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SUSTAINABLE DIGITAL TRADE AND LOW-ALTITUDE ECONOMY: A NEW PATHWAY FOR GLOBAL WINE MARKET EXPANSION IN CHINA

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Abstract. Although China is one of the largest potential markets in terms of wine consumption, international wine imports are still severely constrained by fragmented logistics, carbon-intensive transport structures, and weak digital interaction with consumers. At the same time, the rapid development of the low-altitude economy in China and its policy-driven expansion of sustainable digital trade are reshaping the conditions under which cross-border supply chains operate. The study presents the hypothesis that the nonlinear integration of digitalization, decarbonization, and distributed logistics yields synergistic effects that surpass conventional linear sustainability approaches. To investigate this hypothesis, a novel 3D Sustainable Trade Model, defined as Digitalization^n × Decarbonization^n × Distribution^n, is developed and analyzed based on policy analysis, scenario-based supply-chain modeling, and secondary data from customs statistics and digital trade platforms. The results indicate that synchronously improving the dimensions may reduce logistics-related carbon emissions by around 40–60%, while enabling delivery efficiency and enhancing responsiveness to the market at the same time. The proposed framework is particularly relevant to time-sensitive and premium wine trade, and it points toward a structured way through which exporters and policymakers can align their low-carbon objectives with digital trade strategies.

Keywords: *carbon efficiency, cross-border logistics, digitalization, distributed systems, import dynamics, supply chain resilience, wine imports.*

Rezumat. Deși China este una dintre cele mai mari piețe potențiale în ceea ce privește consumul de vin, importurile internaționale de vin sunt încă sever constrânse de logistica fragmentată, structurile de transport cu emisii mari de carbon și interacțiunea digitală slabă cu consumatorii. În același timp, dezvoltarea rapidă a economiei de joasă altitudine din China și extinderea comerțului digital durabil, determinată de politici, remodelează condițiile în care operează lanțurile de aprovizionare transfrontaliere. Studiul prezintă ipoteza că integrarea neliniară a digitalizării, decarbonizării și logisticii distribuite produce efecte sinergice care depășesc abordările convenționale liniare ale sustenabilității. Pentru a investiga această ipoteză, este dezvoltat și analizat un nou model 3D de comerț durabil, definit ca Digitalizare^n × Decarbonizare^n × Distribuție^n, pe baza analizei politicilor, a modelării

lanțului de aprovizionare bazate pe scenarii și a datelor secundare din statisticile vamale și platformele comerciale digitale. Rezultatele indică faptul că îmbunătățirea sincronă a dimensiunilor poate reduce emisiile de carbon legate de logistică cu aproximativ 40-60%, permițând în același timp eficiența livrării și sporind în același timp receptivitatea la piață. Cadrul propus este deosebit de relevant pentru comerțul cu vinuri premium și cu termene limită și indică o modalitate structurată prin care exportatorii și factorii de decizie politică își pot alinia obiectivele privind emisiile reduse de carbon cu strategiile comerciale digitale.

Cuvinte cheie: *eficiență în materie de emisii de carbon, logistică transfrontalieră, digitalizare, sisteme distribuite, dinamica importurilor, reziliența lanțului de aprovizionare, importuri de vin.*

1. Introduction

The rapid digitalization of global supply chains and the transition toward low-carbon logistics systems have become central themes in contemporary research on international trade and industrial sustainability. Recent studies have demonstrated that digital supply chain technologies, including real-time data integration and platform-based coordination, significantly enhance resilience and efficiency in complex trade environments [1,2]. At the same time, the decarbonization of logistics systems has emerged as a critical requirement for achieving sustainable development goals, particularly in industries characterized by high transport intensity and global distribution networks [3,4]. In the wine sector, sustainability challenges are further amplified by globalization dynamics, evolving consumer expectations, and increasing regulatory pressure toward environmentally responsible production and distribution practices [5,6].

