

Building a Collaborative Ecosystem: Planning and Development of the Airport Industry in the Guangdong-Hong Kong-Macao Greater Bay Area

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Abstract: The primary objective of this research is to propose a framework for building a collaborative ecosystem within the Guangdong-Hong Kong-Macao Greater Bay Area (GBA)'s airport industry, informed by Global Value Chains (GVCs), cooperative game theory, and green growth theory. This framework advocates for cooperation over competition among airports within the region and seeks to establish effective environmental governance mechanisms to attain the dual goals of economic development and environmental conservation. Specifically, the research will analyze the positioning of the GBA's airport industry within the GVC, explore the cooperative game relationships among stakeholders, and recommend policies to promote green growth within the sector. The findings of this study are expected to provide theoretical guidance and practical insights for the planning and development of the GBA's airport industry, thereby contributing to high-quality regional economic development and offering a model for sustainable airport economic development in other bay areas worldwide.

Keywords- global value chains, airport industry, Guangdong-Hong Kong-Macao Greater Bay Area, cooperative game theory, green growth, planning and development, environmental protection

1. Introduction

The intensification of globalization, propelled by the proliferation of Global Value Chains (GVCs), has fundamentally reshaped the global economic order and the traditional international division of labor [1]. Within this transformed landscape, the airport economy has emerged as a critical driver of regional economic growth, facilitating industrial upgrading, fostering regional synergy, and enhancing international competitiveness [2]. The Guangdong-Hong Kong-Macao Greater Bay Area (GBA), one of the world's four largest bay areas, exerts significant influence on both the Chinese and global economies [3]. However, the rapid expansion of the GBA's airport industry, while yielding substantial economic benefits, faces increasing challenges related to environmental sustainability [4]. Therefore, establishing a resource-efficient airport ecosystem that prioritizes environmental protection and harmonizes economic and ecological objectives within a sustainable framework is of paramount importance.

This research investigates the current status and challenges of the GBA's airport industry, leveraging the theoretical frameworks of Global Value Chains (GVCs), Cooperative Game Theory, and Green Growth Theory to explore the development of a collaborative and sustainable ecosystem. GVCs theory elucidates the distribution of value addition and benefits across global production networks [5]. Applying this framework to the GBA's airport industry can potentially optimize resource allocation and enhance overall competitiveness by identifying value-adding activities and streamlining operations. However, the complex interplay of stakeholder interests necessitates a transition from conventional competitive models, which often lead to resource depletion and environmental degradation, towards a more collaborative approach.

Consequently, this study integrates Cooperative Game Theory to analyze stakeholder interactions, particularly between airports, industries, and regulatory bodies, and to identify mechanisms for achieving mutually beneficial outcomes—a prerequisite for sustainable airport industry development. Furthermore, the research incorporates Green Growth Theory, which advocates for decoupling economic growth from environmental degradation through technological innovation and institutional reforms, into the analysis of airport planning and development strategies. This integrated theoretical approach aims to identify pathways for mitigating pollution, improving resource efficiency, and achieving a synergistic balance between economic development and environmental protection within the GBA's airport industry.

2. Literature Review

2.1 Global Value Chains Theory

The concept of Global Value Chains (GVCs) was initially proposed by Gereffi and Lee [6], referring to a globally dispersed, cross-enterprise network that encompasses the various stages of production, sales, and recycling, ultimately aiming to realize the value of goods or services [6]. This chain encompasses the entire process, from raw material procurement and transportation to the production and distribution of semi-finished and finished products, culminating in final consumption and, ideally, recycling. It includes all participants and organizations involved in activities such as production and sales, as well as the distribution of value and profits among them. Currently, companies worldwide occupy diverse positions within the value chain, engaging in a range of value-added activities spanning design, product development, manufacturing, marketing, delivery, consumption, after-sales service, and recycling. Within the value chain's realization process, not every link generates equal value. The key to ultimately realizing substantial value lies in occupying a strategic link within the GVCs [6]. Consequently, an enterprise's prominence within these strategic links determines its overall importance within the industry's global value chain.

