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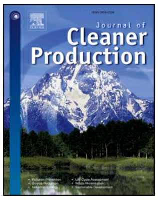

How do board governance and operational management affect carbon emissions among full-service and low-cost carriers?

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ABSTRACT

This study analyses 35 global airlines, comprising 17 full-service carriers (FSCs) and 18 low-cost carriers (LCCs), to examine how different business models, specifically board governance and operational management factors, influence carbon emissions. The findings show that LCCs generally produce lower total carbon emissions than FSCs, primarily due to their smaller operational scale and more uniform fleets. However, further interaction analyses reveal that, when other factors are held constant, certain LCC practices, such as board remuneration schemes and short-haul network structures, are positively associated with total carbon emissions compared with those of FSCs. The study also offers practical recommendations for airline managers and industry professionals who are aiming to balance cost efficiency with environmental responsibility. These insights help airlines operating under different business models reduce their overall carbon footprint.

1. Introduction

With the European Union Emissions Trading System (EU ETS) and the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), reducing the total emissions of airlines is a key focus for aviation operators and professionals. Given that the total emissions of global airlines may rise by over 1000 per cent in 2050 based on 1992's baseline (Macintosh and Wallace, 2009), understanding factors affecting the total emissions of airlines is more important since it is highly related to the goals of the EU ETS and CORSIA. High-emission airlines, including both low-cost carriers (LCCs) and full-service carriers (FSCs), now face rising carbon taxes, financial losses, and reputational risks (Oesingmann, 2022). Although scholars have found that LCCs emit less CO_2 per available seat kilometre (ASK) than FSCs (Lo et al., 2020; Miyoshi and Mason, 2009), the impact of their different business models on their total emissions remains unclear. LCCs and FSCs differ significantly in business strategies and management mechanisms. To better control operating costs, LCCs tend to adopt leaner boards with more direct oversight, while FSCs typically have more complex board structures designed to coordinate a wider range of internal and external stakeholders, which often leads to slower decision-making (Alves and Barbot, 2007). In their day-to-day operations, LCCs achieve higher operational efficiency and lower costs per aircraft than FSCs by consistently pursuing higher fleet utilisation and offering simplified services (Zuidberg, 2017). Understanding how these management differences affect the total emissions of airlines is important for policymakers, aviation professionals and researchers. This is not only due to public concerns about reducing airline carbon footprints but also because airlines themselves have gradually recognised their environmental responsibilities, since the major measurement of these responsibilities becomes total carbon emissions (Oesingmann, 2022). Hence, the research questions for this study are.

- *RQ1: How does board-level management influence airline carbon emissions, and in what ways does this influence differ between LCCs and FSCs?*
- *RQ2: How does operational management affect airline carbon emissions, and how does this effect vary between LCCs and FSCs?*

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This study makes three key contributions. First, it contributes to the literature by comparing LCC and FSC business models in relation to their total carbon emissions. Second, it informs airline decision-making on carbon reduction management. Third, it offers policy recommendations for aviation professionals and policymakers. Section 2 reviews factors influencing airline emissions. Section 3 outlines the methodology. Sections 4 and 5 present results and discussions, respectively, and Section 6 concludes with suggestions based on the findings.

2. Literature review

While the existing literature has extensively explored the factors influencing carbon emissions in the aviation industry, limited attention has been given to the strategic management differences between LCCs and FSCs, particularly in terms of board-level governance and operational strategies. LCCs and FSCs operate under fundamentally different business models, which shape their respective management and operational approaches. In light of the global imperative to reduce airline emissions, it is crucial to examine how these differing strategies may impact their environmental performance.

2.1. Key factors affecting airline carbon emissions

First, operational management factors were frequently discussed in the literature. Guan et al. (2024) found that airline managers' perceptions, such as their level of informedness, perceived risks, and trust, influenced their willingness, decision-making and management methods for reducing carbon emissions. Burns and Bowen (2024) highlighted the impact of network planning on airlines' respective carbon footprints, showing that long-thin routes were more emission-efficient due to the adoption of advanced aircraft such as Airbus 321XLR. Fleet management strategies also played a significant role. Ma et al. (2018) emphasised the effect of fleet planning on reducing carbon emissions by adopting a multi-objective optimisation (MOP) approach that balanced profit maximisation and emission minimisation. Cui and Yu (2021) found that fleet renewal helped reduce energy consumption and carbon emissions. Steven and Merklein (2013) observed that airlines in global alliances had lower carbon intensity than non-alliance carriers due to improved fleet utilisation. Yue and Byrne (2024) found that available seat miles, which represented the scale of operations, accounted for 40 % of the variation in emissions, showing that the operational scale of airlines was a major factor affecting airline emissions. Liu et al. (2020) identified a "link effect" between energy use and available seat kilometres (ASKs) on airline emissions by converting energy inputs into transport capacity. Jeon et al. (2022) showed that pilots' fuel-saving actions also contributed to emission reductions. Finally, Wu et al. (2024) found that the COVID-19 pandemic largely decreased the total capacity of airlines, lowering the total carbon emission generated by the aviation sector. These findings highlighted the critical role of operational management in reducing carbon emissions in the airline industry.

Second, air transport demand and aviation regulations were also important influencing factors. Liu et al. (2020) found that global economic integration increased air transport demand, then driving up emissions. Zhou et al. (2016) estimated a 37 % rise in emissions by 2030 due to growing passenger demand. In China, the aviation liberalisation between China and Central Asian countries improved air connectivity and air traffic flow, increasing total emissions but reducing per capita emissions (Ji et al., 2024). Cui and Yu (2021) highlighted the effect of carbon reduction policies in enhancing airlines' environmental efficiency by increasing the carbon abatement expense. Singh et al. (2017) emphasised that regulations such as carbon taxes and charges encouraged airlines to adopt fuel-efficient aircraft. Chao et al. (2019) used Monte-Carlo simulations to predict that carbon reduction policies, such as the EU ETS, could result in a 10 % substitution of traditional jet fuels with bio-jet fuels. Hu et al. (2022) argued that while policies contributed to short-term emission reductions, technological advancements offered longer-term mitigation.

Technological advancements in aircraft design and jet fuel production were also studied. Airlines were increasingly adopting fuel-efficient aircraft and engines, such as those by Embraer, Airbus and Rolls-Royce, while less fuel-efficient Russian planes were losing market share (Brugnoli et al., 2015). Sustainable Aviation Fuels (SAFs) were also playing a growing role in emissions reduction due to their innovative chemical properties (Wang et al., 2024). Zhou et al. (2016) noted that while coal-based jet fuels increased emissions, biomass-based fuels significantly reduced emissions and improved fuel efficiency, highlighting their potential for sustainable aviation.

Previous studies extensively examined the factors influencing carbon emissions in the aviation industry. However, research comparing emissions between LCCs and FSCs remains limited. While existing studies suggested that LCCs generally produced lower emissions per ASK or per passenger than FSCs (Lo et al., 2020; Miyoshi and Mason, 2009), they did not fully explore how differences in their business models contributed to this disparity. Although scholars have identified a convergence trend in business models between LCCs and FSCs (e.g., Chiambaretto and Combe, 2023; Daft and Albers, 2015; Magdalina and Bouzaima, 2021), this convergence was more pronounced in onboard services (Chiambaretto and Combe, 2023). However, with respect to core operational strategies and financial strategies, LCCs and FSCs remain fundamentally distinct (Chiambaretto and Combe, 2023; Gillen and Morrison, 2017).