In parallel, digital platforms have increasingly influenced the internationalization strategies of wine enterprises, particularly in the Chinese market, where cross-border e-commerce ecosystems play a pivotal role in market access and consumer engagement [6]. Furthermore, technological advancements in logistics, such as unmanned aerial vehicles (UAVs) and drone-assisted delivery systems, have introduced new opportunities for optimizing distribution efficiency and reducing last-mile delivery costs [7,8]. These innovations are particularly relevant in the context of emerging low-altitude economies, where integrated air–ground transportation systems are expected to reshape conventional logistics structures. Additionally, consumer behavior in the wine industry is transforming digital experiences, reinforcing the importance of technology-driven interaction models in shaping demand patterns [9].

From a sustainability perspective, the environmental impact of long-distance food transport, often conceptualized through the “food miles” framework, highlights the urgency of reducing carbon emissions across global supply chains [10]. In response, carbon labeling systems and carbon neutrality policies have been increasingly adopted to guide trade practices and regulatory frameworks, particularly in rapidly developing economies such as China [11,12]. These developments are further supported by national-level strategies, including policy frameworks promoting the low-altitude economy and advanced logistics infrastructure [13,14], as well as statistical evidence indicating the continued growth and structural transformation of China’s wine import market [15,16].

Despite these advances, existing studies largely examine digitalization, decarbonization, and logistics optimization as independent drivers of supply chain performance. However, complex systems theory suggests that interactions among multiple

subsystems may lead to nonlinear effects that cannot be captured through isolated analysis [17]. In the context of cross-border wine trade, where market dynamics, regulatory conditions, and technological infrastructures are deeply intertwined, there remains a significant research gap in understanding how these factors interact at the system level to influence overall performance.

Based on this research gap, this study proposes the following hypothesis: improvements in cross-border wine trade performance cannot be fully explained by individual advancements in digitalization, decarbonization, or distribution infrastructure alone. Instead, it is hypothesized that these elements exhibit nonlinear and mutually reinforcing interactions, generating synergistic effects that enhance both efficiency and sustainability.

To address this hypothesis, this paper develops a three-dimensional nonlinear model integrating digital trade technologies, low-carbon transformation mechanisms, and distributed logistics systems. The model aims to capture the dynamic interactions among these dimensions and to evaluate their combined impact on supply chain performance. China is selected as the empirical context due to its advanced digital infrastructure, rapidly evolving regulatory environment, and active promotion of low-altitude economic applications [13,18,19]. The study further conducts a scenario-based analysis of the cross-border wine supply chain to validate the proposed model and to assess its practical implications for improving trade efficiency and sustainability.

2. Materials and Methods

The integration of the low-altitude economy with digital economic systems is creating new opportunities for the intelligent and sustainable transformation of global supply chains, including the wine industry. By enhancing distribution efficiency, expanding market access channels, and supporting low-carbon logistics solutions, this integration is increasingly recognized as a key driver of structural change in international trade systems [7,8,13].

In China, this transformation is strongly supported by national policy frameworks. The low-altitude economy has been formally identified as a strategic emerging industry, and its development has been further reinforced through dedicated policy instruments. According to the Implementation Plan for the Innovation and Application of General Aviation Equipment (2024–2030), the market size of the low-altitude economy is expected to exceed RMB 1 trillion by 2030 [16]. In parallel, recent reports indicate that since 2024, a wide range of stakeholders—including enterprises, capital markets, and local governments—have actively entered this sector, with more than 20 provinces issuing action plans and substantial investment flows supporting industry expansion [20].

At the same time, China's wine import market has shown signs of recovery, reflecting renewed demand and evolving consumption patterns. According to official statistics, wine imports reached USD 1.592 billion in 2024, representing a year-on-year increase of 37.22%, marking the first positive growth since 2021 [17]. Import volumes also increased to approximately 282,800 kiloliters, corresponding to a 13.61% rise compared to the previous year [17]. This upward trend continued into early 2025, with imports reaching USD 258.3 million between January and February, reflecting a 54.1% increase compared to the same period in 2024 [19], as illustrated in Figure 1.