Sturgeon and Gereffi [7] further elaborated on GVCs from three distinct perspectives: organizational scale, geographical distribution, and participating entities. From the organizational scale perspective, a GVCs encompasses all entities involved in the production activities of a specific product or service. Geographically, the defining characteristic of a GVCs is its global scope. Regarding participating entities, GVCs typically include integrated enterprises, retailers, leading manufacturers, logistics providers, and component suppliers. Sturgeon et al. [7,8] differentiated between the concepts of "value chain" and "production network," positing that a value chain represents the sequential processes from production to delivery, consumption, and service of a particular commodity or service. In contrast, a production network denotes the interconnected production relationships among a group of related enterprises.

GVCs theory provides a robust framework for understanding the organization of industries across geographically dispersed locations and the mechanisms through which value is created and captured within these networks [9]. The theory underscores the significance of inter-firm relationships, governance structures, and upgrading opportunities within global industries. While traditionally applied to manufacturing sectors, GVCs analysis has increasingly been extended to examine service industries, including the dynamically evolving airport industry [10]. Within the context of the airport industry, GVCs theory serves as a valuable tool for analyzing the roles of various actors—such as airports, airlines, ground handling services, logistics providers, and regulatory bodies—and their intricate interactions within the global aviation network [10]. Studies in this domain frequently explore issues such as airport specialization, hub development, connectivity patterns, and the distribution of economic benefits among stakeholders [11]. For instance, recent research has investigated how airports can strategically position themselves within GVCs to attract airlines, stimulate cargo traffic, and secure investments, thereby enhancing their competitiveness and contributing to regional economic development [12].

2.2 Cooperative Game Theory

Cooperative behavior, characterized by the prioritization of collective interests and the suppression of individual short-term self-interests to achieve long-term common goals, has been a subject of extensive research [13]. Traditionally, the explanation of cooperative behavior in academic circles has often relied on the reciprocity theory proposed by Trivers [14], which is based on the iterated prisoner's dilemma game paradigm [15]. The core tenet of this theory is the "tit-for-tat" strategy, wherein cooperation is chosen in the initial round, followed by mirroring the opponent's choice in each subsequent round [16]. Thus, cooperation is reciprocated with cooperation, and defection with defection [16]. However, real-world interactions often deviate from this repeated interaction model. Individuals may opt to "exit" or seek "alternative partners" upon encountering non-cooperative behavior [17]. A growing body of research underscores the crucial role of "partner selection" in the evolution of human cooperative behavior, suggesting that cooperation becomes a stable strategy when individuals can choose to disengage from exploitative relationships and engage with cooperative partners [17].

Noë and Hammerstein [18] introduced the concept of the "biological market," drawing parallels between sexual selection in biology and economic principles, to highlight partner selection or switching and competition for partners—aspects often overlooked in earlier cooperation models. From a biological market perspective, natural selection favors individuals who establish cooperative relationships with the "best" partners, maximizing mutual benefits such as alliance aid, resource sharing, and enhanced resilience [19]. The presence of partner selection can foster competition within partnerships, where only individuals offering substantial or high-quality contributions secure and maintain these relationships, while those contributing less are gradually excluded from cooperative exchanges [20].

In contemporary society, the significance of partner selection is evident across various domains, from addressing global resource challenges and responding to extreme climate anomalies to fostering international strategic alliances and promoting fair market competition by breaking monopolies [21]. Therefore, investigating the influence of partner selection on cooperative behavior and elucidating its underlying mechanisms holds substantial theoretical and practical importance. When examining industrial upgrading on a global scale, integrating Global Value Chain (GVCs) theory with the dynamics of industrial upgrading, emphasizing inter-regional cooperative effects, and leveraging the role of strategic alliances are paramount for fostering the rapid economic development of regions such as the Guangdong-Hong Kong-Macao Greater Bay Area [22]. This is particularly relevant in the context of the airport industry, where cooperation among stakeholders can lead to improved efficiency, innovation, and sustainability.

