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Assessment of aircraft leasing efficiency: An airline perspective

Kristina Marintseva[a,*], Roxani Athousaki[b]

[a] Coventry University, Gulson Road, Coventry CV1 2JH, UK
[b] Coventry University, Wrocław, 53-332, Poland

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ABSTRACT

This research contributes to the theory of assessing aircraft leasing efficiency from an airline's perspective by revising factors influencing leasing decisions and developing an integrated approach to modelling aircraft leasing decisions. Despite the extensive research on aircraft leasing appraisal, modelling tools for informed decision-making require constant updates regarding the attributes to be included and approaches to uncertainty conditions. The key contribution of this research supports the ongoing discussion of the practical deployment of management science in the aircraft leasing field, aiding the industry in quickly adapting to changing market conditions. The research includes brief analyses of key performance indicators in the aircraft leasing industry to identify trends and a literature review to justify the current factors influencing leasing decisions. It is demonstrated that integrating operational modelling into aircraft leasing assessment can provide a data-driven justification for the importance of new, fuel-efficient aircraft in achieving sustainability goals and maintaining operational profitability. The sensitivity analysis further illustrates the robustness of the model and solution, and its capacity to generate scenario assessments reflecting varying conditions such as changes in demand, taxes, fuel costs, and other airline expenses. The simulation of a hypothetical example based on data from airlines' business intelligence platforms reveals that significant initial fixed leasing payments, including taxes, can negatively impact an airline's ability to modernise its fleet through leasing. Fuel efficiency, zero customs duties and VAT on aircraft leasing, and sufficient capital to cover fixed leasing costs are the main drivers stimulating fleet modernisation and can be justified by a slight increase in expected profits.

1. Introduction

During the panel discussion on the expanding role of leasing firms in aviation financing (CAPA 2024a), an audience member asked why airlines fail to achieve returns that cover the cost of capital, while leasing firms consistently generate higher returns from owing aircraft comparing to airlines operating them. A Bernstein Equity Research Analyst responded suggesting that European airline management teams tend to prioritise more passenger growth, revenue and EBIT over return on capital, which is crucial for investors. The panel also noted the intense competing and cyclical nature of the airline industry as additional factors, in contrast to the stable leasing industry. Supporting this view, a representative from the leasing sector emphasised the importance of partnering with strong management teams in airlines that focus on the financial returns of aircraft leasing projects, including the application of various investment appraisal and algorithms.

All panellists – comprising lessors, airline representatives and business analysts – agreed that contemporary aircraft financing decisions are complicated by the risks associated with new technologies (such as Sustainable Aviation Fuel (SAF) and propulsion systems), instability in Environmental, Social, and Governance (ESG) and net-zero policies and related regulations, and supply chain issues. They emphasised that airlines need to understand the economic implications of transitioning to SAF, which is currently priced at 2.5 to 5 times the cost of jet fuel, according to a statement from the CFO of TAP airline (CAPA 2024a).

Recent literature also highlights the importance of integrating sustainability into leasing decisions. For instance, Wandelt et al. (2024) discuss environmental challenges and decision-making methodologies as critical topics in air transport management research. Wendel, Albers, and Dewulf (2024) conclude that despite airlines' central role, they often struggle to cover their capital costs due to high bargaining power of both customers and suppliers and the industry's fragmented value chain. The consolidation of the airframe manufacturer market, notably the Airbus and Boeing duopoly, further limits airlines' options. Sun et al. (2024) emphasise that climate change and sustainability goals significantly influence the aviation industry, driving competition among airlines to attract green-sensitive passengers through sustainable initiatives and advanced technology.

Given these insights, the purpose of this article is to address the complexity of aircraft leasing decisions and provide an integrated ap-

* Corresponding author.
E-mail address: ad1302@coventry.ac.uk (K. Marintseva).

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proach to modelling these decisions from an airline's perspective. Current approaches often fail to capture the full spectrum of factors influencing leasing efficiency and typically focus on either financial or operational aspects in isolation, without comprehensive integration of variables such as tax regulations, existing fleet composition, and market dynamics. This study aims to fill this gap by analysing industry trends and factors influencing leasing decisions to identify the current key parameters of leasing, as well as modelling the operational and financial implications of leased aircraft within the existing fleet. This comprehensive approach can provide a more robust framework for making informed aircraft financing choices, ensuring a balance between profitability, operational efficiency, and justification for investment in a next-generation aircraft fleet.

The outline of this paper is as follows: Section 2 reviews the current trends in aircraft leasing, including the resurgence of global air travel and the increase in aircraft deliveries. Section 3 discusses the supply and demand dynamics in the leasing market. Section 4 introduces the integrated approach used to assess leasing decisions, incorporating modelling and sensitivity analysis to evaluate the robustness of the solution under varying conditions. Section 5 presents the findings from a simulation of a hypothetical example based on data from airlines' business intelligence platforms. Finally, Section 6 concludes with recommendations for aligning leasing practices with sustainability goals and market trends.

2. Current trends in aircraft leasing

2.1. Resurgence of global air travel and increase in aircraft deliveries

Many experts agree that the global aviation sector is anticipating a significant upswing, with the resurgence of international travel from China and the growing influence of India, Saudi Arabia, and the UAE (International Airport Review 2024; CAPA, 2024). IATA announced that global air passenger traffic, measured in revenue passenger kilometres (RPKs), exceeded pre-pandemic levels by 5.7% in February 2024. This marks the first complete global recovery in both domestic and international travel. Average load factors have returned to approximately the levels seen before the pandemic (IATA, 2024). On the manufacturing front, the delivery of new commercial aircraft reached a level of more than 1500 units during 2023-2024 (CAPA, 2 April 2024). According to a survey by Benson et al. (2022), an increase in investment in the global aviation sector started from 2022. Respondents from the EMEA region expressed the most optimistic outlook, with 84 % expecting a rise in financing, followed closely by APAC with 80 %. CAPA (2024b) database currently shows that there are over 37,500 civil aircraft in service worldwide, with an additional 16,874 aircraft on order (Table 1). The Asia Pacific region is expected to have the largest number of available aircraft. In Europe, there are approximately 8,000 planes in service, with more than 3,500 on order (see Fig. 1). As evidenced by these figures, despite previous pandemics affecting the air transportation market, both airlines and investors continue to demonstrate confidence in the recovery and growth of air travel.

Table 1
Global fleet summary, April 2024.

Business models	In Service	Inactive	On order	Total expected
LCC	6,990	412	5,941	13,343
FSC	14,992	846	6,331	22,169
Military/Government	1,791	22	85	1,898
Regional/Commuter	4,273	715	451	5,439
Carter	2,580	391	30	3,001
Cargo	2,305	152	152	2,609
General Aviation	796	231	22	1,049
Virtual Carrier	13	7	0	20
Other	3,755	1,269	3,862	8,886
Total	37,495	4,045	16,874	58,414

Note: compiled according to CAPA Database.

2.2. Aircraft leasing supply and demand

The current supply-demand dynamics are strongly in favour of aircraft lessors due to problems with OEMs, leading to the expectation of potential increases in lease rates, along with aircraft values and funding costs (Cirium, 9 February 2024). This estimation is supported by one of the leading leasing companies, which stated that the aircraft leasing sector is preparing for a surge in demand due to the ongoing shortage of aircraft. They highlighted a significant increase in aircraft values and lease rates, with a 35% hike in 2023 (CAPA 26 January, 2024). This situation underscores a structural deficit in both narrowbody and widebody aircraft availability. The scarcity of aircraft is anticipated to prolong delivery timelines, inflate the value of available aircraft, and extend their operational lifespans.

The data, sourced from the CAPA database in April 2024, reveals that roughly 21,000 aircraft, or 50% of the global fleet, are leased, underscoring the significant role of leasing companies in the air transportation sector. At a global level, the leasing market involves over 500 lessors, with 53% of the aircraft fleet owned by fifteen key leasing players (Table 2). The relatively competitive nature of the leasing market affords airlines flexibility in negotiating leasing agreements, which can potentially result in cost savings.

Furthermore, a notable aspect of aircraft leasing market is the significant role played by Ireland, with companies registered in Ireland owning 25% of the total leased fleet. The high attractiveness of Ireland to aircraft leasing companies can primarily be explained by its favourable corporate tax environment and extensive network of double tax treaties (refer to further discussion in Section 2.5). At the same time,

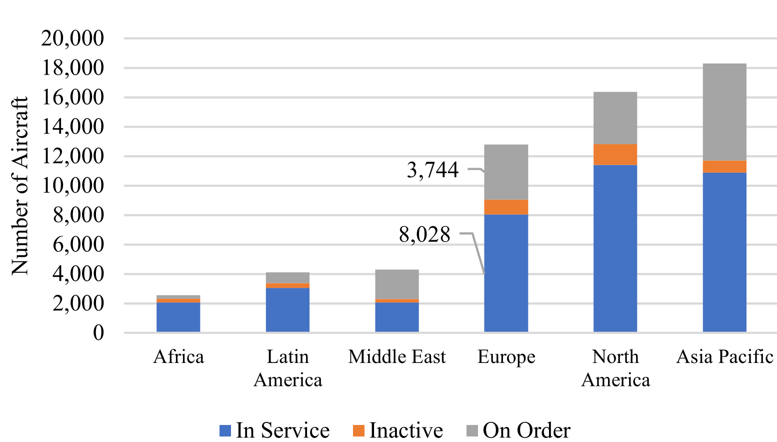


Fig. 1. Global fleet by region. Note: compiled according to CAPA Database.

Table 2
Global top 15 leasing companies.

Lessor	Country	Region	Number of Customers	Owned	% of total owned	Inactive	On order
AerCap	Ireland	Western Europe	298	1761	14%	98	338
SMBC Aviation Capital	Ireland	Western Europe	145	555	5%	32	256
Air Lease Corporation	USA	North America	137	541	4%	17	315
Avolon	Ireland	Western Europe	150	505	4%	25	449
BOC Aviation	Singapore	South-East Asia	120	491	4%	22	214
Dubai Aerospace Enterprise Capital	UAE	Middle East	121	342	3%	27	62
Industrial and Commercial Bank of China (ICBC)	China	Eastern Asia	84	338	3%	25	64
Aviation Capital Group (ACG)	USA	North America	105	313	3%	25	109
Nordic Aviation Capital	Ireland	Western Europe	92	271	2%	97	52
Nomura Babcock & Brown Company Ltd	Japan	North-East Asia	42	265	2%	5	0
Aircastle	USA	North America	96	245	2%	16	11
CDB Leasing Company	China	Eastern Asia	74	235	2%	28	138
China Aircraft Leasing Group (CALC)	Hong Kong	Eastern Asia	58	224	2%	9	157
Unknown Lessor	-	-	-	222	2%	-	-
Bank Of Communications Financial Leasing (BoCom Leasing)	China	Eastern Asia	43	201	2%	18	84
Other (1264 companies in the CAPA list)	-	-	-	5787	47%	-	-
Total	-	-	-	12296	100%	-	-

Note: compiled according to CAPA Database, as at 01-Apr-2024.