In addition, cross-border e-commerce platforms are playing an increasingly important role in shaping the structure of the wine market.

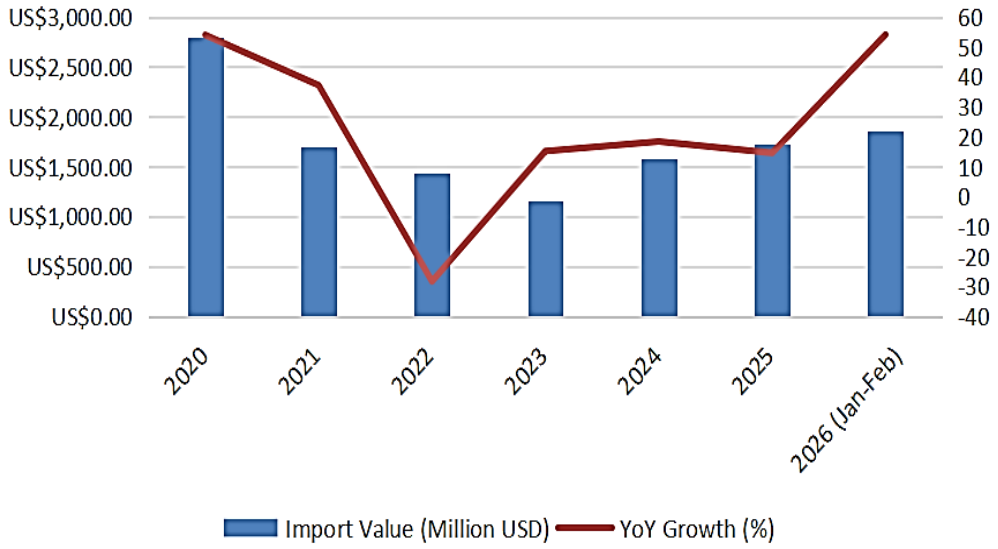

Figure 1. China Wine Import Trends (2020–2025) and Preliminary Data for 2026 (Jan–Feb)**.**
Source: from China customs.

The 2025 Tmall Global Cross-Border Alcohol White Paper reports that the number of alcoholic products available on major platforms increased by more than 40% in 2024, with over 1,700 new products introduced in the first two months alone, indicating a growing consumer preference for diversified and high-quality imported wines [18]. Furthermore, the continuous expansion of digital commerce infrastructure in China provides a favorable environment for international wine producers seeking market entry and brand development [21].

Within this context, the convergence of digital trade systems and low-altitude logistics solutions presents a strategic opportunity for restructuring cross-border wine supply chains. Given the ongoing recovery of import demand, strong policy support, and rapid technological advancement, integrating the wine sector with emerging digital and aerial logistics technologies may provide new pathways for improving efficiency, reducing carbon intensity, and enhancing global market connectivity.

The 3D Sustainable Trade System integrates digitalization, low-altitude logistics, and sustainability to optimize global wine supply chains. Through nonlinear synergy may be calculated by Eq.(1) as follow Digitalization^n × Decarbonization^n × Distribution^n—it enhances efficiency, reduces emissions, and supports adaptive, data-driven growth across production, transport, and retail stages in a coordinated, future-ready model.

$$Sustainability\ Index = \prod_{i=1}^{3}(1 + a_i D_i) \quad (1)$$

where:D_i-represents the implementation level of each dimension (e.g., digital penetration rate, carbon reduction rate, coverage of distributed resources);

a_i-are the weight coefficients, reflecting the strength of each dimension's contribution to overall effectiveness;

The multiplicative relationship (as opposed to additive) reflects the synergistic amplification between the dimensions. In the 3D model, each dimension contributes through a (1 + D) term, and their multiplicative relationship means that improving one enhances the impact of the others. Even if one is absent, the system remains functional, showing resilience.