2.3 The Green Growth Theory

In contemporary academic and policy discussions, green growth has emerged as the primary forward-looking approach to achieving environmental sustainability [23]. As a key element of the broader "Green Economy" framework - which has received support from international bodies including the United Nations - green growth represents a significant shift in environmental thinking. Contemporary environmental economists and eco-modernization advocates propose that environmental challenges stem primarily from inadequate market mechanisms. They suggest that incorporating environmental costs into pricing systems could redirect market forces toward ecological preservation. The green growth paradigm is built on the premise that technological innovation and market-based solutions can address environmental challenges without requiring fundamental changes to existing economic and social structures. This perspective maintains that economic development and environmental protection can be mutually beneficial objectives. At its core, green growth theory seeks to create a balanced approach where economic expansion occurs alongside, rather than at the expense of, environmental conservation [24,25]. This perspective suggests that technological innovation and improved efficiency can enable continued economic prosperity while simultaneously reducing the environmental footprint of human activities. The goal is to maintain or enhance economic output while progressively lowering the total volume of natural resources consumed in the process.

The green growth model emphasizes technological advancement as its primary mechanism for achieving sustainability goals [26]. This approach focuses on enhancing production efficiency through innovative technologies, rather than advocating for significant changes in consumer behavior or consumption patterns. The fundamental strategy centers on developing and implementing sophisticated technological solutions that can maximize output while minimizing resource inputs. Under this framework, the key to environmental preservation lies in technological innovation that can improve resource utilization in manufacturing processes. This perspective suggests that continued economic expansion is possible without increasing environmental pressure, primarily through enhanced production methods and improved efficiency. Rather than calling for major shifts in lifestyle or consumption habits, this model prioritizes technological solutions to environmental challenges.

Based on green growth theory, the sustainable development of airport infrastructure in the Guangdong-Hong Kong-Macao Greater Bay Area should focus on achieving economic growth while minimizing environmental impact through technological innovation and market-based solutions.

3. Challenges for the Guangdong-Hong Kong-Macao Greater Bay Area Airport Industry within Global Value Chains

3.1 Global Value Chains Impacts on Guangdong-Hong Kong-Macao Greater Bay Area Airport-Related Industries

With the continuous acceleration of economic globalization, the institutional barriers to cross-border production layout have gradually weakened, the product production process on a global scale has been reorganized, and a new global value chain division of labor has been formed [27]. The information technology revolution has also promoted the formation of the global industrial value chain. According to the global value chain smile curve (as shown in Figure 1), a country's position or stage in the global value chain determines its industrial level and national competition standards [28]. At present, advances in transportation technology have significantly reduced the cost of cross-border flow of goods. The airport economy has become one of the important ways for countries and even regions to participate in global competition, and it is also the main means to improve competitiveness [29].