Table 3
Fleet ownership structure of key European and UK airlines.

Airline	Total fleet in service	Owned, %	Leased, %
British Airways	237	51.5	48.5
Ryanair	296	100.0	0.0
Turkish Airlines	346	92.5	7.5
easyJet	177	58.8	41.2
Lufthansa	262	93.1	6.9
Virgin Atlantic Airways	41	24.4	75.6
Air France	214	43.0	57.0

Note: compiled according to CAPA Database, as at 01-Apr-2024.

China and the Middle East showed potential for creating competitive environments due to their political ambitions and monetary resources (Shaw-Smith, 2022). Although, it remains uncertain whether lessors are willing to venture into emerging regions.

Major aircraft manufacturers are encountering difficulties in increasing production rates, a situation that has been exacerbated by regulatory measures. For instance, the FAA has imposed production caps on Boeing following safety incidents. These manufacturing delays are causing further postponements in aircraft deliveries, which affects the availability of new aircraft (RTTNews, 2021).

The financial environment is currently characterised by higher interest rates, which has impacted unsecured lending costs. There is hope among lessors and other stakeholders in the aviation industry for a more stable interest rate environment in 2024, that broadly settled at around 5% in the US and UK and 4% in the Eurozone. If this stabilisation occurs, it could positively influence leasing activities and aircraft financing by potentially lowering the cost of capital and making financing terms more favourable for airlines (KPMG, 2024; Hallerstrom, 2020).

According to a study conducted by Bourjade et al. (2017), the optimal level of leasing in the airline industry is approximately 53%. However, it is important to note that there is no universally established practice for the percentage ratio of owned versus leased aircraft in a fleet. Each airline develops its own asset financing strategy to optimise profitability based on its available resources. An examination of a sample of leading airlines in Europe and the UK reveals a wide range of leased aircraft proportions in their fleet structures, from 0% to 75%, as depicted in Table 3. This variation can be attributed to the complexity of fleet financing decisions, which require consideration of multiple factors including financing availability, interest rates, maintenance costs, market focus, and tax requirements (Guzhva, et al., 2019). Despite the diversity the analysis conducted using a Chi-Square test shows that there is a statistically significant association between the airline business model and its tendency to lease (χ^2=6934.066, p-value<0.05). Specifically, the global data indicates that low-cost carriers (LCCs) are more inclined to employ leasing strategies compared to full-service carriers (FSCs). For further details, see Appendix A for the dataset and analysis report.

2.3. Decarbonisation initiatives, ethical and social responsibility

Decarbonisation is becoming a pivotal factor in the aircraft leasing market, influencing decisions and strategies significantly. As airlines and OEMs strive to meet ambitious net-zero targets by 2050, the demand for newer, more efficient aircraft and SAF is driving a transformation in fleet management. Current aircraft models, such as the Airbus A320neo and Boeing 777-X, which can reduce emissions by 15 to 20%, are expected to replace a significant portion of older aircraft over the next decade, thereby supporting the aviation industry's decarbonisation goals (IATA, 2023; McKinsey & Company, 2023; World Economic Forum, 2023; Ishka March 2022).

The shift towards models that support lower emissions is reshaping how lessors and airlines handle leasing agreements and fleet renewals. Financial strategies, such as the implementation of incentives or disincentives based on an airline's Scope 1 emissions – which correspond to the financiers' and lessors' Scope 3 emissions – are becoming common (Halaby et al., n.d.).

Ethical and corporate social responsibility (CSR) have become integral components of contemporary airline business practices (Athousaki, 2020). The newly implemented Sustainable Finance Disclosures Regulation (SFDR) is an EU directive designed to enhance transparency in the financial services sector concerning sustainability (European Commission, 2022). This act effectively addresses a gap that Marie-Louise Kelly, chair of Aircraft Leasing Ireland (ALI), highlighted when she stated that ten years ago, sustainable financing lacked clear regulations and was quite ambiguous (Davies, 2023). Studies indicate that actively engaging in CSR initiatives can result in several advantages for companies, such as improved reputation, enhanced trust from stakeholders, and better financial outcomes (Margolis & Walsh, 2003). It is therefore evident that whether through carbon credits, SAF, or other metrics lessors can encourage and assist airlines to meet sustainability objectives. The challenge lies in assessing the cost associated with implementing sustainable finance and in understanding how ESG investing practices will integrate with traditional financial metrics when making investment decisions (CAPA, 2024a). By prioritising ethical and social responsibility considerations, aircraft leasing companies can contribute to a safer, more sustainable, and socially responsible airline industry.

The inclusion of aircraft leasing in sustainable finance and green policies is complex due to the diverse nature of aircraft technologies and their environmental impacts. The EU's draft technical screening criteria for sustainable finance consider the leasing of aircraft that utilise low-carbon technologies (e.g., electric, hybrid-electric, and hydrogen fuel cells) as low carbon activities (European Commission, 2021). Conversely, conventional aircraft might only be included as transition activities under specific conditions until alternative low-carbon options become viable. This classification system underscores the importance of assessing aircraft types' environmental performance and the transitional role of leasing in promoting greener aviation technologies (Giddings, 2021).

Leasing agreements are increasingly incorporating clauses requiring compliance with environmental standards, such as the ICAO's CO2 emissions standards and SAF compatibility (Norton Rose Fulbright, 2021). Moreover, the impact of regulations like the EU Taxonomy for sustainable activities is evident in the changing structure of these agreements, urging lessors to finance aircraft that meet specific low-emission criteria or are capable of utilising alternative fuels like hydrogen or electricity (Halaby, Duc, Hutchinson and Marrinan, n/d).

Financiers are also setting specific emissions targets, such as grams of CO2 per revenue passenger kilometre (CO2/RPK), which airlines must meet to benefit from better financing terms, such as reduced interest rates or discounts. This approach is designed to incentivise airlines to adopt more sustainable practices, aligning financial motives with environmental objectives.

It should be noted that decarbonisation initiatives will require significant and costly investment from both airlines and lessors. McKinsey & Company (2022) states that the aviation sector could need between \$40 billion to \$50 billion annually through 2030 to reach carbon-neutral growth targets, primarily by enhancing the production of SAF. Efforts to decarbonise will likely increase operating costs for airlines, impacting airfare and potentially reducing profit margins. According to Danicourt et al. (2023), by 2050, the operating costs related to adopting new technologies and fuels could increase by 8% to 18%. Airlines are increasingly concerned about the economic impacts and technological challenges associated with transitioning to SAF and other decarbonisation initiatives. They face uncertainties regarding the scalability of new technologies, the availability of necessary inputs like green hydrogen, and the cost implications of integrating these into their operations. Additionally, there is a broader discussion on the allocation of responsibilities and costs between airlines, fuel producers, and regulatory bodies in driving these green initiatives.

As stated by KPMG (2024), the aviation sector recognises the challenges it faces in reducing its carbon footprint, yet the path forward remains unclear. The report highlights that despite growing ESG concerns, the availability of capital, whether debt or equity, has not been significantly affected. Moreover, the report stresses that for SAF to fulfil its critical role in the industry's transformation, there needs to be a substantial increase in its production.

It is obvious that the path to net zero for airlines and lessors is complex and depends heavily on advancements in technology and supportive regulatory frameworks. The full-scale adoption of technologies like SAF, hydrogen and electric propulsion is faced with economic, technological, and infrastructural challenges that could delay their widespread implementation. (McKinsey & Company, 2023; CAPA 2024).

2.4. Economic and geopolitical challenges

Air transportation expansion faces challenges from a variety of ongoing crises, supply chain pressures, and heightened regulatory oversight. The coming decade may witness a rise in air travel costs, driven not only by heightened sustainability demands, as mentioned in Section 2.3, but also by tighter labour markets and issues with engine durability. Political uncertainties, including the Russia's brutal invasion of Ukraine, tensions in the Middle East, and strains between China and Western countries, are being closely monitored in 2024 (Cirium 2024; Chu, Zhang, Zhang, Cong, & Lu, 2024; NATO, 2024; Wang, Zhang, & Wandelt, 2023). For instance, following Russia's actions, there has been a sharp increase in aircraft insurance premiums. The industry anticipates considerable claims in the coming years related to the confiscation or theft of aircraft, which is expected to affect future insurance premiums (Holder, Benson, Andreeva and Denman, 2022; Georgilidakis, April 7, 2022). These changes highlight the importance of flexibility, thorough risk assessment, and the anticipation of potential geopolitical disruptions in the aircraft leasing and insurance sectors. This approach is reflected in the series of publications by practitioners, particularly by Hallerstrom (2020), who describes the multifaceted risk framework used in assessing and managing aircraft loan and lease portfolios. The author emphasises the importance of jurisdictional and operational risks, including political instability or war, as well as liquidity and currency risks, which can significantly influence the conditions of leases or loans. At the same time, they acknowledge the challenges of accurately modelling these risks in aircraft financing using mathematical methods.

2.5. Taxation and accounting changes

Wandelt et al. (2023) have highlighted the intricacies of aircraft leasing decisions. Their analysis of over 70 papers, published between 1992 and 2022, revealed that the complexity of leasing contracts could limit airlines' flexibility under unforeseen conditions. They also affirmed that Ireland is a prominent low-taxation hub for aviation leasing, benefiting from being an English-speaking country in the UTC-0 time zone and a longstanding member of the European Union with a common law legal system familiar to industry stakeholders. However, as discussed in Li et al. (2020), significant regulatory changes such as the EU Anti-Tax Avoidance Directive (2016/1164, ATAD 1) (Council of the European Union (2016), the Multilateral Convention to Implement Tax Treaty Related Measures to Prevent BEPS (MLI) (OECD, n.d.), and provisions on transfer pricing and mandatory disclosure will significantly alter business operations and the strategies for maintaining tax-efficient structures. Although the full impact of these changes remains unclear, it is essential to start considering these now to appropriately adjust established leasing business frameworks.