Moreover, focusing only on unit airline emissions is insufficient, as, on one hand, environmental regulations (Sgouridis et al., 2011), carbon taxes (Hofer et al., 2010), and public concerns about the green image of airlines (Hagmann et al., 2015) increasingly target airlines based on their total carbon emissions rather than emissions per ASK or per passenger. On the other hand, as LCCs rapidly expand their capacities, their total emissions are also likely to rise quickly, even though their unit emissions are lower than those of FSCs. These gaps highlight the need for further investigation.

2.2. Hypotheses development

Research has shown that firms with larger total assets and greater operational scales tend to generate greater carbon emissions (e.g., Li et al., 2014; Narsa Goud, 2022; Saka and Oshika, 2014). In the aviation sector, LCCs typically maintain smaller fleets than FSCs and operate more standardised narrow-body aircraft (e.g., Chiambaretto and Combe, 2023; Mehta et al., 2019; Wensveen and Leick, 2009). The smaller fleet sizes of LCCs reflect their lower operational scales, which generally lead to fewer flights, reduced fuel consumption, and lower overall carbon emissions (Flouris and Walker, 2005). Furthermore, research conducted in 2019 by the International Council on Clean Transportation (ICCT) indicated that airlines operating narrow-body aircraft emitted, on average, 3 g of CO_2 per revenue passenger kilometre (RPK) less than those operating wide-body aircraft, regardless of airlines' business model, region, or flight length (Graver et al., 2020). Since LCCs predominantly operate narrow-body aircraft while FSCs tend to use mixed fleets comprising both narrow-body and wide-body aircraft (Chiambaretto and Combe, 2023; Wensveen and Leick, 2009), LCCs are expected to produce lower total carbon emissions than FSCs. Based on these considerations, we propose the following hypotheses.

H1a. *Airlines with greater total assets emit more carbon emissions, regardless of their business models.*

H1b. *LCCs emit lower total carbon emissions than FSCs as a result of their distinct fleet structures, controlling for their total assets.*

The business strategies of LCCs and FSCs differ significantly in their day-to-day operations, which are firstly shaped and overseen by their boards (e.g., Alves and Barbot, 2007; Duppati et al., 2016; Lorange, 1998). As the highest level of management, board governance plays a crucial role in determining strategic direction and ensuring effective implementation (Schmidt and Brauer, 2006). According to de Villiers et al. (2011), boards primarily fulfil strategic responsibilities through monitoring performance and providing key resources. One of the most influential factors in board effectiveness is board size, which impacts both the ownership structure and the efficiency of decision-making processes (Narsa Goud, 2022). In general, LCCs' cost-performance focus can prompt them to deliberately limit board sizes in order to reduce administrative costs (Alves and Barbot, 2007; Belobaba, 2009). Therefore, LCCs tend to have smaller board sizes than FSCs, which can facilitate faster and more efficient decision-making on operations (Alves and Barbot, 2007; Narsa Goud, 2022). For carbon emission governance, however, smaller boards can create governance challenges, as the effective monitoring and management of carbon emissions typically require sufficient board members to coordinate cross-departmental efforts and provide timely resource support (Kreuzer and Priberny, 2022; Alkurdi et al., 2023). With fewer board directors, LCCs may lack the diversity of expertise, oversight capacity, and monitoring needed to address their carbon footprint internally (Alkurdi et al., 2023; Kreuzer and Priberny, 2022). Externally, with smaller boards, they may also be less able to engage with stakeholders and allocate resources to carbon-reduction initiatives such as addressing increasing green expectations from passengers (Alkurdi et al., 2023; Elsayih et al., 2021). Consequently, when facing increasing environmental responsibilities, the relatively small board size of LCCs may weaken their overall governance capacity on environmental issues, potentially leading to higher carbon emissions compared with FSCs.

H2a. *LCCs' board sizes lead to higher carbon emissions compared with FSCs.*

In addition to board size, the collective skill set of board members plays a crucial role in how they interpret market signals, engage in strategic discussions, and make informed business decisions (Bear et al., 2010; Garg and Bingham, 2025). LCCs' board members often exhibit more concentrated expertise, typically in aviation or finance, compared with the more diversely skilled boards of FSCs (Alves and Barbot, 2007; Moon et al., 2022). This specialised expertise can support cost efficiency and operational focus, contributing to the strong financial performance of LCCs (Aliani, 2023). However, such narrow skill sets may also constrain the board's ability to address complex environmental challenges (Elsayih et al., 2021). In particular, when environmental issues conflict with the revenue-making activities of LCCs, boards lacking environmental or sustainability expertise may be less motivated or less capable of prioritising carbon-reduction strategies (de Villiers et al., 2011). Consequently, LCCs' concentrated board expertise may hinder their capacity to manage carbon emissions effectively, potentially leading to higher total emissions than FSCs. Based on the above arguments, we propose the following hypothesis.

H2b. *LCCs' board skills lead to higher carbon emissions compared with FSCs.*

Another important governance factor is board remuneration. Compensation schemes shape how actively board members engage in strategic planning and execution (Barontini and Bozzi, 2011; Velte, 2022). In the context of LCCs, higher board compensation may strengthen incentives for board directors to prioritise cost leadership and financial performance in order to justify their remuneration packages (e.g., Brueckner and Spiller, 1994; Oliveira, 2008; Velte, 2022). Consequently, the board members of LCCs can be motivated to push for higher fleet productivity and the maximisation of available seat capacity, as these are core strategies for sustaining cost advantages in highly competitive markets (Haque and Ntim, 2020). However, such a strong emphasis on operational efficiency and fleet utilisation may also increase the number of flights and revenue passenger kilometres (RPKs) operated by LCCs (Barontini and Bozzi, 2011; Jäck et al., 2023). As a result, this operational expansion can lead to greater total fuel and resources consumption and, therefore, higher overall carbon emissions (e.g., Alves and Barbot, 2007; de Villiers et al., 2011; Jäck et al., 2023). Based on the above arguments, we propose the following hypothesis.