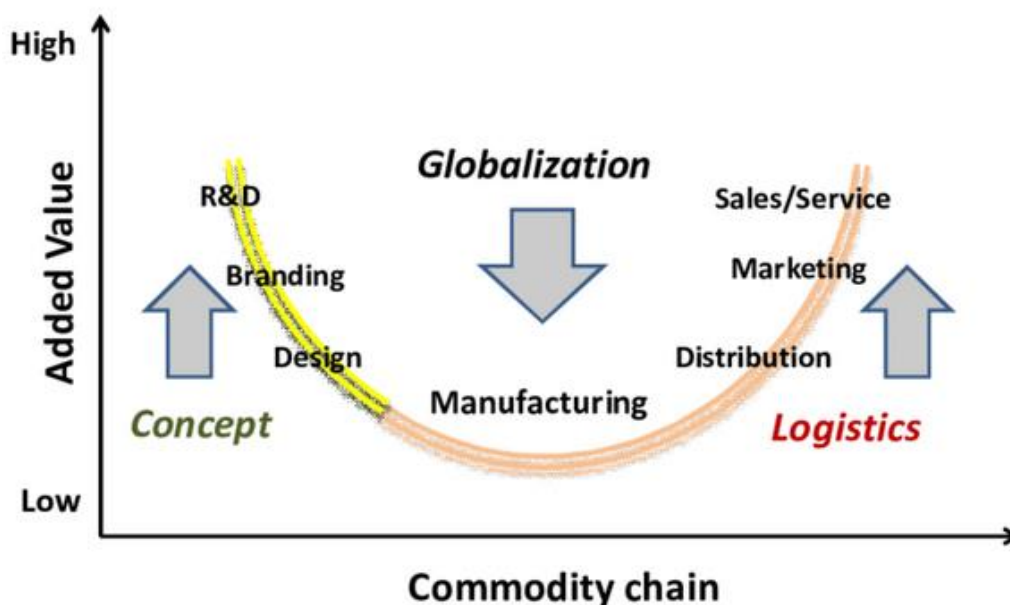


Figure 1. Global value chain smile curve

As the world enters the era of digital economy, the servitization of manufacturing has become the most significant feature of the global value chain [30]. The deep empowerment of industries by digital information technology has led to the degree of servitization of the manufacturing industry becoming the key for manufacturing companies to enter the middle and high end of the global value chain [31]. The widespread application of digital technology in the digital economy era and the deep empowerment of all links in the global value chain have caused the "smile curve" of the value chain to shrink in the middle and become steeper at both ends, exacerbating the inequality in the division of labor among enterprises in the global value chain and the inequality in the world economic and trade pattern.

Currently, the Sino-US trade conflict has posed challenges to China's entry into the high value-added links of the global value chains [32]. In order to avoid this impact, China needs to establish an independent and controllable industrial chain and improve the global layout of the industrial chain [33]. On the other hand, it also needs to pay attention to the layout of the airport economy and airport industry, and make the processing and manufacturing links the "chain leader" of the value chain by extending the value chain, and rely on innovation to enter the middle and high end of the global value chain. Only in this way can China occupy a favorable position in the global competition and enhance its position in the global value chain.

The integration of green growth principles into airport industry planning in the Guangdong-Hong Kong-Macao Greater Bay Area holds paramount practical significance in today's context. As one of the world's most dynamic economic regions with five major airports, the Guangdong-Hong Kong-Macao Greater Bay Area faces mounting environmental pressures from increasing air traffic demands, making sustainable development crucial for long-term viability. China's commitment to carbon neutrality by 2060 and Hong Kong's 2050 carbon neutrality goal, green airport development becomes essential for meeting these national and regional environmental targets. Additionally, green growth strategies can help mitigate local environmental impacts such as noise pollution and air quality issues, which is particularly crucial given the Guangdong-Hong Kong-Macao Greater Bay Area's high population density and urban development.

3.2 Current status of airport-related industries in the Guangdong-Hong Kong-Macao Greater Bay Area

The Guangdong-Hong Kong-Macao Greater Bay Area consists of 11 city clusters distributed around the Pearl River Delta, including Guangzhou, Shenzhen, Zhuhai, Foshan, Huizhou, Dongguan, Zhongshan, Jiangmen, Zhaoqing, Hong Kong and Macao [34]. As one of the most open and economically dynamic regions in China, the Guangdong-Hong Kong-Macao Greater Bay Area is listed as one of the world's four major bay areas along with the New York Bay Area, the San Francisco Bay Area and the Tokyo Bay Area [35]. From the perspective of spatial layout, the 11 cities included in the Guangdong-Hong Kong-Macao Greater Bay Area are closely connected and have certain geographical and transportation advantages. It is one of the most economically developed regions in China, with the largest bay area land area and the largest population, and has good conditions for building a world-class bay area economy [36]. The population, passenger throughput, cargo and mail throughput and global international cargo and mail volume of the Guangdong-Hong Kong-Macao Greater Bay Area far exceed those of the other three major bay areas [37]. The International Air Transport Association predicts that by 2030, the passenger and cargo demand in the Guangdong-Hong Kong-Macao Greater Bay Area will reach 387 million and 20 million tons respectively [38]. In order to meet the growing aviation demand, it is necessary to accelerate the construction of airport clusters, the transformation and upgrading of industrial structure and the improvement of regional transportation structure to support the rapid growth of the Greater Bay Area's economic scale. Supporting airport-related industries and achieving industrial upgrading will ultimately benefit urban development and national prosperity.

