Research on Carbon Offset Decision of Airlines under Mandatory Blending Policy of Sustainable Aviation Fuel

Lei Xu[1], Jirao Yu[2], Junwei Zhang[2] *

[1] School of Management and Economics, Civil Aviation University of China, Tianjin 300300, China
[2] School of Transportation Science and Engineering, Civil Aviation University of China, Tianjin 300300, China

*jwzhangts@163.com

Abstract. Against the backdrop of ICAO's long-term goal of achieving net-zero carbon emissions in international aviation by 2050, mandatory sustainable aviation fuel (SAF) blending policies and carbon trading mechanisms serve as vital tools for airlines' low-carbon transformation. This paper establishes a duopoly Stackelberg game model consisting of a leader airline and a follower airline with different fuel efficiency levels to analyze their carbon offset decisions under uniform and differentiated SAF blending mandates. It derives equilibrium solutions for optimal capacity, profit and carbon allowance surplus, and investigates the impacts of SAF blending ratios. Empirical results based on the Xuzhou–Guangzhou route operated by China Southern Airlines and Loong Air show that if leader airline mixes higher levels of SAF, their high SAF costs will severely compress profits and suppress capacity investment, while follower airline may seize the market through capacity expansion under high mandatory blending ratio policies, relying on its fuel efficiency advantage. Despite being constrained by high SAF usage costs, its profits are relatively less affected than leaders.

Keywords: Sustainable aviation fuel; Mandatory blending policy for sustainable aviation fuels; Carbon offset.

1 Introduction

Against the backdrop of global climate change, carbon emissions constraints in the aviation industry are becoming increasingly stringent. The International Civil Aviation Organization (ICAO) has proposed the goal of "net zero carbon emissions from international aviation by 2050", while policies such as the EU ReFuelEU aviation regulations mandate an increase in the proportion of SAF blending. China has also introduced the "dual carbon" goal and a special plan for green development in civil aviation, and pilot applications of SAF are gradually being promoted. SAF and carbon trading mechanisms have become the core means of emission reduction in the aviation industry, but SAF faces problems such as high costs and insufficient supply. In the duopoly airline market, there are differences in fuel consumption efficiency and market position

T. G. Guan et al. (eds.), *Proceedings of the 2026 4th International Conference on Digital Economy and Management Science (CDEMS 2026)*, Advances in Economics, Business and Management Research 392,
https://doi.org/10.2991/978-94-6239-699-9_22

between leader and follower airlines. Specifically, leader airlines have a large market share, high carbon emissions, and relatively low aircraft fuel consumption efficiency, while follower airlines have a small market share, low carbon emissions, and relatively high aircraft fuel consumption efficiency. Faced with unified or differentiated mandatory blending policies for SAF, airlines' capacity investment and carbon offset strategies are affected by carbon prices and SAF mandatory blending ratios, and there is an urgent need to conduct a systematic analysis from a competitive game perspective.

Therefore, this paper constructs a carbon offset decision model for airlines under the policy of uniform and differential SAF mandatory blending ratios, and studies the following issues:

(1) Based on Stackelberg game theory, analyze the equilibrium solutions of optimal capacity and profit for airlines under two types of policies, and explore the optimal decisions of airlines in capacity adjustment.

(2) Taking the "Xuzhou Guangzhou" route as a case study, this paper compares the optimal carbon offset strategy of airlines with the relationship between carbon price and SAF mandatory blending ratio under two policies through numerical simulation, providing reference for airline operation optimization and policy formulation.

2 Literature Review

At present, most research on the civil aviation industry under the carbon market trading mechanism focuses on the EU Emissions Trading System. CE Delft (2005) evaluated the geographical coverage of airlines, including flight types, quota allocation and compliance, monitoring and accounting data, to study the quality impact of policy choices made to include aviation in the EU Emissions Trading System[1]. Albers et al. (2009) conducted a route based analysis based on the European Commission's recommendation to include the aviation industry in the European Emissions Trading Scheme, simulating the impact on the costs and demand of selected airlines[2].