H2c. *LCCs' board remuneration leads to higher carbon emissions compared with FSCs.*

The daily operations of LCCs and FSCs differ significantly (Graham and Vowles, 2006; Hunter, 2006). These operational differences can result in varying carbon emission levels. One major distinction lies in their revenue-generation strategies, which directly influence carbon emissions (Chiambaretto and Combe, 2023). Unlike FSCs, which offer multi-class cabins, LCCs adopt a standardised all-economy layout to maximise seating capacity (Chiambaretto and Combe, 2023; Ko and Hwang, 2011). Because they are less competitive to earn premium-class revenue, LCCs depend heavily on maintaining high load factors to fully utilise available seats and sell more budget tickets (Hofer et al., 2008; Bitzan and Peoples, 2016). By keeping aircraft highly utilised and load factors consistently high, LCCs can spread fixed costs across more passengers, thereby increasing revenue to offset the lack of premium-class income (Bitzan and Peoples, 2016). However, consistently high load factors can also encourage LCCs to add more flights, increase flight frequencies, or expand their fleets to capture growing low-budget air travel demand (Soyk et al., 2018). This operational growth can drive up total carbon emissions of LCCs. Furthermore, LCCs' high load factors can raise fuel consumption per flight by increasing the total weight of the aircraft, and they can also increase the resources required for ground services (Brueckner and Abreu, 2017). As a result, the strategy of pursuing high load factors can offset the gains from lower emissions per ASK and ultimately lead to higher overall carbon emissions (Bitzan and Peoples, 2016). Based on the above arguments, we propose the following hypothesis.

H3a. *LCCs' revenue strategy leads to higher total carbon emissions than FSCs.*

In addition, differences in cost management strategies between LCCs and FSCs may also affect their carbon emissions. LCCs operate under a cost-leadership model and place strong emphasis on controlling operating costs in all areas (Bitzan and Peoples, 2016; Chiambaretto and Combe, 2023). Their lean management culture relies on tight performance-based monitoring systems, which often track fuel burn per flight and per seat as key metrics (Cook and Billig, 2023; Horiguchi et al., 2017). This cost discipline drives LCCs to implement precise fuel planning, high aircraft utilisation, and fast turnaround times, which reduce aircraft grounding time and fuel waste (Cook and Billig, 2023; Hunter, 2006; More and Sharma, 2014). As a result, these cost management strategies, normally measured by operational costs per aircraft, can contribute to lower total carbon emissions of LCCs by improving energy efficiency and reducing resources required across operations. Based on the above arguments, we propose the following hypothesis.

H3b. *LCCs' cost management leads to lower total carbon emissions than FSCs.*

Finally, LCCs' network structures can also influence their total carbon emissions. LCCs generally operate point-to-point networks consisting mainly of short-to medium-haul routes, enabled by their smaller, standardised narrow-body fleets (Mehta et al., 2019; Wensveen and Leick, 2009). While this model supports high flight frequency and operational flexibility, short-haul operations often result in higher carbon intensity and total carbon emissions (e.g., Baumeister, 2019; Dissanayaka et al., 2020; Pagoni and Psaraki-Kalouptsidi, 2017). This is mainly because a large share of carbon emissions is generated during take-off and landing cycles across all kinds of flights, which leads to more total carbon emissions from short-haul operations (Baumeister, 2019). Consequently, even when using similar aircraft types as FSCs, LCCs' high-frequency short-haul operations can produce more fuel burn and carbon emissions than the longer-haul and less frequent operations of FSCs (Avogadro et al., 2021). Based on the above reasoning, the following hypothesis is proposed.

H3c. *LCCs' short-haul operations lead to higher total carbon emissions than FSCs.*

3. Methodology

3.1. Data and source

This study draws on data from Refinitiv Eikon, Cirium, and airline annual reports. Refinitiv Eikon and annual reports provide financial and corporate data for 98 publicly listed passenger airlines. For the purpose of this analysis, airline groups that operate both individual FSCs and LCCs subsidiaries are excluded. The remaining 35 airlines operate as independent carriers (see Appendix A). Cirium provides comprehensive operational data used to analyse airlines' operational variables. The final dataset is unbalanced and comprises 304 firm-year observations spanning the period from 2004 to 2023.

3.2. Econometric modelling and variables

To test H1a to H2c, we analyse the impact of the LCC business model and airlines' board management factors on total carbon emissions in Equation (1), controlling for operational factors. The dependent variable is the natural logarithm of the estimated total carbon dioxide equivalent emissions (in tonnes) ($\ln CET_{it}$) retrieved from Refinitiv Eikon, with the intercept denoted by α. To stabilise variance and improve interpretability, we apply the natural logarithmic transformation to CET_{it} (Manning and Mullahy, 2001).

Independent variables include the LCC dummy (LCC_t), with 1 for LCC and 0 otherwise (Wang et al., 2018), the board size ($BDSZ_{it}$), the first lag of the natural logarithm of board member compensation (in USD) ($L.\ln BMCS_{it}$) (de Villiers et al., 2011; Elsayih et al., 2021), and the percentage of board members with industry-specific or financial backgrounds (SKL_{it}). $\ln BMCS_{it}$ represents the natural logarithm of board members' total compensation for airline i during fiscal year t, and it is lagged by one year, not only to mitigate potential endogeneity (Brick et al., 2006) but also to better capture the influence of prior-year remuneration on board members' subsequent performance (Lilling, 2006). These three board-related characteristics are selected because they represent fundamental factors influencing the board's governance functions and strategic decision-making (de Villiers et al., 2011; Elsayih et al., 2021).

Control variables (X_{it}) include the COVID-19 pandemic dummy ($COVID_t$), with 1 for pandemic periods including 2020, 2021 and 2022, 0 otherwise (Wu et al., 2024). $COVID_t$ controls for the pandemic's impact on airlines (Atayah et al., 2022). LFT_{it} measures load factor percentage and serves as a proxy for revenue strategies between LCCs and FSCs (Bitzan and Peoples, 2016). $\ln OPCS_{it}$ captures cost management differences between LCCs and FSCs in natural logarithm (Swidan and Merkert, 2019). $\ln CPSZ_{it}$, measured by total assets (in USD) and expressed in its natural logarithmic form, controls for airline size (Elsayih et al., 2018).

In addition, geographical locations and varying policies in different regions may influence airline operations and carbon performance (Dobruszkes and Van Hamme, 2011; Douglas and Tan, 2017). To control for regional effects, we create five regional dummy variables (AS_t, EU_t, NA_t, OC_t, and SA_t) based on the locations of airline headquarters (see Table 1). As there are no African airlines in the sample, the Africa dummy is not included. A value of 1 indicates that an airline is headquartered in the specified region, and 0 otherwise. The South America dummy (SA_t) is selected as the reference group due to its relatively high carbon emissions per aircraft, providing a balanced baseline for comparing other regions (Cui and Jia, 2023). Furthermore, previous studies have shown that a significant portion of flight-related carbon

Table 1
Variable definition and source.