3.3 Critical Issues in the Development of the Guangdong-Hong Kong-Macao Greater Bay Area Airport Industry

3.3.1 The Guangdong-Hong Kong-Macao Greater Bay Area airport industry: confronting problems of coordination, innovation, and sustainability

The Guangdong-Hong Kong-Macao Greater Bay Area currently hosts multiple international airports; however, inter-airport coordination and cooperation remain suboptimal. This deficiency results in resource redundancy, operational inefficiencies, and a neglect of critical environmental protection considerations. Consequently, achieving effective inter-airport collaboration, enhancing overall operational efficiency, and addressing environmental concerns represent pressing challenges. Furthermore, the Guangdong-Hong Kong-Macao Greater Bay Area's aviation industry chain exhibits a lack of upstream and downstream enterprise coordination, hindering its complete development. Notably, in high-value sectors such as aircraft manufacturing, maintenance, repair, and overhaul, and specialized training, resource and enterprise distribution across the region remains uneven, impeding the full realization of industrial agglomeration effects. Moreover, the airport industry's advancement necessitates robust scientific and technological innovation. Nevertheless, the Guangdong-Hong Kong-Macao Greater Bay Area's current investment in, and output from, aviation-related research and development, as well as the commercialization of innovative technologies, remain inadequate. Thus, fostering collaboration between research institutions and industry stakeholders to bolster technological innovation capabilities constitutes a significant challenge for the Guangdong-Hong Kong-Macao Greater Bay Area's airport sector. Finally, the Guangdong-Hong Kong-Macao Greater Bay Area encompasses Guangdong Province, the Hong Kong Special Administrative Region, and the Macao Special Administrative Region, each with distinct policies, regulations, and administrative frameworks. Harmonizing these disparate elements to achieve policy coherence, optimize the business environment, and facilitate factor mobility will require a sustained and concerted effort.

3.3.2 Infrastructural deficits, environmental concerns, and the talent shortage: challenges facing Guangdong-Hong Kong-Macao Greater Bay Area airport development

Despite ongoing advancements in airport and associated infrastructure development within the Guangdong-Hong Kong-Macao Greater Bay Area, certain airport economic zones exhibit infrastructural limitations, particularly in cities such as Zhaoqing, Huizhou, and Jiangmen. The nascent development of these Airport Economic Zones (AEZs) is characterized by limited flight frequencies, restricted route coverage, and underdeveloped supporting facilities, consequently hindering the agglomeration and growth of airport-centric industries. Furthermore, the expansion of airport-related industries imposes significant environmental and resource demands. Consequently, achieving environmentally sustainable development while mitigating pollution and resource depletion constitutes a critical challenge for the Guangdong-Hong Kong-Macao Greater Bay Area's aviation sector. Finally, the advancement of airport-related industries necessitates a substantial pool of highly qualified professionals. However, the Guangdong-Hong Kong-Macao Greater Bay Area currently faces a shortage of skilled personnel in specialized fields such as aviation technology and logistics management. Therefore, attracting and cultivating a robust talent pipeline emerges as a pivotal factor in facilitating the upgrading and sustainable development of the region's aviation industry.

3.3.3 Strategic deficits, environmental neglect, and industrial fragmentation in the Guangdong-Hong Kong-Macao Greater Bay Area airport sector