Generally, as noted by Guzhva et al. (2019), the principal taxes to consider in aircraft leasing include potential *stamp duties, import taxes, customs duties, VAT,* and *registration taxes*, particularly if the aircraft is registered in a new jurisdiction. Additionally, tax obligations also incurred during the lease, including *withholding taxes, sales taxes (VAT), stamp duties (include any local taxes, withholding taxes, income taxes, asset taxes, use taxes, or document taxes on documentation and lease payments)*, and *security deposits* and *maintenance reserves*. These tax obligations highlight the financial responsibilities that both lessors and lessees should thoroughly assess in the aircraft leasing industry.

As noted by Contract Manager at ABL Aviation in an interview for this paper, it is a standard practice in lease agreements to include a clause stating that all payments related to the lease and associated documents must be made without any deductions for withholding taxes. If withholding taxes are legally required, the lessee must increase (gross up) the payment to ensure that the lessor receives the full amount originally agreed upon, net of taxes. The lessee is required to indemnify certain parties – namely the lessor, the lessor's parent company, lenders, the facility agent, and the security trustee (collectively referred to as *Tax Indemnitees*) – against all present and future taxes, fees, and other government charges. This includes a wide array of taxes and fees such as VAT, sales, use, property, license, registration fees, etc. This clause is designed to protect the financial interests of the *lessor* and other stakeholders by ensuring that the *lessee* bears the tax liabilities and government charges related to the aircraft and the lease, except in clearly defined situations. For example, in the UK, as stated by ICLG (n.d.), lessees are typically responsible for VAT on lease payments. This applies if the aircraft is used primarily for domestic purposes or does not qualify for international operation exemptions, and the VAT is usually included as part of the leasing costs. There is generally no withholding tax on lease payments in the UK, which simplifies the process for lessees, especially in cross-border leases. For lessors, the tax implications in the UK are more extensive. They are liable for Corporation Tax on their profits from leasing aircraft, which includes income derived from lease payments. If a lessor decides to sell an aircraft, they may be subject to Capital Gains Tax on the profit realised from the sale. VAT may also apply to the sale of an aircraft unless it qualifies for an exemption, such as being used predominantly for international flights. Moreover, if a lessor imports an aircraft into the UK, importation VAT may be payable unless specific exemptions apply. As the lessee is generally responsible for VAT associated with the transaction, this responsibility could potentially place an undue burden on them at the initial stage of the lease (Guzhva et al., 2019). Therefore, it is important to carefully consider VAT regulations in the lessee's jurisdiction.

In lease agreements, it is common practice that lessees are not required to gross up or indemnify for specific taxes, such as those on distributions or payments made under tokumei kumiai agreements by the lessor to equity investors. These taxes can include those imposed on the lessor by tax authorities concerning the lessor's net income, capital, net worth, turnover, capital gains, gross income, or gross receipts or profits. This applies irrespective of the lessor's jurisdiction of incorporation or any other jurisdiction where the lessor is considered a tax resident. Furthermore, the loss of tax benefits associated with the lessor's ownership of assets like aircraft is typically not indemnified by the lessee.

It is worth noting that under the Agreement on Trade in Civil Aircraft (WTO, n.d.), there are no customs duties imposed on civil aircraft. This agreement includes 33 signatories, among them the UK and members of the European Union.

Regarding accounting changes, the implementation of the IFRS 16 accounting standard, which was issued by the International Accounting Standards Board (IASB) in January 2016, is noteworthy (IFRS, n/d). The inclusion of the IFRS 16 standard underscores the evolving financial reporting landscape, influencing how leases are accounted for on balance sheets and impacting overall fleet management strategies. According to BDO International Limited (2023), with this implementation, the distinction between operating and finance leases has largely been removed for lessees. Furthermore, it is suggested that the new accounting standard may not directly affect general fleet planning decisions and operations of airlines. However, this change could significantly impact the financial statements of airlines by potentially increasing the amount of debt reported on their balance sheets (Guzva et.al, 2019; Chen & Wu, 2023). Lessees now recognise a right-of-use asset and corresponding lease liability for most leases (with certain exemptions), and they depreciate the right-of-use asset similarly to how assets are depreciated under finance leases. The lessee depreciates the asset over the shorter of the asset's useful life or the lease term. This reflects the lessee's assumption of the risks and rewards of ownership. The lease payments are split into a *depreciation charge for the right-of-use asset* and *interest expense on the lease liability*, impacting both the income statement and the balance sheet (IASB, 2016, p. 4.; BDO International Limited, 2023).

2.6. Summary of key trends and drivers in aircraft leasing decisions

The current trends review indicates a complex interplay of financial, operational, and environmental factors influencing the strategic choices of aircraft leasing by airlines. Despite significant advancements, a major gap remains in the comprehensive assessment of the efficiency of new green technologies, particularly next-generation aircraft and new types of fuel such as SAF. In addition to sustainability, other factors such as geopolitical challenges, economic conditions, supply chain dynamics, regulatory changes, and taxation policies significantly influence leasing decisions.

Existing studies often fail to fully integrate the complicated variety of parameters into a single decision-making framework. The lack of a holistic approach that includes the economic implications of adopting new, environmentally friendly technologies leaves airlines without the necessary tools to make fully informed leasing decisions.

In the next sections, this research addresses this gap by developing an integrated approach that synthesises these diverse factors into a cohesive methodology. By incorporating operational modelling and sensitivity analysis, the study evaluates the robustness of the optimal solutions under varying conditions, ensuring that airlines can adapt to changes in market dynamics, regulatory requirements, and technological advancements. This methodological framework provides airlines with managerial insights for aligning leasing decisions with airline's long-term sustainability goals. However, it should be highlighted straightaway that the effectiveness of the suggested approach is contingent on the availability and accuracy of data, and future research should be done on refining these models to enhance their predictive power and applicability across different market scenarios.

3. Modelling for aircraft leasing decisions

To comprehensively address various factors described above and optimise aircraft leasing decisions under conditions of uncertainty, numerous authors recommend utilising modelling as an effective and well-developed tool. Modelling often involves managing budgets for aircraft acquisition and leasing, with the aim of minimising the costs associated with purchase, lease, and maintenance. Operational efficiency is another critical focus, with factors such as aircraft emission rates, fuel costs, and route demands driving fleet size and composition decisions. Strategically, airlines must decide whether to buy, lease, or sell aircraft based on market conditions, demand forecasts, and regulations such as emission charges and noise constraints. Advanced mathematical models, including integer or dynamic programming and stochastic modelling, are frequently employed to optimise these decisions, ensuring that airlines achieve a balance between profitability and sustainability. A review of academic approaches shows that modelling and sensitivity analysis can aid airlines in strategic planning by integrating operational needs with long-term financial and environmental objectives. Additionally, the continuous review and updates of key elements within these models are essential due to the evolving nature of financial practices and market conditions. Below, an analysis of the principal themes in aircraft leasing modelling is provided.

A widely used approach to assessing leasing decisions incorporates the *fleet planning problem*, which in turn may include the sub-task of assigning aircraft to routes based on numerous operational parameters (Grosche, 2009; Carreira et al., 2017; Cadarso & Celis, 2017; Sa et al., 2020; Xu et al., 2021; Şafak et al., 2022; Liu et al., 2023; Hsu, Li, Liu & Chao, 2011; Repko & Santos, 2017). Khoo and Teoh (2014), considering a problem of aircraft acquisition, highlighted that the initial approach in addressing aviation-related environmental issues is to contemplate adopting a green fleet that generates minimal pollution and environmental impact. With a green fleet in place, airlines can subsequently enhance their operational strategies to further reduce their ecological footprint. Therefore, the authors consider *green* parameters, such as green emission index (GEI), green noise index, green fuel efficiency index, in addition to the standard features for aircraft acquisition. Liu et al. (2023) also incorporate aircraft fuel-efficiency as a key factor in the fleet-assignment model, where the number of specific aircraft type to be leased from other airline companies in certain scenario is one of the decision variables.

Chen et al. (2018) conducted a review of published models for aircraft leasing decisions, proposing a model to determine the optimal number of aircraft to be acquired through operating leases, capital leases, and purchases, as well as making decisions about the terms of leases and/or loans. This research was further developed with attempt to incorporate new factors such as the requirements of IFRS 16 and expected aircraft demand (Chen & Wu, 2023). These proposed models are focusing more on optimal investment decision without considering existing fleet of airline.

In the proposed model by Oum (2000), which is based on several differential levels, the features of individual airlines and aircraft fleets are not considered. The demand for transportation is incorporated into the model through a normal distribution of demand growth in the region. This is a rather generalised theoretical assumption that requires adjustments based on actual data. The calculations to validate the model were conducted using data from 1993, so it would be beneficial to test how well the proposed approach remains valid under the current market conditions.

In the approaches of Grosche (2009) and Xu (2021), the efficiency of the leased fleet is reflected through operating costs. It is worth noting, however, that their models do not address capital costs, which are usually key in investment decisions.

The linear programming model by Bazargan and Hartman (2012) is specifically tailored to the aircraft leasing problem and includes decision-making based on the costs of operating owned and leased aircraft fleets. All other costs were compiled by the researchers from various sources as ready input data for the model. The results indicated that short-term leasing of new aircraft was more advantageous for airlines than purchasing them outright. The authors seem to have reached a logical conclusion, as the objective function included the parameter 'Unit purchase price for aircraft of fleet type k'. For leased aircraft, this parameter represented the leasing cost during the leasing period. It is evident that the shorter the lease term, the lower the total cost of operating the aircraft, leading the model to favour aircraft with the minimum lease period as the optimal solution. Therefore, it may be worthwhile to explore alternative approaches to setting parameters that reflect capital investments, such as the costs associated with acquiring aircraft. For instance, in a stochastic mixed-integer optimisation model suggested by Carreira et al. (2017), the objective function includes parameters like the discounted investment cost of a specific aircraft type *per year*, facilitating comparison with leasing annual costs.