The technological iteration, economic optimization, and policy adaptation of SAF, as well as the practical path and effectiveness evaluation of carbon offsetting for airlines, together constitute the core research topics of low-carbon transformation in the civil aviation industry. In SAF related research, Watson et al. (2024) compared five technical routes, FT-SPK and HEFA-SPK, and found that the HEFA route has become the current main commercialization route due to stable raw material supply and significant cost advantages, while the FT route demonstrates long-term potential with nearly 92% emission reduction efficiency, and the HFS-SIP route is temporarily difficult to scale up due to raw material and cost issues[3]; Chen et al. (2023) pointed out that the promotion of SAF can effectively reduce the peak carbon emissions of the industry by constructing a market-oriented emission reduction framework, and with policy guidance, a 23.7% reduction in emissions can be achieved[4]; Dodd and Yengin (2021) reveal the interest deadlock between airlines, manufacturers, and governments, emphasizing that policy interventions such as government subsidies and tax credits are key to breaking the cost bottleneck of SAF[5]; Martinez Valencia et al. (2023) proposed a policy superposition effect, stating that the combination of SAF blended fuel tax credits and local support programs can significantly reduce the minimum selling price and increase producer motivation[6]; Cui et al. (2024) studied the African market and found that an increase in SAF blending ratio is positively correlated with cost increases, requiring an average annual government subsidy of over 3.7 billion US dollars to ensure promotion[7]; Jiang and Liu's (2025) economic model suggests that a sufficiently large SAF tax credit can increase airline profits, but it needs to balance the risk of emission rebound caused by traffic growth[8].

In research related to carbon offsetting, Cordes et al. (2023) found that there are significant regional differences in passengers' willingness to pay for carbon offsetting, which are significantly influenced by moral identity and information transparency. There is a significant gap between attitudes and behaviors[9]; Baumeister (2017) emphasized that there are significant differences in carbon emissions between routes in different geographical markets, and it is necessary to refine carbon footprint calculations to improve the accuracy of offsetting[10].

In summary, few have analyzed the carbon offsetting strategies of airlines under the constraints of carbon trading mechanisms and sustainable aviation fuel regulations. Therefore, this paper studies a duopoly monopoly airline market and designs two carbon offset models for airlines under the mandatory blending ratio policy of SAF. Specifically, we explore the impact of different SAF mandatory blending ratio policies on the carbon offset decisions of two airlines by comparing their optimal capacity inputs and profits under different models.

3 Problem Description and Model Construction

This section considers the competing airlines in a single OD route market: the leader airline and the follower airline, both of which develop market competition strategies with the goal of maximizing profits. The focus of this article is on the impact of the mandatory blending ratio policy for sustainable aviation fuel, which has a direct effect on the fuel costs of airlines. Therefore, in order to simplify the model specification and obtain more accurate economic insights, this article normalizes other non fuel operating costs to 0. Without loss of generality, this chapter assumes:

Referring to the research of Huang (2013), this article assumes that the inverse demand functions of the leader airline 1 and follower airline 2 are: $p_1 = a - q_1 + \beta q_2$, $p_2 = 1 - a - q_2 + \beta q_1$, a is the market size of the leading airline, β represents the sensitivity coefficient between unit capacity price and capacity investment, and q_i is the capacity investment of airline $i (i = 1,2)$ in the passenger transport market. This article assumes that an airline operating in a certain airline market receives a free initial quota of E_i allocated by the government, $E_i = mq_i$, m is the benchmark carbon emissions of the aircraft model used on this route.

When the aircraft fully uses traditional aviation fuel (TAF), the unit carbon dioxide emissions of airline i in the market of this route are e_i^t. The unit carbon dioxide emissions are related to factors such as aircraft type, age, and operation, so there are $e_1^t > e_2^t$.The unit operating cost of airlines based on traditional aviation fuel is c_i^t. When the aircraft fully uses SAF, the unit carbon dioxide emissions of airline i in the market of this route are e_i^s, $e_1^s > e_2^s$.