The Guangdong-Hong-Kong-Macao Greater Bay Area's airport-related industries currently lack a cohesive, region-wide strategic plan, particularly one that integrates environmental protection objectives. Presently, Airport Economic Zones across the Guangdong-Hong Kong-Macao Greater Bay Area are developing autonomously, devoid of a unified planning and coordination framework. This decentralized approach results in resource dispersion, inhibits the formation of synergistic relationships, and risks overlooking crucial environmental considerations. Furthermore, upstream and downstream industrial chains within these AEZs exhibit inadequate integration, with limited synergistic interaction among logistics, manufacturing, and service sectors, thus impeding the development of a comprehensive industrial ecosystem. Additionally, insufficient information

sharing mechanisms hinder effective communication and resource exchange among AEZs, constraining inter-enterprise collaboration in areas such as supply chain management and market intelligence. Moreover, the absence of clearly defined industrial positioning for AEZs has led to a lack of differentiation in several cities, fostering industry homogeneity, redundant infrastructure development, and resource inefficiency. Finally, many AEZs remain heavily reliant on traditional manufacturing and processing trade activities, with a comparatively low proportion of innovation-driven high-technology industries and modern service sectors, rendering them ill-equipped to meet the evolving demands of a contemporary airport-centric economic model.

3.3.4 Transportation bottlenecks, environmental concerns, and planning fragmentation in the Guangdong-Hong Kong-Macao Greater Bay Area AEZs

Currently, transportation connectivity between AEZs and their respective urban centers within the Guangdong-Hong-Kong-Macao Greater Bay Area remains inadequate. Several cities are characterized by a deficiency in efficient public transit and expressway networks, resulting in protracted travel times and diminished accessibility. Furthermore, inter-city transportation linkages among Guangdong-Hong Kong-Macao Greater Bay Area cities exhibit a lack of coordination, impeding seamless logistics and personnel mobility within the region. The deficiency is further compounded by an underdeveloped comprehensive transportation system within the Guangdong-Hong Kong-Macao Greater Bay Area's AEZs. Specifically, the integration of various transportation modalities, including road, rail, waterway, and aviation, remains insufficient, posing challenges not only to efficient mobility but also to environmental sustainability goals. Moreover, overlapping industrial positioning and fragmented planning efforts have led to a lack of differentiation among the Guangdong-Hong Kong-Macao Greater Bay Area's AEZs. Multiple cities are concurrently pursuing the development of similar airport-centric industries, such as logistics, manufacturing, and commerce, resulting in resource redundancy and intensified intra-regional competition. This issue is further exacerbated by the autonomous development planning processes undertaken by individual AEZs, which lack regional coordination and synergy, thus hindering the realization of a cohesive and optimized regional development outcome. A greater emphasis on integrating environmental protection into transportation planning within the AEZs is crucial for achieving long-term sustainability.

4. Enhancing the Global Value Chains Competitiveness of Airport-Related Industries in the Guangdong-Hong Kong-Macao Greater Bay Area

4.1 Strategic Development and Industrial Collaboration for the Guangdong-Hong Kong-Macao Greater Bay Area Airport Sector

The advancement of the airport industry within the Guangdong-Hong-Kong-Macao Greater Bay Area presents a significant opportunity to bolster regional economic development. This can be achieved through enhancing the Guangdong-Hong Kong-Macao Greater Bay Area's status as a global aviation hub, optimizing its industrial structure and upgrading, and fostering regional cooperation. A strategic development framework for the Guangdong-Hong Kong-Macao Greater Bay Area airport industry is proposed, encompassing the following three key pillars:

- 1) **Elevating Global Aviation Hub Status:** This involves strengthening synergistic coordination among major airports, including Guangzhou Baiyun International Airport, Shenzhen Bao'an International Airport, Hong Kong International Airport, and Macau International Airport. Efforts should focus on augmenting airport capacity, optimizing air traffic management systems, and elevating service quality to establish the Guangdong-Hong Kong-Macao Greater Bay Area as a preeminent international aviation hub [39].
- 2) **Optimizing Spatial Layout and Industrial Agglomeration:** This entails the strategic planning and development of AEZs surrounding the primary airports. Priorities include fostering the agglomeration of key industries such as aviation logistics, aircraft maintenance, repair, and overhaul, and advanced aviation

manufacturing, thereby forming a multi-nodal airport industrial network characterized by functional complementarity [40].

3) Promoting Industry-City Integration: This necessitates the development of integrated aviation-centric urban centers in proximity to airports. These centers should encompass comprehensive supporting infrastructure, including commercial, residential, educational, and healthcare facilities, to facilitate the deep integration of the airport economy with urban development [41].