The developed fleet planning models vary in terms of parameter detail; however, the main ones can be identified as follows: *aircraft capacity and fuel consumption, aircraft purchasing or leasing costs, aircraft operational costs, and demand*. Most models incorporate sets of airline routes and aircraft types within the existing or newly acquired fleet through purchase or leasing agreements. The reviewed models primarily focus on optimising this process, simplifying the complex fleet financing issue to merely introducing a 'leasing costs' parameter (see Appendix B). Furthermore, while some authors focus on financial leasing, others are limited to operating leasing.

Guzhva et al. (2019), Vasigh et al. (2020), and Morrell (2021) advocate for an *investment appraisal* approach to aircraft acquisition decisions, often referred to as *lease versus buy decision*. They explain that planning an airline's fleet typically centres on financing non-current assets using either owned or borrowed capital. A critical question in financial management is identifying the most suitable financing option, considering current conditions and future projections. The selection of a particular option is influenced by the following factors:

- Sufficiency of own financial resources to support the economic development of the airline in the upcoming period.
- The cost of a long-term financial loan compared to the level of profit achievable from investments in new aircraft.
- The achieved ratio of own to borrowed capital, which influences the airline's financial stability.
- The availability of long-term financial credit to the airline.

The essence of the lease versus buy decision is to determine the minimum cost of financing the aircraft, whether through its purchase or lease. This includes looking at the *present value costs* of both options using a discount rate that reflects the cost of capital or borrowing (European Central Bank n.d). If a lessee decides to lease the aircraft, the relevant cash flows for evaluation is the *lease payment* for the lease and *potential tax benefits*. For buyers, cash flows include *loan payments, tax benefits from interest and depreciation*, and the *expected residual value of the aircraft* at the end of the lease or its life, that is a significant factor. If the aircraft is expected to retain a substantial portion of its value, purchasing might be more advantageous. This calculation influences whether the after-tax cash flow from selling the purchased aircraft will be beneficial compared to the costs associated with leasing. Buying allows for *depreciation benefits* and *deductions on interest expenses* if the purchase is financed.

The final step in decision making is to compare the present value of purchase cost versus the present value of leasing cost:

$$NAL = PV_{purchase\ cost} - PV_{lease\ cost} \tag{1}$$

If the present value of leasing cost ($PV_{lease\ cost}$) is lower than the present value of purchase cost ($PV_{purchase\ cost}$), then there is a *net advantage to leasing* ($NAL > 0$), and therefore leasing is preferred to purchase. If the present value of purchase cost is lower than the present value of leasing ($NAL < 0$), purchasing is preferred.

It is worth noting that when using the *NAL* to determine whether leasing or purchasing is more advantageous, the threshold value of 0 is standard because it indicates the point of indifference where both options have equal financial impact. However, it is acceptable to incorporate a specific threshold value instead of 0 to account for various factors such as risk, cost of capital, or a required rate of return expressed in monetary terms.

The adjusted *NAL* criteria can then be expressed as: if $NAL > \varphi$, leasing is more advantageous than purchasing, where φ is the adjusted threshold based on the identified advantageous factors; if $NAL < \varphi$, purchasing is more advantageous than leasing; if $NAL = \varphi$, both options are equally advantageous.

Investment appraisal approach typically concentrate on new acquisitions without sufficiently addressing strategies for integrating new resources with an airline's existing fleet. Future research could greatly benefit from the development of integrated approach that perform more detailed analyses of how different aircraft types operate and are financed under various operational and regulatory scenarios.

4. Modelling for aircraft leasing decisions: integrated assessment

4.1. Integrated approach

The *integrated approach* to assessing the economic efficiency of aircraft leasing for airline can involve considering various objectives and strategies related to fleet operations. These include meeting air transportation demands, rational utilisation of resources, including financial, increasing fleet productivity through optimal aircraft allocation, ensuring compliance with operational standards, and other relevant factors influenced by specific business, operational, and legal conditions.

The idea of the integrated assessment of aircraft leasing is depicted in Fig. 2.

As stated in the Section 3, the literature review confirms that financial leasing can be reasonably compared to credit purchases. Therefore, in Fig. 2, they are combined into one block titled *comparative assessment* of leasing efficiency. The integrated approach encompasses not only a comparative evaluation, deemed essential for aircraft leasing, but also an assessment achieved through modelling the entire airline's aircraft fleet. The latter sub-problem is inherently complex due to the multitude of parameters involved, necessitating their prediction and justified assessment. Since methodologies for comparative assessment of airline fleet are extensively covered in the literature (Guzhva et al., 2019; Vasigh et al., 2020; Morrell, 2021), the focus hereafter is on operational modelling of leased aircraft within the existing fleet and the projected network of routes.

Fig. 3 provides a simplified representation of the complex modelling process, which involves analysing actual data and forecasting parameters.

In practice, airlines constantly need to adjust their existing fleet due to current and future financial conditions, the availability of financial

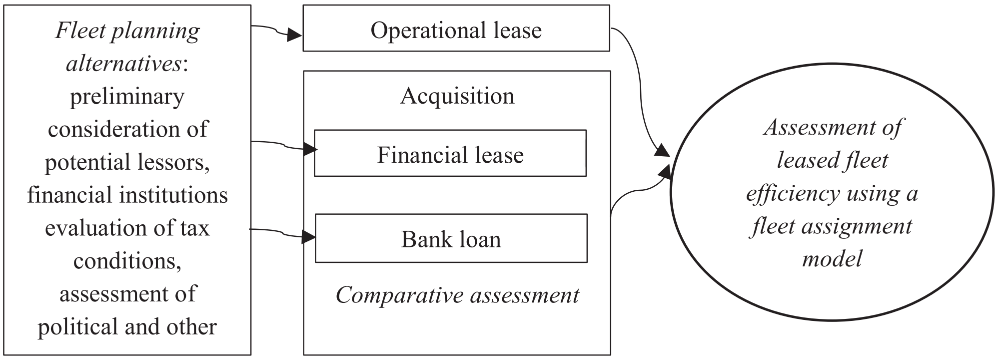


Fig. 2. Integrated approach to aircraft leasing assessment.

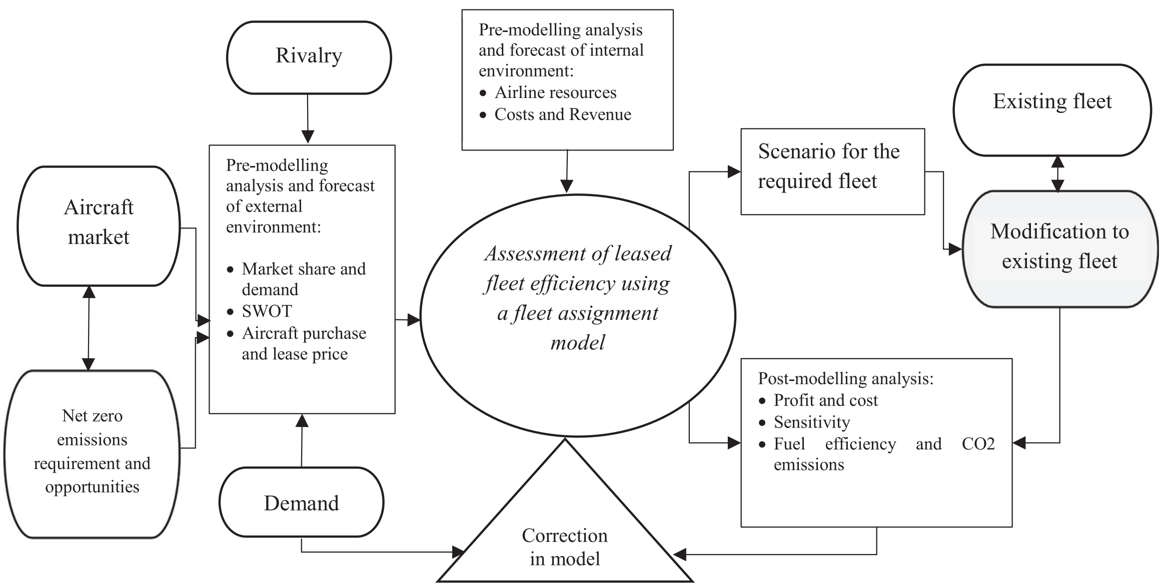


Fig. 3. Interplay of analysis, forecasting, and modelling procedures within the integrated approach to assessing aircraft leasing efficiency.

resources for acquiring new aircraft, competition in the air transportation market, and the unstable nature of the operational (internal and external) environment. Most reviewed models (see Appendix B) primarily focus on a deterministic representation of all input data for practical implementation, or they introduce probability distribution functions for the parameters. This implies that parameter values are determined unambiguously. It also reflects that in real conditions, decision-makers often accept some level of uncertainty.

After analysing the market share and the airline's operating environment and having gathered all the data on the existing fleet, aircraft leasing modelling can be conducted. This includes developing and testing the model, finding the optimal solution, and analysing the sensitivity and stability of the solution to assess risks associated with the developed scenario. Thus, the effect of leasing an aircraft can be assessed across the set of feasible combinations of its utilisation within the dynamic structure of the airline fleet based on economic criteria.

The relative accuracy of modelling results depends not only on the chosen mathematical tool but also on the ability to analyse and forecast all planning components with sufficient precision. It is recommended to include the following key parameters in the modelling process: variety of aircraft types, demand, discount rate, operational and leasing costs, airline network, and fare policies.

The assessment model for leased fleet efficiency described below will derive the growth of passenger demand from a specialised passenger forecast model. This model estimates the need for air travel, which in turn influences the mix of aircraft required to meet this demand effectively, considering factors such as fuel efficiency and emission standards. The suggested concept adopts a similar approach to that used in the DfT Aviation Fleet Mix Model, which does not inherently include future growth in demand (Department for Transport, 2022; Ricardo Energy & Environment, 2017).

The proposed model also suggests that the fuel efficiency of aircraft or the efficiency of new technologies will be reflected in the forecast of operational costs for a flight performed by a specific aircraft from a range of possible options. Parameters that reflect leasing payments are also be included in the operational costs of the flight, depending on the type of aircraft. One-time payments associated with acquiring an aircraft on lease should be considered separately to verify the constraints on the allocated investment budget for the planning period.