Follower airlines have a fuel efficiency advantage (i.e. fuel consumption advantage per ton kilometer), represented by δ, $\delta \in (0,1]$, compared to leader airlines. The smaller the coefficient, the greater the fuel efficiency. According to the International Civil Aviation Organization Carbon Emission Calculation Method 13.1, there is a linear relationship between the carbon emissions per passenger and the quality of fuel consumption; Therefore, the fuel advantage is also reflected in the unit carbon emissions and fuel based unit operating costs, such as $e_2^t = \delta e_1^t$, $c_2^t = \delta c_1^t$.

Under the mandatory blending ratio policy of SAF, airlines are required to blend SAF in uniform or differential ratios. Under the unified blending ratio policy, the SAF blending ratio of the two airlines is θ, while under the differential blending ratio policy, the SAF blending ratios of the two airlines are θ_1 and θ_2.

(1) Airline carbon offset model under the unified SAF mandatory blending ratio policy

In this model, leader airline 1 and follower airline 2 make capacity decisions, and the expected revenue of the airlines is as follows. u represents the case of uniform SAF blending ratio, and d represents the case of different SAF blending ratios The optimization problem in this case is:

$$maxE[\pi_{1u}(q_1)] = [P_1 - \theta c_1^s - (1-\theta)c_1^t]q_1 + \{E_1 - [\theta e_1^s + (1-\theta)e_1^t]q_1\}\mu \quad (1)$$

$$maxE[\pi_{2u}(q_2)] = \{P_2 - \delta[\theta c_2^s + (1-\theta)c_2^t]\}q_2 + \{E_2 - \delta[\theta e_2^s + (1-\theta)e_2^t]q_2\}\mu \quad (2)$$

(2) Airline carbon offset model under the mandatory blending ratio policy of differential SAF

In this model, leader airline 1 and follower airline 2 make capacity decisions, and the expected revenue of the airlines is as follows, the optimization problem in this case is:

$$maxE[\pi_{1d}(q_1)] = [P_1 - \theta_1 c_1^s - (1-\theta_1)c_1^t]q_1 + \{E_1 - [\theta_1 e_1^s + (1-\theta_1)e_1^t]q_1\}\mu \quad (3)$$

$$maxE[\pi_{2d}(q_2)] = \{P_2 - \delta[\theta_2 c_2^s + (1-\theta_2)c_2^t]\}q_2 + \{E_2 - \delta[\theta_2 e_2^s + (1-\theta_2)e_2^t]q_2\}\mu \quad (4)$$

4 Model Solving and Analysis

4.1 Airline Carbon Offset Model under the Unified SAF Mandatory Blending Ratio Policy

Theorem 1: The optimal capacity investment for leading airlines is $q_{1u}^* = \frac{a(-2+\beta)-m(2+\beta)\mu+2\theta c_1^s-2(-1+\theta)c_1^t-\beta+\beta\delta\theta c_2^s-\beta\delta(-1+\theta)c_2^t+\mu(2\theta e_1^s-2(-1+\theta)e_1^t+\beta\delta(\theta e_2^s-(-1+\theta)e_2^t))}{2(-2+\beta^2)}$, The optimal profit for a leading airline is $\pi_{1u}^* =$

$\frac{\left(\begin{array}{c}2a+\beta-a\beta+m(2+\beta)\mu-2\theta c_1^s+2(-1+\theta)c_1^t-\beta\delta\theta c_2^s+\\ \beta\delta(-1+\theta)c_2^t+\mu(-2\theta e_1^s+2(-1+\theta)e_1^t+\beta\delta(-\theta e_2^s+(-1+\theta)e_2^t)))\end{array}\right)^2}{-8(-2+\beta^2)}$. The optimal capacity investment for follower airlines is