4.2 Achieving Full Value Chain Integration in Airport-Related Industries: A Strategic Approach

Leveraging international best practices in airport development and principles of green growth theory, a holistic and sustainable approach is imperative for the advancement of the airport industry within the Guangdong-Hong-Kong-Macao Greater Bay Area. This necessitates the establishment of a robust industrial ecosystem that not only fosters interconnectedness across the value chain but also prioritizes environmental stewardship and resource optimization [42].

The 11 cities within the GBA possess unique developmental trajectories and environmental contexts. Therefore, a differentiated approach, informed by green growth principles, is crucial. When developing their airport industries, these cities should tailor their strategies to their specific regional advantages, environmental capacities, and technological capabilities. This involves identifying and developing currently underdeveloped or niche 'blue ocean' industries within the broader value chain that align with green growth principles. Such industries might include sustainable aviation fuel production, green logistics, or environmental technology innovation hubs.

Furthermore, strategic spatial planning, guided by resource efficiency and ecological considerations, should be implemented. This approach allows each city to fully leverage the region's geographical advantages while fostering sustainable connections between upstream and downstream segments of the value chain [43].

Concurrently, the establishment of a Guangdong-Hong Kong-Macao Greater Bay Area wide development coordination mechanism is paramount. This mechanism should not only facilitate the integrated management of shoreline resources but also actively promote a green division of labor and cooperation system. Crucially, it should incorporate market-based environmental management instruments, such as emissions trading schemes or green taxes, alongside unified environmental standards and monitoring systems [44].

Specifically for air-side industries, the differentiated development strategy should prioritize green technologies and practices. Cities with strong research capabilities could focus on developing and deploying advanced air traffic management systems to improve fuel efficiency. Others might specialize in areas like electric ground support equipment or sustainable airport infrastructure. By identifying and filling gaps in the green technology value chain, each city can contribute to a more sustainable and resilient air-side industry ecosystem [45].

This integrated, green growth-oriented approach will facilitate the expeditious yet environmentally responsible development of airport-related industries within the Guangdong-Hong Kong-Macao Greater Bay Area. It will contribute to sustained economic prosperity while safeguarding the region's ecological integrity. The core principle is to decouple economic growth from environmental degradation by fostering innovation, implementing effective environmental policies, and promoting regional cooperation. This strategy will position the Guangdong-Hong Kong-Macao Greater Bay Area as a global leader in sustainable airport development, aligning economic progress with long-term environmental sustainability [46].

4.3 Enhancing Service Quality Across the Airport Economy Value Chain: An International Benchmarking Approach

The aviation industry value chain encompasses five principal production and service segments: design and development, manufacturing, operational services, maintenance, repair, and overhaul, and service support [47]. This extensive value chain exerts a significant driving force on regional economic development. To attract a

greater concentration of aviation-related businesses and enhance the sustainable development capacity of airport industrial parks within the Guangdong-Hong-Kong-Macao Greater Bay Area, it is crucial to elevate the service capacity and operational efficiency of the airport economy [48]. This extensive value chain exerts a significant driving force on regional economic development. To attract a greater concentration of aviation-related businesses and enhance the sustainable development capacity of airport industrial parks within the Guangdong-Hong-Kong-Macao Greater Bay Area, it is crucial to elevate the service capacity and operational efficiency of the airport economy. Airports within the Guangdong-Hong Kong-Macao Greater Bay Area should provide stable, reliable, efficient, and high-quality support services tailored to the specific needs of diverse airlines. These services encompass a range of critical functions, including aviation fueling, aircraft parking and layover, and information management. For example, implementing advanced digital platforms for real-time information sharing between airports and airlines can significantly improve turnaround times and enhance overall operational efficiency [49]. The quality of these support services, as well as the responsiveness of service delivery, are pivotal factors influencing airlines' decisions regarding collaboration and establishment within the Guangdong-Hong Kong-Macao Greater Bay Area.