4.2. Problem statement for modelling

At the start of the planning period $t = 1$, the airline operates a fleet, designated as $A_0 = \{1, \dots, M_0\}$, each aircraft of which has well-known technical and economic specifications. Using *comparative assessment*, specific aircraft or sets of aircraft (L) are identified for which $NAL > 0$ (refer to equation (1)), indicating that leasing is considered economically efficient and meets the necessary conditions for leasing. The fleet may be renewed or supplemented with an identified set of leased aircraft during the sub-period $t \in [1, T]$, where T is the planning horizon of the project. Thus, the initial fleet A_t at the start of each sub-period

$t = 1, 2, .., T$ can be expressed as:

$$A_t = M_0 - \sum_{t=1}^{t} M_t + \sum_{t=1}^{t} L_t - \sum_{t=1}^{t-1} Q_t \text{ for } t = \overline{1,T} \tag{2}$$

where

M_t is the set of aircraft that are retired from the fleet in the sub-period t, for $t = \overline{1,T}$,

L_t is the set of aircraft that airline is considering for lease in the sub-period t, for $t = \overline{1,T}$,

Q_t is the set of aircraft for which the leasing agreement expired in the sub-period t, for $t = \overline{1,T}$.

4.3. Objective function and decision-making constraints

The problem involves forming an optimal aircraft fleet composition for the period $[1, T]$, taking into account the dynamics of decommissioning individual aircraft from the set Q_t and replenishing it with aircraft from the set L_t. This should be done while considering the type of leasing, lease terms, and other leasing conditions, as well as the residual value of the fleet, in order to maximise its net present value (NPV_L):

$$NPV_L = \sum_{t=1}^{T} \left(1 + r_t\right)^{-t} \left\{ \sum_{i=1}^{A_t} \sum_{j=1}^{n_t} \left(\tau_{jt} k_{ij} N_i - c_{ijt}\right) x_{ijt} - \sum_{i=1}^{A_t} C_i \left(\zeta_{duty} + \zeta_{VAT} + \zeta_i^{deposit}\right) y_{it} \right\} \to max \tag{3}$$

where:

- i, j, t are indices for aircraft registry number, airline route, and sub-period (season), respectively;
- n_t is the number of airline routes in the network for the sub-period t;
- r_t is the discount rate for the sub-period t;
- $\boldsymbol{x_{ijt}}$ is a decision variable representing the number of flights conducted by aircraft *i,* on airline route *j,* during sub-period *t*;
- $\boldsymbol{y_{it}}$ is a binary decision variable, where 1 indicates that the aircraft is assigned to the routes, and 0 otherwise for all $i \in L$;
- τ_{jt} is the average ticket price on route j during the sub-period t;
- k_{ij} is the average seat load factor for aircraft i on route j;
- N_i is the seating capacity of aircraft i;
- c_{ijt} is the operating costs per flight for aircraft i on route j for the sub-period t;
- $\zeta_i^{deposit}$ is the security deposit rate for all aircraft $i \in L$ used to determine the initial payment that lessee must make at the start of the lease;
- C_i is the leased aircraft acquisition cost – the initial purchase price of aircraft $i \in L$;
- ζ_{duty} and ζ_{VAT} denote the customs duty rate and the VAT rate, respectively.

For aircraft $i \in L$ operating on route j during sub-period t, the operating costs (c_{ijt}), are influenced by the leasing payments, $\varepsilon_{it}(C_i, \Delta_i, A_{it}, \psi_{it}, B_{it}, p_{it})$. This relationship presupposes that the operational and initial expenses are directly tied to leasing conditions and payments, which are influenced by several factors:

- Aircraft acquisition cost (C_i).
- Governmental or industrial incentives (Δ_i). These may include tax breaks or subsidies linked to the aircraft's environmental performance metrics, such as fuel efficiency, emissions levels, noise levels, and the utilisation of sustainable technologies.
- Right-of-use costs that encompass depreciation of the aircraft (A_{it}), interest on the lease liability (ψ_{it}), lessor charges (B_{it}), and aircraft insurance payments (p_{it}) during the sub-period t.

Aircraft leasing conditions and operations impose several constraints on the decision-making range. Each of these operational constraints can be expressed through the following mathematical expressions, providing a precise framework for decision-making and strategic planning:

1. The projected unconstrained passenger demand for transportation should be met within the economic benefits for the airline:

$$\sum_{i=1}^{A_t} k_{ij} N_i x_{ijt} \le d_{jt}, \ j = \overline{1, n_t}; \ t = \overline{1,T}, \tag{4}$$

where d_{jt} is unconstrained passenger demand for transportation on route j for the sub-period t.

2. The average frequency of flights per sub-period on an air route should not be below the minimum established for the expected demand (Das, Bardhan & Fageda, 2022; Hsu & Wen, 2003):

$$\sum_{i=1}^{A_t} x_{ijt} \ge v_{jt}, \ j = \overline{1, n_t}; \ t = \overline{1,T}, \tag{5}$$

where v_{jt} is minimum frequency of flights in the sub-period t.

3. Fleet capacity limitations per sub-period, based on existing and newly leased aircraft. The flight hours of each aircraft in a sub-period cannot exceed the upper limit of flight hours that an aircraft is allowed to operate under regulatory and safety standards. The annual flight hours could be determined depending on the aircraft model and an expected life span (JETechnology Staff, 2021; FAA, 2016):

$$\sum_{j=1}^{n_t} h_{ij} x_{ijt} \le H_{it}, \ i = \overline{1, A_t}; \ t = \overline{1,T}, \tag{6}$$

where H_{it} is the upper limit of flight hours that an aircraft i is allowed to operate under regulatory and safety standards in the sub-period t and h_{ij} is flight hours per flight for aircraft i on route j;

4. The airline's project budget must be sufficient to cover the initial costs of leasing (customs duties, VAT, security deposit, retraining costs, etc.):

$$\sum_{i \in A_t} C_i \left(\zeta_{duty} + \zeta_{VAT} + \zeta_i^{deposit}\right) y_{it} \le \mathrm{K}_t, \ \forall i \in L, \ t = \overline{1,T}, \tag{7}$$

where K_t is the amount of financial resources available to the airline for covering one-time payments in the sub-period t.

5. The duration of the project life cycle – from the initial expenditure to the last profit related to aircraft leasing – should not exceed the term of the planned period T:

$$\max\left(T_i\right) y_{it} \le T, \quad \forall i \in L, \tag{8}$$

where T_i is the lease expiry period for all leased aircraft.

6. The non-negativity constraint ensures that the number of flights x_{ijt} conducted by aircraft *i,* on airline route *j* during sub-period *t* is non-negative:

$$x_{ijt} \ge 0, \ i = \overline{1, A_t}; \ j = \overline{1, n_t}; \ t = \overline{1,T}. \tag{9}$$

7. The binary variable y_{it} is used to indicate whether a leased aircraft is assigned to a route, thereby incorporating the fixed costs associated with this aircraft into the objective function and constraint (7). To ensure that y_{it} equals 1 when a nonzero number of flights conducted by aircraft *i,* on route *j,* a forcing constraint is employed:

$$x_{ijt} \le M y_{it}, \ \forall i \in L; \ j = \overline{1, n_t}; \ t = \overline{1,T}, \tag{10}$$

where the coefficient M is a large number that limits the value of x_{ijt}.

8. The number of flights x_{ijt} must be an integer value ($\mathbb{Z}$), reflecting real-world conditions where fractional flights are not possible:

$$x_{ijt} \in \mathbb{Z}, \ i = \overline{1, A_t}; j = \overline{1, n_t}; \ t = \overline{1,T}. \tag{11}$$

9. The binary variable y_{it} indicates whether aircraft $i \in L$ is assigned to routes in sub-period t (1 if assigned, 0 otherwise):

$$y_{it} \in \{0,\ 1\},;\ \forall i \in L,\ t = \overline{1,T} \tag{12}$$

In general, the model (3)-(12) represent a dynamic problem of linear integer programming (LIP). The problem of assessing the efficiency of aircraft leasing can be reduced to a decision-making problem regarding the number of flights by type and quantity of leased aircraft in sub-period t for $t \in [1, T]$. By parameterising it with T_i, it can be reduced to a family of linear programming problems of small dimensionality (approximately $A_t \times n_t \times T$ variables and T constraints), which can be numerically implemented using software for LIP, such as LINGO (Lindo Systems, Inc., n.d.).

It is worth noting that the found value of NPV_L is not yet a final estimate of the efficiency of leasing the aircraft, as it includes the effect that existed before the start of leasing the aircraft fleet. The following formula can be utilised to determine the 'net' impact, specifically attributable to leasing:

$$\textit{Net Leasing Effect} = NPV_L - \sum_{t=1}^{T_i} \left(1 + r_t\right)^{-t} C^{RV}_{i\in L}\left(C_i,\ T,\ T_i,\ A_{it}\right) - NPV_0 \tag{13}$$

where NPV_0 is the net present value from the operation of the aircraft fleet without considering the aircraft leased.

$C^{RV}_{i\in l}$ is residual value of the aircraft i at the period T_i in the case of financial leasing.

4.4. Sensitivity analysis

Sensitivity analysis can be used to improve understanding of how the model works and to verify its correctness before data collection for a real project begins (Borgonovo, 2017; Ohsaki & Ikeda, 2007). By assessing how changes in model parameters affect the optimal solution, sensitivity analysis also enables airlines and lessors to anticipate potential issues and adjust their strategies accordingly (Allonen, 2013; Jackson, Pascual, Mac Cawley, & Godoy, 2023). This process mitigates risks associated with parameter uncertainty and ensures more resilient and adaptable operational plans.

The challenge is that in integer linear programming, which is the class of the problem described by model (3)-(12), the concept of sensitivity analysis differs from continuous linear programming due to the discrete nature of decision variables (Jensen, 1968). While traditional shadow prices are not directly applicable, several techniques can be employed to understand the robustness of ILP solutions under varying parameters (Dawand & Hooker, 2000). The simplest approach to sensitivity analysis for integer programming often involves examining how changes in the parameters of the problem (such as the coefficients in the objective function or the right-hand side of the constraints) affect the optimal solution (Jabarnejad, 2018). The sensitivity analysis can start with considering the range of optimality, which defines the span of values over which an objective function coefficient can vary without altering the optimal decision variables. This ensures that the solution remains optimal within specified limits, providing stability against parameter fluctuations, such as r_t, τ_{jt}, k_{ij}, $c_{ijt}(\varepsilon_{it})$. For right-hand side values (d_{jt}, h_{ij}, H_{it}, v_{jt}, K_t), sensitivity analysis investigates the implications of constraints volatility. By incrementing these values, it is possible to identify the new optimal point and the corresponding objective function value (NPV_L), thereby evaluating the robustness of the solution. Although this technique is computationally expensive, it provides insight how minor changes can influence the feasibility and optimality of the solution.