$q_{2u}^* = \frac{\begin{array}{c}(-4+\beta^2-a(-4+\beta(2+\beta))+m(-4+(-2+\beta)\beta)\mu+2\beta\theta c_1^s-2\beta(-1+\theta)c_1^t-(-4+\beta^2)\delta\theta c_2^s\\ +(-4+\beta^2)\delta(-1+\theta)c_2^t+\mu(2\beta\theta e_1^s-2\beta(-1+\theta)e_1^t+(-4+\beta^2)\delta(-\theta e_2^s+(-1+\theta)e_2^t)))\end{array}}{4(-2+\beta^2)}$, the optimal profit for a leader airline is

$$\pi_{2u}^* = \frac{\begin{pmatrix}4+a\big(-4+\beta(2+\beta)\big)+4m\mu-\beta(\beta+m(-2+\beta)\mu)-2\beta\theta c_1^s+2\beta(-1+\theta)c_1^t+\big(-4+\beta^2\big)\delta\theta c_2^s\\ -\big(-4+\beta^2\big)\delta(-1+\theta)c_2^t+\mu\Big(-2\beta\theta e_1^s+2\beta(-1+\theta)e_1^t-\big(-4+\beta^2\big)\delta\big(-\theta e_2^s+(-1+\theta)e_2^t\big)\Big)\end{pmatrix}^2}{16(-2+\beta^2)^2}.$$

Corollary 1: Under the unified SAF mandatory blending ratio policy, the relationship between the capacity investment and profit of the two airlines and the SAF blending ratio is as follows:

a) When $\mu < \frac{-2c_1^s+2c_1^t+\beta\delta(-c_2^s+c_2^t)}{2e_1^s-2e_1^t+\beta\delta(e_2^s-e_2^t)}$, the capacity investment of the leading airline increases with the increase of SAF blending ratio, and if $\theta > \frac{a(-2+\beta)-\beta-m(2+\beta)\mu+2c_1^t+2\mu e_1^t+\beta\delta(c_2^t+\mu e_2^t)}{-2c_1^s+2c_1^t+2\mu(-e_1^s+e_1^t)-\beta\delta\big(c_2^s-c_2^t+\mu(e_2^s-e_2^t)\big)}$ is also met, its profits increase with the increase of SAF blending ratio.

b) When $\mu > \frac{2\beta c_1^s-2\beta c_1^t-(-4+\beta^2)\delta(c_2^s-c_2^t)}{-2\beta e_1^s+2\beta e_1^t+(-4+\beta^2)\delta(e_2^s-e_2^t)}$, the capacity investment of follower airline increases with the increase of SAF blending ratio, and if $\theta > \frac{\begin{array}{c}-4+\beta^2-a\big(-4+\beta(2+\beta)\big)+m(-4+(-2+\beta)\beta)\mu\\ +2\beta c_1^t-\big(-4+\beta^2\big)\delta c_2^t+2\beta\mu e_1^t-\big(-4+\beta^2\big)\delta\mu e_2^t\end{array}}{\begin{array}{c}-2\beta c_1^s+2\beta c_1^t+(-4+\beta^2)\delta c_2^s-(-4+\beta^2)\delta c_2^t\\ +\mu\big(-2\beta e_1^s+2\beta e_1^t+(-4+\beta^2)\delta(e_2^s-e_2^t)\big)\end{array}}$ is also met, its profits increase with the increase of SAF blending ratio.