Variables		Definitions	Data sources
Total carbon emissions	*CET*	Total estimated CO_2 and CO_2-equivalent emissions (in tonnes) generated by an airline in a given fiscal year.	Refinitiv Eikon
Board size	*BDSZ*	Total number of board members of an airline serving at the end of a given fiscal year.	Refinitiv Eikon and annual reports
Board member compensation	*BMCS*	Total compensation (in USD) paid to all board members of an airline during a given fiscal year.	Refinitiv Eikon and annual reports
Board skill	*SKL*	Percentage of board members of an airline with either an industry-specific or strong financial background during a given fiscal year.	Refinitiv Eikon and annual reports
Load factor	*LFT*	Company-level average load factor (percentage) of an airline during a given fiscal year.	Refinitiv Eikon and annual reports
Operational costs	*OPCS*	Total costs of revenue (in USD) of an airline during a given fiscal year divided by the airline's fleet size.	Refinitiv Eikon and annual reports
Company size	*CPSZ*	Total assets (in USD) reported by an airline at the end of a given fiscal year.	Refinitiv Eikon and annual reports
Proportion of short-haul flights	*STHL*	Proportion of ASMs from short-haul flights (less than 4000 km) of an airline to total flight ASMs in a given fiscal year.	Cirium
LCC dummy	*LCC*	Dummy variable equal to 1 if an airline operates under the LCC business model, and 0 otherwise.	Coded by authors
COVID dummy	*COVID*	Dummy variable equal to 1 if the observation falls within the COVID-19 pandemic period (2020–2022), and 0 otherwise.	Coded by authors
Asia dummy	*AS*	Dummy variable equal to 1 if an airline's headquarters is located in an Asian country, and 0 otherwise.	Coded by authors
Europe dummy	*EU*	Dummy variable equal to 1 if an airline's headquarters is located in a European country, and 0 otherwise.	Coded by authors
North America dummy	*NA*	Dummy variable equal to 1 if an airline's headquarters is located in a North American country, and 0 otherwise.	Coded by authors
Oceania dummy	*OC*	Dummy variable equal to 1 if an airline's headquarters is located in an Oceanian country, and 0 otherwise.	Coded by authors
South America dummy	*SA*	Dummy variable equal to 1 if an airline's headquarters is located	Coded by authors

(*continued on next page*)

Table 1 (*continued*)

Variables		Definitions	Data sources
		in a South American country, and 0 otherwise.	
The interaction term of LCC and board size	*LCC×BDSZ*	Interaction term capturing the effect of board size within an LCC.	Calculated by authors
The interaction term of LCC and board member compensation	*LCC×L.lnBMCS*	Interaction term capturing the effect of the previous year's board compensation within an LCC.	Calculated by authors
The interaction term of LCC and board skill	*LCC×SKL*	Interaction term capturing the effect of board skill composition within an LCC.	Calculated by authors
The interaction term of LCC and load factor	*LCC×LFT*	Interaction term capturing the effect of load factor within an LCC.	Calculated by authors
The interaction term of LCC and operational costs	*LCC×lnOPCS*	Interaction term capturing the effect of operational costs per aircraft within an LCC.	Calculated by authors
The interaction term of LCC and Proportion of short-haul flights	*LCC×STHL*	Interaction term capturing the effect of short-haul operation intensity within an LCC.	Calculated by authors

emissions occurs during the take-off and landing phases (Dissanayaka et al., 2020; Pagoni and Psaraki-Kalouptsidi, 2017). Airlines that operate more short-haul flights may therefore have higher total emissions (Baumeister, 2019). To account for this effect, we obtain the available seat mile (ASM) data for both short-haul and long-haul flights from Cirium and construct a variable ($STHL_{it}$) to measure the share of short-haul ASMs relative to total ASMs. Following Dobruszkes et al. (2022), we define short-haul flights as those shorter than 4000 km.

To examine how board management strategies differ between LCCs and FSCs in influencing carbon emissions (H2a to H2c), we create interaction terms ($LCC \times BDSZ_{it}$, $LCC \times L.\ln BMCS_{it}$ and $LCC \times SKL_{it}$) in Equation (2) using the mean-centred method to address multicollinearity (Afshartous and Preston, 2011). $\beta_{1\text{-}10}$ are coefficients to be estimated. ϵ_{it} represents the error term.

$$logCET_{it} = \alpha + \beta_1 BDSZ_{it} + \beta_2 L.logBMCS_{it} + \beta_3 SKL_{it} + \delta X_{it} + \epsilon_{it} \tag{1}$$

$$logCET_{it} = \alpha + \beta_4 LCC_t + \beta_5 BDSZ_{it} + \beta_6 (LCC \times BDSZ)_{it} + \beta_7 L.logBMCS_{it} + \beta_8 (LCC \times L.logBMCS)_{it} + \beta_9 SKL_{it} + \beta_{10} (LCC \times SKL)_{it} + \delta X_{it} + \epsilon_{it} \tag{2}$$

To test H3a to H3c, we examine whether differences in operational strategies between LCCs and FSCs can affect their carbon emissions. The dependent variable remains $\ln CET_{it}$. LCC_t is one of the key explanatory variables. In addition, LCCs are characterised by lower operational costs per aircraft, achieved by reducing frills and improving load factors due to the absence of premium classes (Bitzan and Peoples, 2016; Ko and Hwang, 2011). Based on these features, we further use LFT_{it} and $\ln OPCS_{it}$ as independent variables. Moreover, we consider flight-haul characteristics ($STHL_{it}$) of LCCs and the influence of the company size ($\ln CPSZ_{it}$) in generating airline emissions. Control variables (X_{it}) include $COVID_t$, corporate governance variables, and regional dummies. By controlling these factors, we explore how LCCs and FSCs differ in carbon emissions due to their diverse operational features. Similar to Equation (2), we test interaction effects ($LCC \times LFT_{it}$, $LCC \times \ln OPCS_{it}$, and $LCC \times STHL_{it}$) to examine how operational strategies differ between LCCs and FSCs in influencing carbon emissions. These three interaction terms are created using the same mean-centred method. α is the intercept. $\beta_{11\text{-}20}$ are coefficients to be estimated. ϵ_{it} is the error term. Equations (3) and (4) present the model specifications.

$$logCET_{it} = \alpha + \beta_{11} LCC_t + \beta_{12} LFT_{it} + \beta_{13} logOPCS_{it} + \delta X_{it} + \epsilon_{it} \tag{3}$$

$$logCET_{it} = \alpha + \beta_{14} LCC_t + \beta_{15} LFT_{it} + \beta_{16} (LCC \times LFT)_{it} + \beta_{17} logOPCS_{it} + \beta_{18} (LCC \times logOPCS)_{it} + \beta_{19} logCPSZ_{it} + \beta_{20} (LCC \times STHL)_{it} + \delta X_{it} + \epsilon_{it} \tag{4}$$

Before conducting the analysis, we perform unit root tests using both the Augmented Dickey–Fuller (ADF) method (Kurozumi, 2002) and the Phillips–Perron (PP) method (Phillips and Perron, 1988). The results indicate that none of the dependent, independent, or control variables contain a unit root. Table 1 presents the definitions of all variables used in this study.

4. Results

4.1. Descriptive statistics

Table 2 presents the descriptive statistics of the non-dummy variables. The mean of ln*CET* is 22.349, which is approximately five times higher than that of firms listed on the London Stock Exchange (4.43) (Khatib and Al Amosh, 2024), highlighting higher emission levels of airlines. *BDSZ* averages 10.7 with a standard deviation of 2.9. ln*BMCS* has a mean of 13.7 and a standard deviation of 1.1, indicating relatively stable variation in board compensation. *SKL* averages 0.46, meaning 46 % of board members have aviation or financial expertise. The mean of ln*CPSZ* is 22.9, larger than the top 350 UK-listed companies (15.1) (Luo and Tang, 2021), reflecting airlines' asset-intensive nature. *LFT* averages 78.7 %, with the minimum (15 %) observed during the COVID-19 pandemic. *STHL* has a mean of 0.78, meaning that, on average, 78 % of ASMs are operated on short-haul flights. ln*OPCS* has a standard deviation of 0.7, showing stable changes in operational costs.