Weight coefficients vary by industry, and in wine, all three digitalization, decarbonization, and distribution are vital.

3. Results and Discussion

The scenario-based estimation reveals clear structural differences between the linear additive model and the proposed nonlinear multiplicative model, presented in Table 1.

Table 1

Scenario-based illustrative estimation comparing linear additive and nonlinear multiplicative models under assumed implementation levels

Model Type	Initial scenario (D=0.1)	Improved scenario (D=0.5)	Growth Rate, %
Linear Additive Model	0.3	1.5	400
Multiplicative Model	$1.3^3=2.2$	$1.5^3=3.4$	55

Note: The numerical values represent assumed estimates under discrete implementation scenarios, where the implementation level D reflects low and medium system adoption conditions. Equal weighting parameters ($\alpha_i = 1$) are applied for illustrative purposes. Although interval-based estimates are not presented, sensitivity considerations suggest that moderate variation around the assumed D levels would not alter the comparative relationship between the two model structures.

As shown in Table 1, when the implementation level increases from D = 0.1 (low adoption scenario) to D = 0.5 (moderate adoption scenario), the linear additive model increases from 0.3 to 1.5, corresponding to a proportional growth rate of 400%. In contrast, the multiplicative model increases from 2.2 to 3.4, representing a 55% growth rate under the same conditions.

Despite the higher percentage increase observed in the linear model, the multiplicative model maintains consistently higher absolute values across both scenarios, indicating stronger system-level performance. These results demonstrate that the nonlinear model captures compounded interaction effects among system dimensions, which are not reflected in additive structures.

Furthermore, the comparative analysis indicates that the relative advantage of the multiplicative model remains stable under moderate variations in implementation levels. As noted in Table 1, sensitivity considerations suggest that small fluctuations in D values do not alter the dominance of the nonlinear structure, confirming the robustness of the model under different adoption conditions.

The interaction among the three dimensions: digitalization, decarbonization, and distribution, forms a cyclic structure, indicating the presence of interdependent relationships within the system as illustrated in Figure 2. The graphical representation highlights that improvements in one dimension are associated with corresponding changes in the others, reflecting coordinated system behavior.

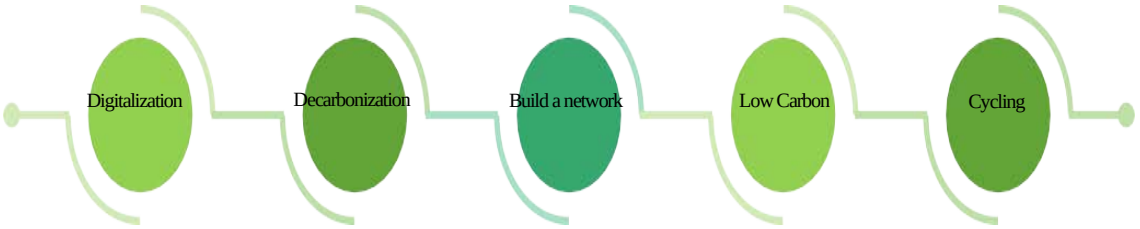

Figure 2. Synergistic Cycling of 3D Model.

Figure 3 presents the structural configuration of the proposed 3D nonlinear model. The model integrates the three dimensions within a unified framework and remains operational under partial implementation conditions, indicating system resilience. Even when one dimension exhibits lower implementation levels, the model continues to generate measurable outputs through the remaining components.