4.2 Airline Carbon Offset Model under the policy of Mandatory Blending Ratio of differential SAF

Theorem 2: The optimal capacity investment for leader airlines is $q_{1d}^* = -\frac{\begin{array}{c}2a+\beta+m(2+\beta)\mu+2c_1^t(-1+\theta_1)-2c_1^s\theta_1\\ +\beta\delta c_2^t(-1+\theta_2)-\beta\delta c_2^s\theta_2+\mu(2e_1^t(-1+\theta_1)\\ -a\beta-2e_1^s\theta_1+\beta\delta(e_2^t(-1+\theta_2)-e_2^s\theta_2))\end{array}}{2(-2+\beta^2)}$, the optimal profit for a leader airline is $\pi_{1u}^* = \frac{\left(\begin{array}{c}2a+\beta-a\beta+m(2+\beta)\mu-2\theta c_1^s+2(-1+\theta)c_1^t-\beta\delta\theta c_2^s+\\ \beta\delta(-1+\theta)c_2^t+\mu(-2\theta e_1^s+2(-1+\theta)e_1^t+\beta\delta(-\theta e_2^s+(-1+\theta)e_2^t)))\end{array}\right)^2}{-8(-2+\beta^2)}$. The optimal capacity investment for follower airlines is $q_{2d}^* = \frac{\begin{array}{c}-a\big(-4+\beta(2+\beta)\big)+m(-4+(-2+\beta)\beta)\mu-2\beta c_1^t(-1+\theta_1)\\ -4+\beta^2+2\beta c_1^s\theta_1+\big(-4+\beta^2\big)\delta c_2^t(-1+\theta_2)-\big(-4+\beta^2\big)\delta c_2^s\theta_2\\ +\mu\Big(-2\beta e_1^t(-1+\theta_1)+2\beta e_1^s\theta_1+\big(-4+\beta^2\big)\delta\big(e_2^t(-1+\theta_2)-e_2^s\theta_2\big)\Big)\end{array}}{4(-2+\beta^2)}$, the optimal profit for a leader airline is

$$\pi_{2d}^{*}=\frac{\left(\begin{array}{c}4+a\left(-4+\beta(2+\beta)\right)+4m\mu-\beta(\beta+m(-2+\beta)\mu)\\+2\beta c_1^t(-1+\theta_1)-2\beta c_1^s\theta_1-\left(-4+\beta^2\right)\delta c_2^t(-1+\theta_2)\\+\left(-4+\beta^2\right)\delta c_2^s\theta_2+\mu\left(\begin{array}{c}2\beta e_1^t(-1+\theta_1)-2\beta e_1^s\theta_1\\-\left(-4+\beta^2\right)\delta\left(e_2^t(-1+\theta_2)-e_2^s\theta_2\right)\end{array}\right)\end{array}\right)^2}{16(-2+\beta^2)^2}.$$

Corollary 2: Under the unified SAF mandatory blending ratio policy, the relationship between the capacity investment and profit of the two airlines and the SAF blending ratio is as follows:

a) When $\mu<\frac{-c_1^s+c_1^t}{e_1^s-e_1^t}$, the capacity investment of leading airline decreases as its SAF blending ratio increases, and if $\theta_1<\frac{2a+\beta-a\beta+m(2+\beta)\mu-2c_1^t-2\mu e_1^t+\beta\delta\left(c_2^t(-1+\theta_2)+\mu e_2^t(-1+\theta_2)-c_2^s\theta_2-\mu e_2^s\theta_2\right)}{2\left(c_1^s-c_1^t+\mu\left(e_1^s-e_1^t\right)\right)}$ is also met, its profit decreases with the increase of SAF blending ratio.

b) When $\mu>\frac{-c_1^s+c_1^t}{e_1^s-e_1^t}$, the capacity investment of follower airline increases with the increase of SAF blending ratio, and if $\theta_2<\frac{\begin{array}{c}-4+\beta^2-a\left(-4+\beta(2+\beta)\right)+m(-4+(-2+\beta)\beta)\mu-\left(-4+\beta^2\right)\delta c_2^t\\-\left(-4+\beta^2\right)\delta\mu e_2^t-2\beta c_1^t(-1+\theta_1)+2\beta c_1^s\theta_1+2\beta\mu\left(-e_1^t(-1+\theta_1)+e_1^s\theta_1\right)\end{array}}{(-4+\beta^2)\delta\left(c_2^s-c_2^t+\mu\left(e_2^s-e_2^t\right)\right)}$ is also met, its profit decreases with the increase of SAF blending ratio.

