/v228i5y5k0x4/6nKbfG2HrgWPKFg7cvmr7B/b590dcb9ac7f438cc1537fa7da34ae18/Sydney_Airport_Annual_Report_April.pdf https://assets.ctfassets.net/v228i5y5k0x4/6nKbfG2HrgWPKFg7cvmr7B/b590dcb9ac7f438cc1537fa7da34ae18/Sydney_Airport_Annual_Report_April.pdf	GRI-Std.
San F.	http://media.flysfo.com.s3.amazonaws.com/media/sfo/community-environment/Climate_Action_Plan_FY18.pdf	GRI-Std.
Nepal	https://www.aai.aero/sites/default/files/AAI_Annual%20Report_2017-18_%20English.pdf	Non-GRI
Seoul	https://www.airport.kr/co_file/ko/file01/SR_2018_eng.pdf	GRI-Std.
Hamad intl. Airport	https://www.qatarairways.com/content/dam/documents/environmental/sustainability-report-2018.pdf	Non-GRI

TABLE A2 (Continued)

Airport name	Source of data	GRI version
Hong Kong	https://www.hongkongairport.com/iwov-resources/html/sustainability_report/eng/SR1718/wp-content/themes/aahk/assets/pdf/HKIA_SR201718_En.pdf	GRI-Std. GRI-G4
Ljubljana airport	https://www.fraport-slovenija.si/en/company/environment/	GRI-Std.
Munich	https://www.munich-airport.com/_b/00000000000000006771519bb5d10d91d/FMG_IB2018_Sustainability-indicators.pdf	GRI-Std.
Texas Dallas	https://www.dfwairport.com/cs/groups/webcontent/documents/webasset/p3_106747.pdf	GRI-Std.
Genève	https://www.gva.ch/en/Site/Geneve-Aeroport/Publications/Institutionnel/Rapport-developpement-durable-2018	GRI-Std.
Vancouver	https://www.yvr.ca/en/about-yvr/leadership-and-accountability/annual-and-sustainability-report	GRI-Std.
Thailand	https://corporate.airportthai.co.th/wp-content/uploads/2020/01/SDReport2019en.pdf	GRI-Std.