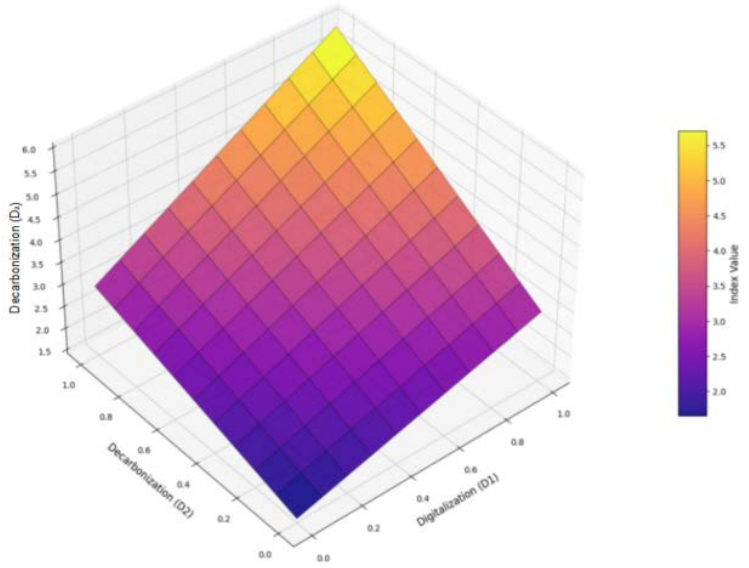

Figure 3. The 3D Nonlinear Synergy Model.

Scenario-based evaluation further indicates that coordinated implementation of the three dimensions is associated with a substantial reduction in logistics-related carbon emissions. Under moderate-to-high adoption conditions, the integrated system demonstrates the potential to reduce carbon emissions by approximately 40–60% compared to baseline linear scenarios.

It should be noted that this estimated reduction is derived from scenario-based modeling rather than direct empirical measurement. The observed reduction reflects the combined effects of improved logistics efficiency, reduced transport distances, and optimized inventory management enabled by system integration. Overall, the results support the hypothesis that cross-border wine trade performance is influenced by nonlinear interactions among digitalization, decarbonization, and distribution systems. Compared with linear models, the proposed 3D structure demonstrates enhanced system performance, stability, and integration capacity under varying implementation scenarios.

The results of the scenario-based analysis confirm that cross-border wine trade performance is influenced by nonlinear interactions among digitalization, decarbonization, and distribution systems, rather than by independent improvements in individual dimensions. The multiplicative structure of the proposed model reflects the presence of systemic interdependencies, where the effectiveness of each dimension is contingent upon the development of the others.

3.1. Synergistic Mechanisms in Logistics Systems

Within the distribution dimension, the integration of low-altitude logistics systems, particularly unmanned aerial vehicles (UAVs), plays a critical role in enhancing supply chain responsiveness. The results indicate that UAV-assisted delivery contributes to reduced transportation time and improved delivery flexibility, especially in geographically complex or high-density urban environments.

This effect can be explained by the interaction between distribution efficiency and digital coordination. UAV systems rely heavily on real-time data processing, route optimization, and intelligent scheduling, which are enabled by digital infrastructure. As a result, improvements in digitalization amplify the operational effectiveness of distribution systems, supporting the multiplicative relationship identified in the model.

3.2. Digitalization as a Feedback Amplifier

The findings also highlight the role of digitalization in strengthening the feedback loop between supply and demand. Technologies such as AI-driven recommendation systems, virtual wine tasting platforms, and digital marketing tools enhance consumer engagement and reduce information asymmetry in cross-border wine markets. From a system perspective, enhanced consumer interaction improves demand predictability, which allows for more efficient inventory allocation and logistics planning. This reduces unnecessary transportation and storage activities, indirectly contributing to emission reduction. Therefore, digitalization acts not only as an independent dimension but also as an amplifier of both distribution efficiency and decarbonization outcomes.

3.3. Integrated Effects on Carbon Reduction

The estimated reduction in carbon emissions observed in the results can be attributed to the combined effects of multiple system-level improvements. These include shorter transportation distances due to distributed warehousing, reduced idle inventory through real-time monitoring, and increased logistics efficiency enabled by digital coordination. Importantly, the reduction effect does not arise from a single technological intervention but from the interaction among multiple dimensions. This finding supports the argument that system-level integration is more effective than isolated optimization strategies in achieving sustainability goals within complex supply chains.