5 Numerical Analysis

This section selects the "Xuzhou Guangzhou" route as the research object, with a range of 1263km. The two major operating airlines of this route are China Southern Airlines and Long Dragon Airlines, with A320/214 and A320/251 (N) aircraft types respectively. Two airlines on this route choose to mix HEFA in response to the policy, with a mandatory mixing ratio of 1%. The traditional aviation fuel life cycle value (LS) is 89gCO2e/MJ, while the HEFA life cycle value is 13.9gCO2e/MJ. According to CORSIA accounting data, the fuel consumption of A320ceo (CFM56-5B4/P) operated by China Southern Airlines is 6300KG, and the fuel consumption of A320neo (LEAP-1A26) operated by Long Dragon Airlines is 5400KG. As the calorific value of aviation fuel is fixed at 42.8MJ/kg, the conversion coefficient of passenger kilometers to ton kilometers for domestic flights is 13.89:1. Therefore, through calculation, the unit carbon emissions (tCO2e/t * km) of China Southern Airlines (Airline 1) and Long Dragon Airlines (Airline 2) in this case are 0.001721668 and 0.001289131, respectively.

Based on the solution results and the parameter values mentioned above, the relationship between the profit, capacity investment, carbon quota surplus, and SAF mandatory blending ratio of leader airlines and follower airlines under the unified SAF mandatory blending ratio policy is obtained. The results are shown in Figure 1.

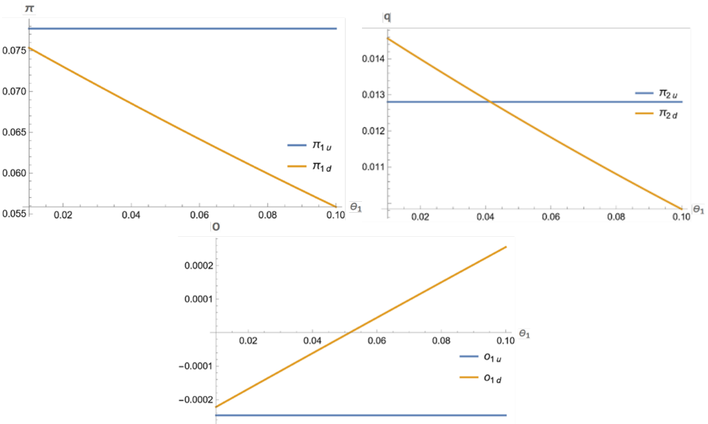

Fig. 1. Relationship between the profits, capacity investment, carbon quota surplus, and θ_1 of leader airline.

Based on the solution results and the parameter values mentioned above, the relationship between the profit, capacity investment, carbon quota surplus, and SAF mandatory blending ratio of the leader airline and follower airline under the differential SAF mandatory blending ratio policy is obtained. The results are shown in Figure 2.

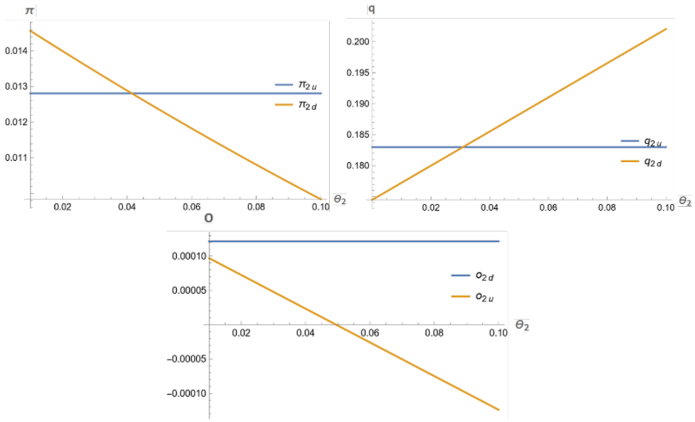

Fig. 2. Relationship between the profits, capacity investment, carbon quota surplus, and θ_2 of follower airline.