5. Validation of the (3)-(12) model on a hypothetical scenario

To demonstrate the application of model (3)-(12), calculations were conducted using data approximating real conditions. All necessary input parameters for the model were calculated based on the CAPA, RDC Apex, and Cirium SRS Analyser databases (Coventry University licences) and are presented in Appendix C. Specifically, data on the technical and economic characteristics and the cost of a single round trip were obtained and calculated using the RDC Apex-Route Performance application, average route fares were generated based on Cirium SRS Analyser data, and demand was approximately estimated based on Cirium and CAPA data.

It was assumed in the scenario t=1 that a hypothetical airline at the beginning of the planning period operates ten routes from Warsaw Chopin Airport (WAW) (refer to Table C.1 for route input data). Airline fleet consists of leased B737-700 and B737-800. In the scenario, the airline has the option, during period $t = 1$, to choose the following aircraft for which $NAL > 0$: B737Max8 or A321-200N. The necessary technical and economic fleet specification is presented in Table C.2. In the scenario, the initial fixed leasing payment for the A321-200N is 2.4% higher compared to the B737MAX8.

The pre-modelling assessment (see Tables C.3-C.7, Fig.4) provides several preliminary insights. Calculations based on the RDC Apex dataset for the simulated route network show that the B737-700 and B737-800 have higher average operating costs excluding fuel and leasing payments (66.24% and 66.29% of total operating costs, respectively) compared to the A321-200N (59.97%) and slightly higher compared to the B737 MAX 8 (63.79%) (refer to Fig.4(a)). The B737 MAX 8 has average fuel costs that are 2.07% lower than the A321-200N (17.73% compared to 19.80% of total operating costs), indicating that newer aircraft models are indeed more fuel-efficient and have significantly lower fuel costs compared to the B737-700 (27.50%) and B737-800 (22.08%). However, the right-of-use costs are significantly higher for the B737 MAX 8 (16.43%) and A321-200N (18.00%) compared to the B737-700 (5.58%) and B737-800 (10.37%). Both the B737 MAX 8 and A321-200N have higher insurance payments (2.05% and 2.23% of total costs, respectively) compared to the B737-700 (0.68%) and B737-800 (1.26%).

Fig. 4(b) shows the average absolute values of cost components per flight. In summary, the B737MAX 8 is the most fuel-efficient with the lowest fuel costs per flight; however, it has the highest operating costs excluding fuel and leasing payments. The B737-700 has the lowest total operating costs.

As evident from the brief analysis above, despite the comprehensive cost evaluation and future projections, it remains very difficult to decide regarding the fleet composition without a holistic vision and simulating the functioning of the fleet for the planned period.

The scenario t=1 was simulated using the fleet assignment model (3)-(12), which was recorded with special syntax and ran in Lingo (see Fig. C.1). Presented in Fig.C.2 and Table 4 simulation results show that, considering all constraints, the optimal decision can be obtained by operating three aircraft: B-737-700 (a total of 22 flights), B737-800 (350 flights), and A321-200N (450 flights). Thus, for t=1, it is recommended to lease the A321-200N. The maximum forecasted NPV_L, considering the discount rate, will be:

$$NPV_L = \frac{13321}{(1 + 0.0375)} = 12839.52\ \textit{thousand GBP}$$

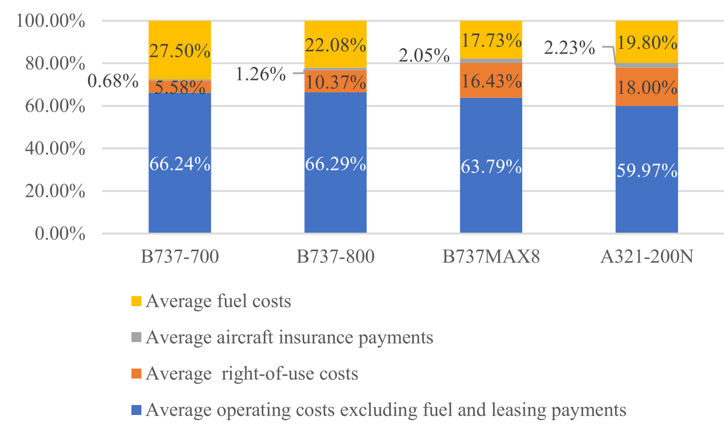
Running model (3)-(12) with A_0 and applying the formula (13) the airline can assess the $\textit{Net Leasing Effect}$, which for scenario t=1 will be:

$$12839.52 - \frac{12926}{(1 + 0.0375)} = 380.72\ \textit{thousand GBP}$$

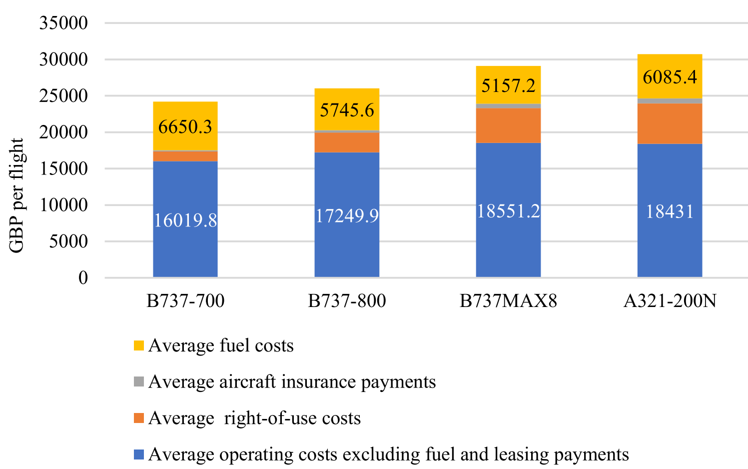
The $C^{RV}_{i\in l}$ was not accounted for as operating leasing was assumed.

The airline can then perform calculations using the proposed integrated assessment methodology for the entire planning period if T is greater than 1.

The sensitivity analysis based on key parameter variations reveals that changes in duty rates, VAT, and fuel costs significantly impact the optimal solution (refer to Table 5). Thus, increases in duty rates and VAT result in changes to the aircraft selection, with the recommended



a)



b)

Fig. 4. Cost distribution for key cost items of simulated fleet, scenario t=1: (a) in %, (b) in absolute value.

Table 4
Optimal fleet assignment for scenario t=1.

Number of flights, x_{ijt}	Route	WAW-AMS	WAW-ATH	WAW-BCN	WAW-CDG	WAW-FCO	WAW-FRA	WAW-IST	WAW-LHR	WAW-LTN	WAW-VIE	Total per aircraft
Aircraft	i/j	1	2	3	4	5	6	7	8	9	10	
B737-700	1	0	3	18	1	0	0	0	0	0	0	22
B737-800	2	0	32	84	89	100	4	30		9	2	350
B737Max8	3	0	0	0	0	0	0	0	0	0	0	0
A321-200N	4	72	0	0	0	3	58	2	100	111	56	402
	Total per route	72	35	102	90	103	62	32	100	120	58	

Table 5
Sensitivity analysis of the optimal solution for scenario t=1.

Parameter	Base value	Variation (%)	New value	Change in objective (%)	The optimal solution changes
ζ_{duty}	0%	+20	20%	-2.97	Y(B737_700)=1; Y(B737_800) =1 Y(B737MAX8) = 0; Y(A321_200N) = 0
ζ_{VAT}	0%	+5	5%	-2.97	Y(B737_700)=1; Y(B737_800) =1 Y(B737MAX8) = 0; Y(A321_200N) = 0
Fuel cost	See Table C.6 (a)	+20	See Table C.6 (b)	-5.63	Changes for x_{ijt} values only
Aircraft Insurance	See Table C.5 (a)	+20	See Table C.5 (b)	0	No changes in the optimal solution
Exclusion of B737-700 from the aircraft dataset	$i = 4$	n/a	$i = 3$	-0.44	Y(B737_800) =1; Y(B737MAX8) = 0 Y(A321_200N) = 1
d_{jt}	See Table C.1	-5	See table C.1	-5.19	Changes for x_{ijt} values only

optimal strategy in this case being to continue operating the current fleet, as maximum hourly utilisation does not appear to be a binding constraint. Increases in fuel costs lead to the inclusion of the A321-200N in the optimal solution. The exclusion of the B737-700 and changes in demand also result in changes to the optimal solution for x_{ijt}, indicating the solution sensitivity to these parameters. Conversely, variations in aircraft insurance costs did not affect the optimal solution.

6. Conclusion

Aircraft leasing, in all its diversity, remains an important financial tool for airline businesses, especially those operating on a low-cost model. This study has provided several novel insights into the complexities of the current aircraft leasing landscape, alongside an integrated approach to assessing leasing efficiency.

The study underscores that current stage of the aviation transportation and aircraft leasing market is characterised by significant volatility, with notable shifts in the contributing factors. Prior to 2020, demand was the primary source of unpredictability. However, the focus has now shifted to regulatory policies related to decarbonisation, ESG criteria, and green financing, which introduce considerable instability. This volatility in the transport sector is further compounded by political and jurisdictional risks, as well as the ambiguity surrounding the development of new technologies and design pathways for both aircraft and corresponding infrastructures. To address these uncertainties, the proposed integrated approach highlights the importance of integrating qualitative methods, such as SWOT analysis, for assessing leasing efficiency with a fleet assignment model.

A literature review also revealed that new financial accounting standards for aircraft leasing transactions do not significantly impact the business's operational component and leasing deal effectiveness. However, tax costs and anticipated changes in the international taxation system can significantly influence the financial sustainability of decision-making. The "tax" parameter must be carefully forecasted for use in the model's input data to obtain an adequate optimal solution.