3.4. Policy Context and Implementation Constraints

The applicability of the proposed model is closely linked to the institutional and technological context in which it is implemented. China provides a favorable environment due to strong policy support for digital trade, rapid development of low-altitude logistics infrastructure, and high levels of technological adoption.

However, the results should be interpreted with caution when applied to other regions. The analysis is based on scenario-based modeling rather than firm-level empirical data, and the effectiveness of the model may vary depending on infrastructure maturity, regulatory conditions, and market dynamics.

Despite these limitations, the proposed framework offers a scalable and adaptable approach for restructuring wine supply chains. By emphasizing interaction effects and system integration, the model provides insights that may be applicable to other high-value, time-sensitive agricultural products facing similar logistical and environmental challenges.

4. Conclusions

This study demonstrates that the low-altitude economy and sustainable digital trade function as interdependent components within an integrated system, rather than as isolated developments. The results confirm that nonlinear interactions among digitalization, decarbonization, and distribution significantly influence the performance of cross-border wine supply chains.

The proposed 3D nonlinear model provides a structured and quantifiable framework for capturing these interaction effects. This study contributes to the literature by introducing a nonlinear systems-based approach to cross-border wine trade analysis, highlighting the importance of interaction effects among digitalization, decarbonization, and distribution in shaping supply chain performance and sustainability outcomes. By incorporating a multiplicative relationship among key dimensions, the model offers an alternative to conventional linear approaches and enables a more comprehensive assessment of system-level efficiency and sustainability.

Within the context of China, the rapid development of low-altitude logistics, digital trade platforms, and cross-border e-commerce infrastructure creates favorable conditions for applying the proposed framework. These factors collectively support more flexible, efficient, and environmentally sustainable wine import systems.

From a practical perspective, the findings suggest that wine exporters should adopt integrated strategies that combine digital technologies, low-carbon logistics, and distributed supply networks, rather than relying on incremental improvements in individual areas. Such coordinated approaches are more likely to enhance market responsiveness, reduce operational inefficiencies, and improve environmental performance.

Overall, this study contributes to the growing body of research on sustainable trade systems by providing a conceptual and analytical framework for understanding how emerging technologies can reshape global wine supply chains.

Despite these contributions, the study is subject to several limitations. The analysis is based on scenario-based modeling rather than empirical data, and the results may vary under different institutional and infrastructural conditions. Future research should focus on empirical validation of the proposed model and explore its applicability across different Chine's regions and premium product categories.

Research Data Availability Statement: The data supporting this study are obtained from publicly available sources, including official statistical databases and industry reports, as cited in the references. No new raw data were generated. The dataset constructed and analyzed during the current study is available from the corresponding author upon reasonable request. The analytical procedures and data processing steps are described in sufficient detail to ensure reproducibility.

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Contribution of Authors

Wei Pang: Conceptualization, Methodology, Investigation, Resources, Data curation, Formal analysis, Writing – original draft preparation.

Ecaterina Covaci: Software, Methodological guidance, Validation, Supervision, Writing – review & editing, Visualization, Project administration.

Mariana Godoroja: Validation, Supervision, Conceptual discussion.