4.2. Multicollinearity and heteroscedasticity tests

To address potential multicollinearity and heteroscedasticity, we calculate variance inflation factors (VIFs) (see Table 3). The results indicate no concerns regarding multicollinearity. The heteroscedasticity test (Prob > Chi2 = 0.000) suggests the presence of heteroscedasticity, and thus robust standard errors are employed in the model estimation.

4.3. Estimation results

To determine whether the fixed effects (FE) or random effects (RE) model is more appropriate, we perform a Hausman test (Borenstein et al., 2010). The result (Prob > chi^2 = 0.8759) indicates that the RE model is more suitable for our analysis (Borenstein et al., 2010). Following previous studies, we treat ln*BMCS* as an endogenous variable in the aviation industry, as it likely exhibits reverse causality with total carbon emissions (de Villiers et al., 2011; Elsayih et al., 2021). Using only a one-year lag may not fully address this endogeneity concern. Therefore, we employ a two-stage least squares (2SLS) estimation to

Table 2
Descriptive statistics of variables.

Variables	Mean	Std. D	Min	Max
ln*CET*	22.35	1.31	16.71	24.47
BDSZ	10.67	2.86	5.00	20.00
ln*BMCS*	13.65	1.13	10.31	16.50
SKL	0.46	0.20	0.00	1.00
ln*CPSZ*	22.92	1.11	19.97	25.01
LFT	0.79	0.11	0.15	0.96
STHL	0.78	0.26	0.15	1.00
ln*OPCS*	17.06	0.66	14.78	20.21

Table 3
Variance inflation factors (VIFs).

Variable	VIF
LCC×ln*OPCS*	5.76
LCC×*STHL*	5.23
NA	5.21
STHL	4.94
ln*OPCS*	4.58
LCC	4.36
AS	4.09
ln*BMCS*	3.40
EU	3.06
LFT	2.85
LCC×ln*BMCS*	2.69
BDSZ	2.61
LCC×*BDSZ*	2.48
LCC×*LFT*	2.36
ln*CPSZ*	2.00
COVID	1.94
OC	1.78
SKL	1.44
LCC×*SKL*	1.43
Mean VIF	**3.27**

correct for potential bias (de Villiers et al., 2011; Elsayih et al., 2021) and to test the robustness of the model. In the first stage, ln*BMCS* is regressed on all exogenous variables to obtain fitted values and capture the residuals. In the second stage, we re-estimate the model using these fitted values along with the other explanatory variables (Elsayih et al., 2018). The first-stage F statistic (2787.25) and the significant result from the underidentification test ($p = 0.0057$) confirm the relevance of the fitted variable and the validity of the 2SLS model (Chan et al., 2012). Table 4 presents the regression results, where regional dummy variables and *STHL* are progressively included in the RE model to observe how the coefficients of other variables change (see RE 1, 2, and 3).

Results show that ln*CPSZ* is significant at the 1 % level across all models, supporting H1a proposed in Section 2. The positive coefficients (0.81–0.85) indicate that a 1 % increase in an airline's total assets is associated with a 0.81–0.85 % increase in its CO_2 emissions. For example, for an airline currently emitting 100,000 metric tons of CO_2 annually, this implies an additional 810–850 metric tons of CO_2 per year. This positive result aligns with prior studies (Elsayih et al., 2021; Narsa Goud, 2022), which suggests that airlines with larger total assets tend to offer more air transport services and attract more revenue passengers (Cui and Li, 2016), thereby generating higher levels of carbon emissions.

Table 4
Results of random-effect and two-stage least squares analyses.

Dependent variable (ln*CET*)				
Variables	RE (1)	RE (2)	RE (3)	2SLS
LCC	−0.197*	−0.229**	−0.193	−0.256*
	(0.103)	(0.112)	(0.138)	(0.132)
BDSZ	0.034	0.034	0.041*	0.530
	(0.023)	(0.025)	(0.024)	(0.356)
SKL	0.394**	0.430**	0.460**	0.507**
	(0.181)	(0.209)	(0.197)	(0.231)
L.ln*BMCS*	0.110	0.090	0.091	0.054
	(0.087)	(0.093)	(0.096)	(0.070)
LFT	1.357**	1.327**	1.508**	1.485**
	(0.547)	(0.581)	(0.636)	(0.639)
ln*OPCS*	0.322***	0.330***	0.171	0.181*
	(0.116)	(0.113)	(0.111)	(0.101)
ln*CPSZ*	0.809***	0.825***	0.828***	0.846***
	(0.055)	(0.064)	(0.082)	(0.076)
STHL			−0.310	−0.161
			(0.319)	(0.284)
AS		−0.519**	−0.468*	−0.472*
		(0.235)	(0.260)	(0.265)
EU		−0.280**	−0.289**	−0.263*
		(0.130)	(0.117)	(0.135)
NA		−0.238	−0.245	−0.234
		(0.226)	(0.245)	(0.227)
OC		−0.209	−0.250	−0.485***
		(0.363)	(0.371)	(0.167)
COVID	−0.304***	−0.310***	−0.298***	−0.298***
	(0.085)	(0.090)	(0.098)	(0.093)
R^2(overall)	0.815	0.822	0.803	0.808

Remarks: Robust standard errors in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

The results from RE (1), RE (2), and the 2SLS indicate that *LCC* has a significant negative effect on total carbon emissions at the 5–10 % significance level, supporting H1b proposed in Section 2. This finding is likely attributable to the fact that LCCs generally operate with narrow-body fleets and more uniform aircraft types than FSCs. The average fleet size is 220.4 for LCCs and 455.3 for FSCs. These differences in fleet composition and operational strategies may help explain the observed emissions gap between the two airline types (Miyoshi and Mason, 2009). However, when *STHL* is included in RE (3), the statistical significance of both the *LCC* and ln*OPCS* variables disappears, suggesting that LCCs' carbon emissions may also be influenced by their network structures in addition to their fleet composition. Further analysis is needed to determine whether the flight-haul characteristics of LCCs contribute to the variation in their carbon emissions.

BDSZ is statistically significant at the 10 % level in RE (3); however, this result is not consistent across other models, particularly the 2SLS model, which offers more robust explanatory power. Therefore, we consider that *BDSZ* is not a consistently significant explanatory variable.

The results show that the *SKL* variable is significantly positively associated with airline carbon emissions at the 5 % level, with coefficients ranging from 0.39 to 0.50 across all models. For example, for an airline emitting 100,000 metric tons of CO_2 annually, a 1 % increase in *SKL* is associated with an increase of approximately 390–500 metric tons of CO_2 per year. This aligns with the findings of Aliani (2023), indicating that airlines with a concentrated board skill set tend to prioritise financial and operational performance over environmental concerns.