4.4 A Systems Approach to Transportation Hub Integration for Sustainable Development of the Guangdong-Hong Kong-Macao Greater Bay Area Airport Economy

The development of the airport economy within the Guangdong-Hong-Kong-Macao Greater Bay Area necessitates a framework of mutual cooperation, support, a clear division of labor, and a steadfast commitment to both environmental protection and green growth among the region's international hub airports (Guangzhou, Shenzhen, Hong Kong, and Macau) and secondary airports (Zhuhai, Zhaoqing), Huizhou, and Jiangmen). This collaborative approach will ultimately foster the sustainable and synergistic upgrading of the entire Guangdong-Hong-Kong-Macao Greater Bay Area airport industry. By capitalizing on the inherent advantages of the Bay Area and leveraging the strategic role of its transportation hubs, a mutually beneficial scenario can be realized among the various airports, strengthening resource complementarity and fostering reciprocal assistance to enhance overall synergistic performance. In this developmental trajectory, it is crucial to adaptively apply the airport economy development model, tailoring it to the specific stage characteristics of each airport, with a concerted focus on integrating green technologies, promoting resource efficiency, and minimizing environmental impacts [50]. This will promote coordinated industrial development, continuously enhance the comprehensive strength and international competitiveness of the Guangdong-Hong-Kong-Macao Greater Bay Area's airport economy, and establish a model for environmentally responsible airport development.

5. Conclusion

The Guangdong-Hong Kong-Macao Greater Bay Area holds immense potential for developing a world-class airport economy, but its current state is hampered by a series of interconnected challenges. These include a lack of cooperation and coordination among the region's multiple international airports, leading to inefficient resource allocation and intensified competition. The industrial clusters are underdeveloped, particularly in high-end sectors like aviation manufacturing and maintenance, and technological innovation remains insufficient. Policy harmonization across Guangdong, Hong Kong, and Macao is still a work in progress. Furthermore, some airport economic zones suffer from inadequate infrastructure, especially in cities like Zhaoqing, Huizhou, and Jiangmen, while also facing environmental pressures and a shortage of high-end talent. The airport industry chain integration is weak, with unclear industry positioning and an overreliance on traditional development models. Finally, insufficient coordination among transportation hubs, an imperfect multimodal transport system, and a lack of synergy among airport economic industries further hinder progress.

To overcome these challenges and unlock the Guangdong-Hong Kong-Macao Greater Bay Area's full potential, a comprehensive and coordinated approach is necessary. The overarching strategy should focus on enhancing the region's status as an international aviation hub, optimizing the spatial layout of airport economic zones, and promoting the integration of industry and city development. Clear development goals should be established,

aiming for the creation of a world-class aviation hub by 2035, the formation of robust industrial clusters, and the promotion of regional coordinated development through policy coordination and resource sharing.

Crucially, achieving full industry chain integration, clarifying the positioning of airport-related industries, and innovating development models are paramount. This involves adopting a differentiated, green growth-oriented approach tailored to each city's unique strengths and environmental context. It also necessitates establishing a Guangdong-Hong Kong-Macao Greater Bay Area -wide development coordination mechanism that promotes a green division of labor and cooperation system, incorporates market-based environmental management tools, and unifies environmental standards.

Improving the service quality of the entire industrial chain, benchmarked against international standards, is essential for attracting related industries and fostering sustainable growth. Moreover, leveraging the advantages of the Bay Area and its transportation hubs will enhance overall synergy. This requires a collaborative approach among international hub airports and branch trunk airports, fostering a win-win situation through resource complementarity and mutual support.

In conclusion, the development of the airport economy in the Guangdong-Hong Kong-Macao Greater Bay Area requires a strategic shift from isolated, competitive growth to a coordinated, integrated, and sustainable model. By addressing the existing challenges through enhanced cooperation, strategic planning, green innovation, and a focus on service quality, the Guangdong-Hong Kong-Macao Greater Bay Area can establish a world-leading airport economy that drives economic prosperity while ensuring environmental sustainability. This collaborative and forward-thinking approach will be crucial to realizing the full potential of the region and solidifying its position as a global economic powerhouse.

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