The results indicate that there are significant differences in the impact of different SAF blending policies on airline profits and capacity investment. Under differentiated policies, if leaders mix higher levels of SAF, the high cost of SAF will severely compress profits and inhibit capacity investment. However, if followers mix a relatively lower proportion of SAF compared to leaders, they may rely on their own fuel efficiency advantages to seize the market through capacity expansion under high performance blending policies.

6 Conclusion

This paper constructs a duopoly Stackelberg game model consisting of a leader airline and a follower airline, under the dual constraints of carbon trading mechanisms and mandatory blending policies for sustainable aviation fuels. Intended to explore the optimal decisions for capacity investment, profit, and carbon offset of two airlines under two policy scenarios of "unified SAF mandatory blending ratio" and "differential SAF mandatory blending ratio"

Research has found that: (1) This indicates that a one size fits all unified SAF blending ratio policy, although easy to manage, may not accurately adapt to the cost structure of airlines with different efficiencies, while differentiated policies may reshape the market competition landscape and provide opportunities for efficient follower airlines to overtake on the curve. (2) Under the differential blending policy, when the mandatory blending ratio of SAF by followers exceeds a certain threshold (about 5%), although considerable emission reduction measures are taken, the rapid expansion of transportation capacity may lead to a reduction in carbon quota surplus until a small gap appears. This means that follower airlines with high fuel efficiency aircraft also need to be vigilant about carbon compliance risks under aggressive market strategies.

Future research can consider the nonlinear mixing cost and emission reduction effect of SAF and traditional aviation fuels to reflect the possible technological threshold and efficiency changes under different mixing ratios; Construct a multi-level supply chain game model that includes SAF manufacturers, aviation fuel suppliers, airlines, and even airports, and study the transmission effects and overall emission reduction efficiency of industry support policies such as subsidies and tax incentives when applied at different stages of the supply chain.

Acknowledgements

This work was supported by Graduate Research Innovation Project of Civil Aviation University of China (2025YJSKC08012).

Disclosure of Interests

I declare that I am not involved in competing interests in relation to the content of this article.

References

1. Delft C E. Giving wings to emission trading, inclusion of aviation under the European emission trading system (ETS): design and impacts[J]. Delft, The Netherlands, 2005.
2. Albers S, Bühne J A, Peters H. Will the EU-ETS instigate airline network reconfigurations?[J]. Journal of Air Transport Management, 2009, 15(1): 1-6.

3. Watson M J, Machado P G, Da Silva A V, et al. Sustainable aviation fuel technologies, costs, emissions, policies, and markets: A critical review[J]. Journal of Cleaner Production, 2024, 449: 141472.
4. Chen D, Yin J, Xu F, et al. A market-based framework for CO2 emissions reduction in China's civil aviation industry[J]. Transport Policy, 2023, 143: 150-158.
5. Dodd T, Yengin D. Deadlock in sustainable aviation fuels: A multi-case analysis of agency[J]. Transportation Research Part D: Transport and Environment, 2021, 94: 102799.
6. Martinez-Valencia L, Peterson S, Brandt K, et al. Impact of services on the supply chain configuration of sustainable aviation fuel: The case of CO2e emission reductions in the US[J]. Journal of Cleaner Production, 2023, 404: 136934.
7. Qiang Cui, Yilin Lei, Ye Li. Co-benefit scenario analysis on replacing aviation kerosene with sustainable aviation fuels in Africa[J]. Environmental Impact Assessment Review, 2024, 104: 107318.
8. Jiang C, Liu Y. The role of sustainable aviation fuel in CORSIA: An economic analysis[J]. Energy Economics, 2025, 143: 108238.
9. Cordes H, Baumeister S, Käyrä M. Factors influencing the willingness to pay for aviation voluntary carbon offsets: A literature review[J]. European Journal of Tourism Research, 2024, 36: 3602-3602.
10. Baumeister S. 'Each flight is different': Carbon emissions of selected flights in three geographical markets[J]. Transportation Research Part D: Transport and Environment, 2017, 57: 1-9.