LFT consistently shows a positive effect on airline carbon emissions at the 5 % significance level, with coefficients ranging from 1.33 to 1.51 across all models. For an airline emitting 100,000 metric tons of CO_2 annually, a 1 % increase in *LFT* is associated with an increase of approximately 1330 to 1510 metric tons of CO_2 per year. This finding aligns with the previous paper (Brueckner and Abreu, 2017), suggesting that higher load factors increase the weight of fully loaded aircraft, thereby leading to greater fuel and resource consumption and, consequently, higher carbon emissions.

The ln*OPCS* variable has a significant effect on airline carbon emissions in the RE (1), RE (2), and 2SLS models. This suggests that a 1 % increase in operational costs per aircraft is associated with a 0.18–0.33 % rise in total carbon emissions. Specifically, for an airline emitting 100,000 metric tons of CO_2 annually, a 1 % increase in operational costs per aircraft is associated with an increase of approximately 180–330 metric tons of CO_2 per year. This finding aligns with Lee et al. (2017), implying that airlines with stringent cost management tend to utilise fewer resources to provide the same level of air transport services, thereby decreasing total emissions (Gillen and Lall, 2004). Similarly, the explanatory power of ln*OPCS* may be absorbed when *STHL* enters the model.

Three regional dummy variables, *AS*, *EU* and *OC*, are statistically significant and negative in the 2SLS model. These negative coefficients indicate that airlines operating in these three regions have lower carbon emissions compared with those in South America. Possible reasons include stricter regulations (Ko et al., 2017), more advanced fleets (Hooper, 2005), and greater operational efficiency (Lee et al., 2017). Moreover, *COVID* has a significant negative effect on airline carbon emissions, consistent with the findings of Nižetić (2020), as the pandemic forced airlines to substantially reduce flights and capacities in response to declining air travel demand.

4.4. Interaction effect analyses

To further investigate how management strategies differ between LCCs and FSCs in influencing carbon emissions, six interaction terms are tested using the 2SLS model, and the results are presented in Table 5.

The interaction term, *LCC*×*L*.ln*BMCS*, indicates that higher board compensation in LCCs is positively associated with increased carbon emissions. The coefficients for both LCCs and FSCs are statistically significant at the 5 % level, supporting H2c proposed in Section 2. Model 3 suggests that a 1 % rise in board remuneration in the previous fiscal year is associated with a 0.14 % emission reduction in FSCs. However, for LCCs, the same amount of enhancement in board compensation is associated with 0.39 % higher emissions than the coefficient estimated for FSCs. This implies that, assuming an annual emission baseline of 100,000 metric tons, a 1 % increase in board remuneration may result in a net increase of approximately 250 metric tons of CO_2 per year for LCCs compared with FSCs. Namely, board remuneration plans appear to reduce carbon emissions in FSCs, whereas they are associated with higher emissions in LCCs. These results may be explained by the distinct business models and governance structures of LCCs and FSCs. Board members in FSCs consider both profit maximisation and environmental impacts, thereby incentivising greener airline operations. In contrast, board members in LCCs may prioritise operational performance over environmental concerns. More specifically, LCCs keep operating costs lower than those of FSCs primarily by maximising economies of density (Brueckner and Spiller, 1994; Oliveira, 2008). This allows LCCs to make the most use of each aircraft by increasing flying time and maximising the number of available seats (Williams and Baláž, 2009). Boards in LCCs prioritise quick decision-making to accelerate operations (Alves and Barbot, 2007), thereby helping them achieve economies of density and maintain lower costs. Hence, higher board compensation in LCCs may further encourage board members to maximise aircraft utilisation and add more flights, thereby increasing seat capacities. However, this approach can also result in higher carbon emissions for LCCs than for FSCs when both types of airlines add the same number of aircraft (Lee et al., 2017).

The interaction term *LCC*×*STHL* is statistically significant at the 5 % level, supporting H3c proposed in Section 2, whereas the main effect of *STHL* alone is not significant, with a coefficient of −0.29. This suggests that increasing the proportion of short-haul flights in FSCs' networks does not have a significant affect on their total carbon emissions. However, the coefficient for *LCC*×*STHL* is 0.98, indicating that, for the same increase in short-haul flights, LCCs experience a 0.98 % greater increase in carbon emissions than FSCs. The net effect for LCCs is a 0.69 % increase in total emissions, showing that short-haul operations have a much stronger impact on total emissions under the LCC model. This finding is partially consistent with previous studies (e.g., Avogadro et al., 2021; Baumeister, 2019; Dobruszkes et al., 2022), which point out that short-haul flights tend to generate more emissions due to more take-off and landing cycles. Since LCCs typically operate a higher proportion of short-haul routes with quicker turnaround times (Dobruszkes, 2006; Morrell, 2008), their total carbon emissions are generally higher

Table 5
Results of interaction effect analyses.

Dependent variable (ln*CET*)						
Variables	(1)	(2)	(3)	(4)	(5)	(6)
LCC×*BDSZ*	0.122 (0.078)					
LCC×*SKL*		0.786 (0.680)				
LCC×*L*.ln*BMCS*			0.389** (0.153)			
LCC×*LFT*				0.466 (1.654)		
LCC×ln*OPCS*					−0.003 (0.304)	
LCC×*STHL*						0.982** (0.483)
LCC	−0.152* (0.088)	−0.317 ** (0.136)	−0.239** (0.104)	−0.274** (0.125)	−0.267 (0.199)	−0.415*** (0.115)
BDSZ	0.007 (0.015)	0.040 (0.026)	0.044* (0.024)	0.043* (0.024)	0.042* (0.022)	0.041* (0.025)
SKL	0.535** (0.236)	0.467 ** (0.226)	0.489** (0.215)	0.480* (0.253)	0.492** (0.245)	0.479** (0.227)
L.ln*BMCS*	0.038 (0.077)	0.052 (0.078)	−0.143** (0.055)	0.057 (0.078)	0.060 (0.071)	0.059 (0.073)
LFT	1.356** (0.653)	1.306 ** (0.534)	1.394** (0.615)	1.368*** (0.436)	1.493** (0.694)	1.517** (0.638)
ln*OPCS*	0.219** (0.087)	0.203 * (0.110)	0.226** (0.100)	0.170* (0.087)	0.178 (0.121)	0.172* (0.099)
ln*CPSZ*	0.819*** (0.054)	0.834 *** (0.081)	0.818*** (0.058)	0.852*** (0.079)	0.851*** (0.081)	0.861*** (0.077)
STHL	−0.205 (0.256)	−0.075 (0.278)	−0.230 (0.254)	−0.167 (0.285)	−0.173 (0.343)	−0.293 (0.278)
EU	−0.175 (0.186)	−0.351 ** (0.161)	−0.136 (0.188)	−0.292** (0.148)	−0.282** (0.139)	−0.286* (0.152)
AS	−0.331 (0.225)	−0.563 * (0.288)	−0.521* (0.287)	−0.506* (0.280)	−0.505 (0.345)	−0.531* (0.292)
OC	−0.585*** (0.172)	−0.595 *** (0.182)	−0.545*** (0.207)	−0.533*** (0.159)	−0.544*** (0.157)	−0.577*** (0.165)
NA	−0.104 (0.210)	−0.303 (0.242)	−0.145 (0.217)	−0.244 (0.259)	−0.252 (0.223)	−0.265 (0.245)
COVID	−0.330*** (0.099)	−0.345 *** (0.076)	−0.282*** (0.086)	−0.303*** (0.093)	−0.301*** (0.097)	−0.299*** (0.095)
R^2(overall)	0.820	0.807	0.816	0.806	0.806	0.804