Furthermore, the study suggests that integrated assessment methodologies can enhance strategic decision-making, allowing airlines to navigate the complexities of the current leasing landscape more effectively. When evaluating the efficiency of aircraft leasing, as evidenced by practical and academic publications, the criteria must reflect the investment nature of the transaction. Therefore, accurately forecasting the discount rate to bring cash flows to their present value is essential. The proposed integrated approach includes modelling of the leased aircraft fleet's operation within the existing fleet structure, aiding managers in making data-driven decisions regarding the actual efficiency (or inefficiency) of fleet replacement or modernisation by leased aircraft over the planned period.

This study proposes a straightforward ILP model that can be implemented using existing software products. From a practical perspective, costs ultimately determine business efficiency and the return on capital forecast, which is vital for investors. Moreover, sustainability requirements can be reflected through the operational cost. This task is further complicated by the high level of uncertainty, such as the costs associated with a new generation of aircraft or SAF.

In the simulation the integrated assessment of aircraft leasing efficiency for scenario t=1, which utilised the fleet assignment model (3)-(12) and was conducted in Lingo, the optimal fleet composition recommended leasing the A321-200N to the existing fleet of two aircraft: B737-700 and B737-800, when compared with the B737MAX 8. This recommendation is consistent with Bağcı and Kartal's (2024) findings using the COPRAS method, which ranked narrow-body passenger aircraft with the A321neo as the best option, followed by the B737 MAX 10, B737 MAX 9, A320neo, B737MAX8, A319neo, and B737MAX7. Furthermore, Kiracı and Akan (2020) highlight that the Airbus A321neo is the most suitable aircraft alternative for airline companies, primarily due to its technical, economic, and environmental performance. The second most suitable alternative identified was the B737MAX8. However, given the grounding of the B737MAX8 worldwide since March 2019, airlines must consider both performance and safety aspects in their fleet decisions (Kiracı & Akan, 2020).

Sensitivity analysis of the optimal solution contributes to understanding its robustness and the degree of risk and dependency on factors such as demand, taxes, and fuel price volatility. The findings highlight several managerial and policy implications. Airlines and lessors are recommended to focus on aligning their strategies with regulatory policies and sustainability goals. To mitigate environmental impact and align with decarbonisation objectives, airlines are encouraged to invest in new, fuel-efficient aircraft. Policymakers could develop clearer pathways to support investments in conscientious lessors and lessees who drive positive 'green' change, as this will more effectively address emerging challenges in achieving sustainability goals. These measures could include continuing tax reductions or exemptions for new low-emission aircraft types to help airlines maintain stability in aircraft leasing practices, given that variations in duty rates and VAT have a substantial impact on the optimal solution, as revealed in the simulation.

Despite the study's aim for comprehensiveness, several limitations are inherent. The model's accuracy is contingent on the reliability of the input data, which may be subject to fluctuations in economic conditions, regulatory changes, and technological advancements. Additionally, the study's provided a hypothetical scenario, which limits its immediate applicability to real-world settings without further validation. The exclusion of certain costs, such as those associated with unforeseen political or jurisdictional risks, may also affect the model's robustness.

Future research could aim to address these limitations by testing real-world data for airlines with various business models and exploring the impact of varying economic and political conditions on the model's outcomes. Enhancements to the model (3)-(12) could include further modification, for example, by using Bayesian Dynamic Programming for more accurate passenger demand forecasting (Xiao & Yang, 2021). Additionally, a constraint can be included to mathematically represent the risk of delays in the delivery of new aircraft. It is evident that the model can be adapted based on the specific constraints of individual airlines.

It is essential to highlight that the complexity of the mathematical modelling is not the primary concern in the proposed methodology, but rather the necessity of focusing on providing a detailed description of the problem parameters, particularly the expected cost components. Ultimately, the integrated approach should help airline to enhance strategic decision-making in aircraft leasing, enabling them to better navigate the complexities of the current aircraft leasing landscape, ensuring a resilient and adaptable approach to fleet management in an increasingly volatile market.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Kristina Marintseva: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Roxani Athousaki:** Writing – review & editing.

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Supplementary materials

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References

Şafak, Ö., Çavuş, Ö., & Aktürk, M. S. (2022). A two-stage decision dependent stochastic approach for airline flight network expansion. *Transportation Research Part B: Methodological, 158*, 78–101. https://doi.org/10.1016/j.trb.2022.02.003.

Allonen, M. (2013). *Master's thesis*. Aalto University School of Business, Department of Finance.

Athousaki (2020). *Airline Sustainability in a Liberalised Environment: Generating a Conceptual Framework with a Holistic Approach to Airline Sustainability*. Doctoral dissertation, Coventry University.

Bağcı, B., & Kartal, M. (2024). A combined multi-criteria model for aircraft selection problem in airlines. *Journal of Air Transport Management, 116*, Article 102566. https://doi.org/10.1016/j.jairtraman.2024.102566.

Bazargan, M., & Hartman, J. (2012). Aircraft replacement strategy: Model and analysis. *Journal of Air Transport Management, 25*, 26–29. https://doi.org/10.1016/j.jairtraman.2012.05.001.

BDO International Limited (2023). *IFRS 16 in Practice 2023-2024- IFRS 16 Leases.* https://www.bdo.global/getmedia/4b4c5f48-af18-4caa-b598-630ba9b937cf/IFRS-16-In-Practice-2023-2024.pdf?ext=.pdf.

Benson, J., et al., (2022). *Overall investment outlook for global aviation finance*. White&Case website https://www.whitecase.com/insight-our-thinking/overall-investment-outlook-global-aviation-finance-0.

Borgonovo, E. (2017). *Sensitivity Analysis An Introduction for the Management Scientist*: 2017 (1st ed).

Bourjade, S., Huc, R., & Muller-Vibes, C. (2017). Leasing and profitability: Empirical evidence from the airline industry. *Transportation Research Part A: Policy and Practice, 97*, 30–46.

Cadarso, L., & de Celis, R. (2017). Integrated airline planning: Robust update of scheduling and fleet balancing under demand uncertainty. *Transportation Research Part C: Emerging Technologies, 81*, 227–245. https://doi.org/10.1016/j.trc.2017.06.003.

CAPA. (2024). *Fleet Deliveries by Year. Aviation Data & Statistics Tools*. CAPA centreforaviation.com.

CAPA. (2024). *Avolon forecasts record passenger numbers and 1450 aircraft deliveries in 2024*.

CAPA. (2024a). *Airline Leader Summit - Airlines in Transition 2024*. Granada, Spain: CAPA Airline Leader Summit - Airlines in Transition 2024 | CAPA 7-8 March 2024centreforaviation.com.

CAPA, 2024b. Global Fleet by Lessor. On-line database: https://centreforaviation.com/data.

Carreira, J. S., Lulli, G., & Antunes, A. P. (2017). The airline long-haul fleet planning problem: The case of TAP service to/from Brazil. *European Journal of Operational Research, 263*(2), 639–651. https://doi.org/10.1016/j.ejor.2017.05.015.

Chen, W.-T., & Wu, C.-L. (2023). Aircraft acquisition optimization under demand and cost fluctuations: Before and after leasing standard changes. *Journal of Air Transport Management, 112*, Article 102453. https://doi.org/10.1016/j.jairtraman.2023.102453.

Chen, W.-T., Huang, K., & Ardiansyah, M. N. (2018). A mathematical programming model for aircraft leasing decisions. *Journal of Air Transport Management, 69*. https://doi.org/10.1016/j.jairtraman.2018.01.005.

Chu, C., Zhang, H., Zhang, J., Cong, L., & Lu, F. (2024). Assessing impacts of the Russia-Ukraine conflict on global air transportation: From the view of mass flight trajectories. *Journal of Air Transport Management, 115*, Article 102522. https://doi.org/10.1016/j.jairtraman.2023.102522.

Cirium, 9 February 2024, DEALS REPORT: Key takeaways from the Dublin air-finance gathering (cirium.com).

Council of the European Union. (2016). Council Directive (EU) 2016/1164 of 12 July 2016 laying down rules against tax avoidance practices that directly affect the functioning of the internal market. *Official Journal of the European Union*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32016L1164.

Danicourt, J., Harris, J., Papania, A., & Kim, A. (2023). *A realistic path to net-zero emissions for commercial aviation* , June 5. Bain & Company https://www.bain.com/insights/a-realistic-path-to-net-zero-emissions-for-commercial-aviation.

Das, A. K., Bardhan, A. K., & Fageda, X. (2022). What is driving the passenger demand on new regional air routes in India: A study using the gravity model. *Case Studies on Transport Policy, 10*(1), 637–646. https://doi.org/10.1016/j.cstp.2022.01.024.

Davies, H. (2023). Lessors mull sustainability challenges. *Airfinance Journal (Online)*.

Dawande, M. W., & Hooker, J. N. (2000). Inference-Based Sensitivity Analysis for Mixed Integer/Linear Programming. *Operations Research, 48*(4), 623–634. https://doi.org/10.1287/opre.48.4.623.12420.

Department for Transport. (2022). Jet Zero: modelling framework. https://assets.publishing.service.gov.uk/media/62384b518fa8f540f3202bd4/jet-zero-modelling-framework.pdf.

European Central Bank. (n.d.). Key ECB interest rates. https://www.ecb.europa.eu/stats/policy_and_exchange_rates/key_ecb_interest_rates/html/index.en.html.

European Commission. (2021). *Call for feedback by the Platform on Sustainable Finance on preliminary recommendations for technical screening criteria for the EU taxonomy*. European Commission Call for feedback by the Platform on Sustainable Finance on preliminary recommendations for technical screening criteria for the EU taxonomyeuropa.eu.

European Commission. (2022, October 31). Commission Delegated Regulation (EU) 2023/363 of 31 October 2022 amending and correcting the regulatory technical standards laid down in Delegated Regulation (EU) 2022/1288 as regards the content and presentation of information in relation to disclosures in pre-contractual documents and periodic reports for financial products investing in environmentally sustainable economic activities (Text with EEA relevance). C/2022/7545. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32023R0363.

FAA. (2016). *Advisory circular 120-104: Runway and Taxiway Surface Condition Assessment, Measurement, and Reporting* [PDF document]. Retrieved from https://www.faa.gov/documentLibrary/media/Advisory_Circular/120-104.pdf.

Georgilidakis, S. (April 7, 2022). Aircraft Insurance Costs Exploding After Russia's Actions. *Aircraft Insurance Costs Exploding After Russia's Actions - Mentour Pilot*.

Giddings, E. (2021). *Developing policies for green and sustainable finance for the aviation industry | Global law firm*. Norton Rose Fulbright.