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References

1. Ivanov D (2020) Digital supply chain and Industry 4.0: Managing disruptions. International Journal of Production Research 58(10):2904–2915. https://doi.org/10.1080/09537287.2020.1768450
2. Queiroz MM, Ivanov D, Dolgui A, Wamba SF (2020) Impacts of epidemic outbreaks on supply chains: Mapping a research agenda amid the COVID-19 pandemic. Annals of Operations Research 290:247–276. https://doi: 10.1007/s10479-020-03685-7
3. Bektaş T, Laporte G (2011) The pollution-routing problem. Transportation Research Part B: Methodological 45(8):1232–1250. https://doi.org/10.1016/j.trb.2011.02.004
4. Gilinsky A, Newton SK, Vega RF (2016) Sustainability in the global wine industry: Concepts and cases. International Journal of Wine Business Research 28(2):109–125. https:// doi.org/10.1016/j.aaspro.2016.02.006
5. Castaldi RM, Cholette S, Frederick A (2006) Globalization and the wine industry. Journal of Wine Research 17(3):211–224. https: doi.org/10.19030/iber.v4i3.3577
6. Hu L, Galli M, Sebastiani R (2024) How digital platforms affect the internationalisation of wine firms in China. International Journal of Retail & Distribution Management 52(9):875–891. https://doi.org/10.1108/IJRDM-11-2022-0438
7. Otto A, Agatz N, Campbell J, Golden B, Pesch E (2018) Optimization approaches for civil applications of unmanned aerial vehicles (UAVs) or aerial drones: A survey. Transportation Research Part C: Emerging Technologies 92:1–20. https://doi.org/ 10.1002/net.21818
8. Dorling K, Heinrichs J, Messier GG, Magierowski S (2017) Vehicle routing problems for drone delivery. IEEE Transactions on Systems, Man, and Cybernetics: Systems 47(1):70–85. https://doi.org/10.1109/TSMC.2016.2582745
9. Gastaldello G, Rossetto L, Giampietri E (2024) Consumer behavior toward virtual wine experiences as a technology-based sustainable transformation. Frontiers in Sustainable Food Systems 8:1384011. https://doi.org/10.3389/fsufs.2024.1384011
10. Paxton A, (1994) The food miles report: The dangers of long-distance food transport. The SAFE Alliances, ISBN 1899779051, 62 p.
11. Qiu F (2021) International practices of carbon labeling systems and their implications for China. Southwest Finance 12:28–42. https://doi.org/10.18282/ff.v9i3.1100
12. Lian P, Chang R (2022) Challenges and policy responses to the impact of carbon neutrality on China's foreign trade. New Finance 1:4–9. https://doi.org/10.3390/su10072547
13. Ren G, Zhang X, Li Y, et al (2025) Survey on comprehensive visual perception technology for future air–ground intelligent transportation vehicles in all scenarios. Engineering Proceedings 80(1):50, p.1-18. https://doi.org/10.3390/engproc2024080050
14. McKinnon A (2018) Decarbonizing Logistics: Distributing Goods in a Low Carbon World. Kogan Page, London, ISBN 0749483806, 310 p.
15. Sterman JD (2000) Business Dynamics: Systems Thinking and Modeling for a Complex World. McGraw-Hill, Boston, ISBN 0072311355, 982 p.
16. China ITS: Ministry of Industry and Information Technology (MIIT) (2024) Implementation Plan for the Innovation and Application of General Aviation Equipment (2024–2030). Beijing https://www.gov.cn/zhengce/zhengceku/202403/content_6942115.htm Accessed 20 may 2025
17. General Administration of Customs of the People's Republic of China (GACC) (2025) China's import and export of wine, 2024 statistical bulletin. https://english.customs.gov.cn/. Accessed 15 March 2026
18. Jizhuan GI (2025) Tmall Global cross-border alcohol white paper. Alibaba Group, Hangzhou, 214 p.
19. Shibata T., Shiliang Xu. (2025) China: Wine market update 2025. GAIN Report USDA Foreign Agricultural Service, 1-6, https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Wine%20Market%20Update%202025_Shanghai%20ATO_China%20-%20People%27s%20Republic%20of_CH2025-0190.pdf. Accessed 20 January 2026
20. Xinhua News Agency (2024) China's low-altitude economy takes off nationwide: Over 20 provinces release action plans. https://www.xinhuanet.com/. Accessed 15 July 2025

21. U.S. Department of Commerce, International Trade Administration (2025) China – eCommerce. https://www.trade.gov/. Accessed 20 March 2026

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