than those of FSCs when both LCCs and FSCs have similar fleet sizes operating short-haul flights. More specifically, FSCs usually adopt a wave-based network structure that consolidates flights into coordinated banks, resulting in fewer take-off and landing cycles (Burghouwt and de Wit, 2005). In contrast, LCCs primarily operate point-to-point short-haul flights with less emphasis on connecting waves, which leads to more frequent take-off and landing cycles and consequently higher emissions (Miyoshi and Mason, 2009). Based on the above analyses, Hypotheses H1a, H1b, H2c, and H3c proposed in Section 2 are supported, whereas H2a, H2b, H3a, and H3b lack sufficient statistical evidence to be supported.

5. Discussion

This study analyses a sample of 35 airlines to address an important question: How do different business strategies affect airline carbon emissions? It focuses on the two main airline business models, LCCs and FSCs and examines how differences in board governance and operational management influence their emission levels. This research is valuable not only because it contributes to the existing literature, but also because it offers a new perspective on the strategic management factors that shape airlines' total emissions. This is especially relevant given that previous studies have shown LCCs generally produce lower emissions per passenger or per ASK compared with FSCs (Lo et al., 2020; Miyoshi and Mason, 2009). However, how the strategic management factors affecting total emissions remains poorly understood. As concerns about aviation-related carbon emissions continue to grow, understanding how different airline business models contribute to emission reduction can help airline professionals mitigate emission risks and support policymakers in developing better regulations, encouraging airlines to adopt more sustainable management practices.

5.1. Theoretical contributions

The results of this study contribute to the theoretical understanding of the relationship between airline business strategies and carbon emissions. Both board governance and operational management influence the total emissions of LCCs and FSCs, albeit in different ways. At the top management level, board governance affects total emissions primarily through the skill sets of board members. When boards have a high concentration of expertise, particularly in finance or the aviation industry, airlines tend to emit more CO_2, as such boards often prioritise financial performance over environmental responsibilities (Tanthanongsakkun et al., 2023). To mitigate carbon emissions, airlines could adopt more diverse board skill sets to achieve a better balance between financial performance and green transformation.

Moreover, operational strategies, which more directly impact carbon emissions, have a stronger effect on total airline emissions. Specifically, operational scale (measured by total assets) revenue-generating strategies (measured by load factors) and cost-saving strategies (measured by unit operational costs) all play important roles. The underlying logic is that when airlines expand the operational scale to generate additional revenue, such as increasing asset sizes or improving load factors, their total emissions also increase (Cui et al., 2022), which shows that operational scale is a major factor affecting airlines' total emissions. However, airlines' cost-control practices can partially offset this increase. Even as airlines expand their operational scale, cost-saving measures can help reduce total emissions by lowering the resources consumed. This suggests that maintaining a slower pace of scale expansion while focusing on reducing unit operating costs may help airlines lower their carbon emission levels.

The results become particularly interesting when considering how the business strategies of LCCs and FSCs influence their total emissions. In general, LCCs emit less CO_2 than FSCs, mainly because they operate on a smaller scale and use more uniform fleets consisting primarily of narrow-body aircraft. However, beyond this fleet structure, certain strategic practices unique to LCCs can substantially affect their emissions. For example, board compensation schemes in LCCs may drive higher emissions than those in FSCs. By pursuing economies of density and maximising fleet utilisation, LCCs maintain a competitive advantage over both other LCCs and FSCs (Williams and Baláž, 2009). When board members receive higher pay, they are more likely to promote strategies that increase fleet utilisation, which in turn raises total capacities and emissions (Alves and Barbot, 2007). In contrast, the negative coefficient of the board compensation in Table 5 shows that FSCs tend to be more balanced in financial performance, scale growth, and environmental responsibilities, illustrating how different business models influence total emissions through board governance. Accordingly, this finding suggests that LCCs may need to adopt more carefully designed board compensation schemes to place greater emphasis on environmental responsibilities.

Additional insights come from operational management. Because LCCs focus more on economies of density, they have a stronger capability to maximise fleet utilisation (Williams and Baláž, 2009), potentially generating more emissions when expanding assets by the same percentage as FSCs. However, LCCs typically maintain tighter cost control and offer fewer services (Hunter, 2006), which may result in lower emissions at the same unit cost as FSCs, since fewer onboard and boarding services consume less energy. Therefore, encouraging the cost-reduction strategies used by LCCs could help aviation professionals and policymakers develop effective measures to reduce carbon emissions across different airlines.

In addition, the significant interaction between LCCs and the proportion of short-haul flights suggests that LCCs experience greater increases in carbon emissions when they expand short-haul operations, primarily because their higher operational efficiency generates more take-off and landing cycles. Although LCCs are known for their cost control, their network structures, typically focused on frequent short-haul, point-to-pint flights, can lead to higher overall emissions. In contrast, FSCs operate more diversified network structures that employ wave-system (hub-and-spoke) scheduling to connect short- and long-haul routes. This operational complexity allows FSCs to generate fewer take-off and landing cycles and achieve better carbon efficiency while operating the same fleet size as LCCs. This finding challenges the common perception that such complexity in FSCs' fleet structures is a disadvantage (Brueckner and Abreu, 2017; Lo et al., 2020). It also reinforces earlier studies that associate short-haul flights with increased emissions, particularly within the LCC model (Miyoshi and Mason, 2009). Therefore, if LCCs continue to rely heavily on short-haul expansion, they are likely to face increasing environmental risks. To address this, LCCs should consider diversifying their route networks or investing in fleet renewal as strategies to reduce total carbon emissions.

Unlike previous studies, this research offers a fresh perspective on the role of strategic management practices in affecting the total carbon emissions of LCCs and FSCs. While Miyoshi and Mason (2009) compared emissions between these two airline models, they found that LCCs produce lower emissions per passenger, largely due to factors such as more fuel-efficient aircraft, denser seating configurations, and higher load factors. They also noted that the lower fares offered by LCCs can increase total emissions by attracting more passengers and stimulating the expansion of flight operations. Other evidence from Ryanair and EasyJet (Lo et al., 2020) shows that LCCs have lower emissions per ASK than FSCs. However, this finding focuses only on unit emissions between LCCs and FSCs and does not explicitly explain how the management strategies inherent to each business model drive these differences in emissions. These conclusions raise an important question about the trade-offs between unit-level emission efficiency and airlines' overall emissions. Building on these findings, this paper examines ways to reduce total emissions for both LCCs and FSCs, with the aim of mitigating their overall carbon risks. Rather than merely comparing unit emissions, this study investigates how management strategies influence total emissions and contribute to more sustainable airline operations.