Grosche, T. (2009). Integrated Airline Scheduling. 10.1007/978-3-540-89887-0_4.

Guzhva, V., Raghavan, Sunder, author, & D'Agostino, Damon J., author. (2019). Aircraft leasing and financing: Tools for success in international aircraft acquisition and management.

Halaby, M., Duc, C. P., Hutchinson, C. & Marrinan B. (n/d). Financing aviation decarbonisation. In *Environmental and Aviation Outlook*. ENVReport2022_Art9.pdf (icao.int).

Hallerstrom. (2020). Modelling Aircraft Loans & Leases. *Microsoft Word - Modeling Aircraft Loan & Lease Portfolios*. hallerstrom.com.

Holder, J., Benson, J., Andreeva, A., & Denman, H. (2022). *Aviation insurance and other claims arising out of Russian sanctions* , July 12. White & Case LLP https://www.whitecase.com.

Hsu, C.-I., & Wen, Y.-H. (2003). Determining flight frequencies on an airline network with demand–supply interactions. *Transportation Research Part E: Logistics and Transportation Review, 39*(6), 417–441. https://doi.org/10.1016/S1366-5545(02)00060-1.

Hsu, C.-I., Li, H.-C., Liu, S.-M., & Chao, C.-C. (2011). Aircraft replacement scheduling: A dynamic programming approach. *Transportation Research Part E: Logistics and Transportation Review, 47*(1), 41–60. https://doi.org/10.1016/j.tre.2010.07.006.

IASB (2016) Effects Analysis International Financial Reporting Standard https://www.ifrs.org/content/dam/ifrs/project/leases/ifrs/published-documents/ifrs16-effects-analysis.pdf.

IATA (2023). Net zero 2050: sustainable aviation fuels. https://www.iata.org/en/iata-repository/pressroom/fact-sheets/fact-sheet-alternative-fuels.

IATA (2024). Air Passenger Market Analysis. February 2024. https://www.iata.org/en/iata-repository/publications/economic-reports/air-passenger-market-analysis-february-2024/.

ICLG. (n.d.). United Kingdom: Aviation finance and leasing laws and regulations 2023. Retrieved from https://iclg.com/practice-areas/aviation-finance-and-leasing/united-kingdom.

IFRS (N/D). IFRS 16 Leases. https://www.ifrs.org/issued-standards/list-of-standards/ifrs-16-leases/#about.

International Airport Review (1 April, 2024). Talking passenger recovery and retail opportunities with SEA Milan Airports Talking passenger recovery and growth with SEA Milan Airports (internationalairportreview.com).

Ishka (March 2022). Aviation green and sustainable finance transactions to date. impact-on-sustainable-aviation.org/shared-files/426/?ESG-DS-Mar-15-2022-2.pdf.

Jabarnejad, M. (2018). Approximate optimal transmission switching. *Electric Power Systems Research, 161*, 1–7. https://doi.org/10.1016/j.epsr.2018.03.021.

Jackson, C., Pascual, R., Mac Cawley, A., & Godoy, S. (2023). Product-service system negotiation in aircraft lease contracts with option of disagreement. *Journal of Air Transport Management, 107*, Article 102343. https://doi.org/10.1016/j.jairtraman.2022.102343.

Jensen, R. E. (1968). Sensitivity Analysis and Integer Linear Programming. *The Accounting Review, 43*(3), 425–446.

JETechnology Staff. (2021). *What determines the life span of an airplane? What Determines the Life Span of an Airplane?*. JETechnology Solutions aircraftmaintenancestands.com.

Khoo, H. L., & Teoh, L. E. (2014). A bi-objective dynamic programming approach for airline green fleet planning. *Transportation Research Part D: Transport and Environment, 33*, 166–185. https://doi.org/10.1016/j.trd.2014.06.003.

Kiracı, K., & Akan, E. (2020). Aircraft selection by applying AHP and TOPSIS in interval type-2 fuzzy sets. *Journal of Air Transport Management, 89*, Article 101924. https://doi.org/10.1016/j.jairtraman.2020.101924.

KPMG. (2024). *Aviation report 2024.* Retrieved from https://assets.kpmg.com/content/dam/kpmg/ie/pdf/2024/01/ie-aviation-report-2024.pdf.

Li, J., Semenov, D., & Smyth, P. (2020). The Future of Aircraft Leasing Through Ireland. *Tax notes international* january 27, 2020The Future of Aircraft Leasing Through Ireland 2020ey.com.

Lindo Systems, Inc. (n.d.). LINGO and Optimization Modeling. Retrieved from https://www.lindo.com/index.php/products/lingo-and-optimization-modeling.

Liu, M., Ding, Y., Sun, L., Zhang, R., Dong, Y., Zhao, Z., Wang, Y., & Liu, C. (2023). Green Airline-Fleet Assignment with Uncertain Passenger Demand and Fuel Price. *Sustainability, 15*(2), 899. https://doi.org/10.3390/su15020899.

Margolis, J. D., & Walsh, J. P. (2003). Misery Loves Companies: Rethinking Social Initiatives by Business. *Administrative Science Quarterly, 48*(2), 268–305. https://doi.org/10.2307/3556659.

McKinsey & Company. (2022). *Decarbonizing aviation: Making net zero possible*. McKinsey.

McKinsey & Company. (2023). *Decarbonizing aviation: Executing on net-zero goals*. McKinsey.

Morrell, P. (2021). *Airline finance* (5th ed.).

NATO. (March 21, 2024). [Response to Russia's invasion of Ukraine]. Retrieved from https://www.nato.int/cps/en/natohq/topics_192648.htm.

Norton Rose Fulbright. (2021). *Developing policies for green and sustainable finance for the aviation industry: The EU Taxonomy Regulation. Developing policies for green and sustainable finance for the aviation industry | Global law firm*. Norton Rose Fulbright.

OECD. (n.d.). Multilateral Convention to Implement Tax Treaty Related Measures to Prevent BEPS. Retrieved from Multilateral Convention to Implement Tax Treaty Related Measures to Prevent BEPS - OECD.

OECD (n/d). What is BEPS? About - OECD BEPS.

Ohsaki, M., & Ikeda, K. (2007). *Stability and optimization of structures: generalized sensitivity analysis (Mechanical Engineering) (1. Aufl.)*. Springer-Verlag https://doi.org/10.1007/978-0-387-68184-9.

Oum, T. H., Zhang, A., & Zhang, Y. (2000). Optimal demand for operating lease of aircraft. *Transportation Research Part B: Methodological, 34*(1), 17–29. https://doi.org/10.1016/S0191-2615(99)00010-7.

Repko, M. G. J., & Santos, B. F. (2017). Scenario tree airline fleet planning for demand uncertainty. *Journal of Air Transport Management, 65*, 198–208. https://doi.org/10.1016/j.jairtraman.2017.06.010.

Ricardo Energy & Environment. (2017). A review of the DfT aviation fleet mix model. *Department for Transport*. https://assets.publishing.service.gov.uk/media/5a82d54640f0b6230269cf29/a-review-of-the-dft-aviation-fleet-mix-model.pdf.

RTTNews. (2021). *FAA halts Boeing MAX production expansion, to allow jets to resume flying* August 5. RTTNews https://www.rttnews.com/3419039/faa-halts-boeing-max-production-expansion-to-allow-jets-to-resume-flying.aspx?refresh = 1.

Sa, C. A. A., Santos, B. F., & Clarke, J.-P. B. (2020). Portfolio-based airline fleet planning under stochastic demand. *Omega, 97*, Article 102101. https://doi.org/10.1016/j.omega.2019.08.008.

Shaw-Smith, P. (2022). Chinese companies dominate Asia-Pac aircraft leasing space. *Aviation International News*. Retrieved from https://www.ainonline.com/aviation-news/air-transport/2022-02-12/chinese-companies-dominate-asia-pac-aircraft-leasing-space.

Sun, X., Zheng, C., Wandelt, S., & Zhang, A. (2024). Airline competition: A comprehensive review of recent research. *Journal of the Air Transport Research Society*, (2), Article 100013. https://doi.org/10.1016/j.jatrs.2024.100013.

Vasigh, B., & Rowe, Zane C. (2020). *Foundations of airline finance: Methodology and practice* (Third ed.). London: Routledge.

Wandelt, S., Antoniou, C., Birolini, S., Delahaye, D., Dresner, M., Fu, X., Gössling, S., Hong, S.-J., Odoni, A. R., Zanin, M., Zhang, A., Zhang, H., Zhang, Y., & Sun, X. (2024). Status quo and challenges in air transport management research. *Journal of the Air Transport Research Society*, (2), Article 100014. https://doi.org/10.1016/j.jatrs.2024.100014.

Wandelt, S., Sun, X., & Zhang, A. (2023). Is the aircraft leasing industry on the way to a perfect storm? Finding answers through a literature review and a discussion of challenges. *Journal of Air Transport Management, 111*. https://doi.org/10.1016/j.jairtraman.2023.102426.

Wang, X., Zhang, J., & Wandelt, S. (2023). On the ramifications of airspace bans in aero-political conflicts: Towards a country importance ranking. *Transport Policy, 137*, 1–13. https://doi.org/10.1016/j.tranpol.2023.04.003.

Wendel, L., Albers, S., & Dewulf, W. (2024). Creating architectural advantage in the airline industry: Strategic options for airlines to migrate value. *Journal of the Air Transport Research Society, 2*, Article 100002.

World Economic Forum. (2023). *Decarbonizing aviation: How can airlines and aircraft makers meet net-zero goals by 2050? Decarbonizing aviation: How can we meet net-zero by 2050?*. World Economic Forum weforum.org.

WTO. (n.d.). *Agreement on trade in civil aircraft*. Retrieved 05 May 2024 from https://www.wto.org/english/tratop_e/civair_e/civair_e.htm.

Xiao, B., & Yang, W. (2021). A Bayesian learning model for estimating unknown demand parameter in revenue management. *European Journal of Operational Research, 293*(1), 248–262. https://doi.org/10.1016/j.ejor.2020.11.049.

Xu, Y., Wandelt, S., & Sun, X. (2021). Airline integrated robust scheduling with a variable neighborhood search heuristic. *Transportation Research Part B: Methodological, 149*, 181–203. https://doi.org/10.1016/j.trb.2021.05.005.