5.2. Management and policy implications

This paper provides valuable insights for airline managers in both LCCs and FSCs. First, managers should recognise that fleet size and operational scale are key drivers of an airline's total emissions. To reduce overall emissions, airlines must strike a careful balance between fleet expansion and environmental responsibility. Second, while increasing the load factor can improve efficiency, it may also lead to higher carbon emissions. However, effective cost-control measures can help offset some of these negative effects. As such, both LCCs and FSCs should adopt cost management strategies to mitigate the environmental impact associated with higher load factors. Third, LCCs should diversify the skill sets of their board members by actively recruiting individuals with expertise in environmental management, sustainable aviation technologies, or environmental, social, and governance (ESG) practices. This could be achieved by including sustainability officers or external advisors with proven experience in low-carbon strategy implementation. Such diversification would enhance the board's ability to integrate environmental considerations into strategic decisions, thereby improving the airline's overall emissions performance. Fourth, LCCs could explore operating longer-haul routes or modernising their fleets as strategies to reduce the emissions associated with their heavy reliance on short-haul flights. Finally, as LCCs expand to achieve economies of density through high-frequency short-haul operations, they are likely to face a more critical trade-off between scale growth and environmental sustainability than FSCs. While increasing load factors and network coverage can boost airline profitability, they may also drive up total carbon emissions. To manage this trade-off, LCCs should adopt green-scaling metrics, such as emissions per RPK, emissions per flight hour, and marginal emissions per additional aircraft, etc. Monitoring these indicators can help ensure that LCCs' growth strategies remain aligned with their carbon reduction objectives.

This paper also provides valuable insights for policymakers seeking to improve carbon emission management in the aviation industry. First, regulating the overall operating scale of airlines is crucial, as their asset and fleet sizes directly influence total emissions. Policies should encourage both LCCs and FSCs to expand at a balanced pace, improving emission performance while maintaining financial stability. Second, policymakers should promote innovation in airline governance structures, particularly by introducing board remuneration schemes that place greater emphasis on environmental responsibilities. Finally, policies that support cost-reduction initiatives can facilitate a shift from full-service to more on-demand, no-frills offerings. This not only helps airlines control costs but also reduces energy consumption, thereby lowering the overall carbon emissions of both LCCs and FSCs.

5.3. Limitations and avenues for future research

This study has two main limitations. First, the number of effective observations used in the model is limited to 304, primarily due to data constraints in the Refinitiv Eikon database, particularly regarding total carbon emissions data in the aviation sector. Second, the dataset includes only publicly listed airlines, excluding private airlines, which may introduce sample selection bias. Publicly listed airlines are generally subject to greater regulatory scrutiny and tend to demonstrate better carbon performance (Qian and Xing, 2018), which could affect the estimation results. To address these limitations, future research could draw on additional data sources to expand the number of airline observations and incorporate a broader set of variables. This would provide a more comprehensive understanding of how strategic management practices influence total carbon emissions across different airline types and business models, including both FSCs and LCCs.

6. Conclusion

This study examines how board governance and operational management strategies influence the total carbon emissions of LCCs and FSCs. Drawing on 304 firm-year observations, the findings show that LCCs generally produce lower total carbon emissions than FSCs, largely because they operate with smaller asset bases and more standardised narrow-body fleets. The analysis also reveals that several factors are positively associated with higher emissions across various airlines, including a high concentration of board member expertise, improved load factor performance, higher operational costs per aircraft, and larger company size. When comparing the two business models, the results suggest that, after controlling for other factors, LCCs may generate higher total emissions than FSCs due to efficiency-oriented board compensation schemes and a greater reliance on short-haul operations. Although previous research has emphasised that LCCs achieve lower emissions per passenger or per available seat kilometre (ASK), their strategic focus on operational efficiency, scale expansion, short-haul networks, and the pursuit of economies of density can ultimately lead to greater total emissions than FSCs as LCCs' fleets expand.

These findings carry several important implications. First, broadening the range of board member expertise may help both LCCs and FSCs reduce their carbon emissions. Second, lowering unit operational costs appears beneficial for reducing emissions across all types of airlines. Third, aviation professionals, particularly those in LCCs, should recognise the close link between business models and environmental outcomes. As LCCs continue to expand, managers in LCCs need to incorporate environmental performance considerations into board remuneration schemes. Finally, policymakers can draw on these insights to encourage various airlines to adopt more environmentally sustainable business models, thereby mitigating their carbon emission risks.

This study has several limitations. First, the sample size is constrained by the availability of carbon emission data, and some interaction effects may lack statistical significance due to the limited number of observations. Second, the analysis focuses solely on publicly listed airlines, thereby excluding private carriers. Future research should address these limitations to provide a more comprehensive and generalisable understanding of management-related factors influencing airline carbon emissions.

CRediT authorship contribution statement

Huan Wang: Writing – original draft, Software, Resources, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Kan Wai Hong Tsui:** Writing – review & editing, Supervision, Software, Methodology, Conceptualization. **Qingxia Jenny Wang:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization. **Hanjun Wu:** Writing – review & editing, Supervision, Conceptualization. **Xiaowen Fu:** Writing – review & editing, Data curation. **Fan Hu:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Huan Wang reports was provided by University of Southern Queensland. Huan Wang reports a relationship with University of Southern Queensland that includes: non-financial support. Huan Wang has patent pending to N.A. Not available If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

35 airlines analysed in this paper.

No.	Company Name	IATA Code	Business Models
1	Aegean Airlines	A3	Full-service
2	Air Canada	AC	Full-service
3	Air China	CA	Full-service
4	Air New Zealand	NZ	Full-service
5	Air Transat	TS	Full-service
6	AirAsia	AK	Low-cost
7	AirAsia X	D7	Low-cost
8	Alaska Airlines	AS	Full-service
9	Allegiant Air	G4	Low-cost
10	American Airlines	AA	Full-service
11	Azul	AD	Full-service
12	Cathay Pacific	CX	Full-service
13	China Airlines	CI	Full-service
14	China Southern Airlines	CZ	Full-service
15	Delta Air Lines	DL	Full-service
16	easyJet	U2	Low-cost
17	EVA Air	BR	Full-service
18	Finnair	AY	Full-service
19	Frontier Airlines	F9	Low-cost
20	GOL Linhas Aéreas Inteligentes (GOL)	G3	Low-cost
21	IndiGo	6E	Low-cost
22	Jet2	LS	Low-cost
23	JetBlue	B6	Low-cost
24	LATAM Airlines	LA	Full-service
25	Mesa Airlines	YV	Full-service
26	Norwegian	DY	Low-cost
27	Pegasus Airlines	PC	Low-cost
28	Ryanair	FR	Low-cost
29	Southwest Airlines	WN	Low-cost
30	Spirit Airlines	NK	Low-cost
31	Spring Airlines	9C	Low-cost
32	Thai AirAsia	FD	Low-cost
33	United Airlines	UA	Full-service
34	Volaris	Y4	Low-cost
35	Wizz Air	W6	Low-cost

Data availability

Data will be made available on request.

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