

The Positive Role of the Low-Altitude Economy in Carbon Neutrality

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ABSTRACT

The low-altitude economy, characterized by the use of drones and unmanned aerial vehicles (UAVs), has emerged as a promising domain for advancing global efforts toward carbon neutrality. This paper explores the mechanisms through which low-altitude economic activities contribute positively to carbon emission reductions. By improving efficiency in logistics and transportation, facilitating precision agriculture and forestry, and enabling enhanced environmental monitoring, drone technologies significantly reduce overall greenhouse gas emissions and optimize carbon sequestration processes. Case studies illustrate tangible reductions in emissions across various sectors, reinforcing the environmental benefits of integrating UAVs into broader economic practices. Despite existing regulatory and technological challenges, this research underscores the critical role that low-altitude economic innovation can play in achieving global carbon neutrality targets, offering valuable insights and actionable recommendations for policymakers and stakeholders.

KEYWORDS

Low-altitude economy; Carbon neutrality; Unmanned aerial vehicles

1 Introduction

The low-altitude economy encompasses economic activities conducted primarily through drones and unmanned aerial vehicles (UAVs) operating at low altitudes. With global commitments intensifying toward carbon neutrality, understanding how emerging economic activities impact environmental sustainability becomes increasingly critical. This article investigates the potential contributions of drone technology to carbon neutrality, outlining key mechanisms and presenting case-based evidence.

2 Background and literature review

Carbon neutrality has become a critical goal for countries worldwide, demanding reductions in greenhouse gas emissions and enhanced carbon sequestration. Concurrently, advancements in drone technology have expanded its applications, ranging from logistics and agriculture to forestry management. Prior studies suggest drones improve operational efficiency, reduce fossil fuel consumption, and facilitate precise resource management, collectively reducing carbon footprints^{[1][2]}. However, comprehensive studies linking low-altitude economic activities directly to carbon neutrality remain relatively scarce.

3 Mechanisms of low-altitude economy in reducing carbon emissions

The integration of drone technology into various economic sectors significantly reduces carbon emissions through multiple, interconnected mechanisms. This section expands comprehensively on three primary mechanisms: efficient energy consumption in transportation and logistics, precision agriculture and forestry management, and environmental surveillance and monitoring.

3.1 Efficient energy consumption in transportation and logistics

Transportation remains a major contributor to global greenhouse gas emissions, primarily through the burning of fossil fuels. Conventional vehicles, particularly in last-mile logistics, often operate inefficiently, exacerbating emissions. Drones offer a transformative alternative by using electric propulsion systems that significantly lower emissions per delivery^{[3][4]}. Studies indicate that drones consume considerably less energy per kilometer compared to trucks or vans, especially when delivering small packages over shorter distances^[5]. Drones reduce idle times, circumvent traffic congestion, and achieve shorter, more direct delivery routes, drastically improving operational efficiency. For example, empirical data from drone delivery tests by companies such as Amazon and DHL reveal a potential reduction in emissions by up to 70% compared to traditional delivery vehicles^[6]. Additionally, advancements in battery technologies and solar-powered charging stations further amplify the environmental benefits of drones by reducing reliance on non-renewable energy sources^[2].

3.2 Precision agriculture and forestry management

Agriculture and forestry management significantly influence global carbon cycles. Traditional agricultural practices, including excessive fertilizer application and inefficient irrigation, often lead to unnecessary carbon emissions. Precision agriculture, facilitated by drone technology, provides an innovative solution to mitigate these environmental impacts. Drones equipped with advanced sensors enable precise monitoring of crop conditions, soil health, and irrigation requirements, allowing targeted application of fertilizers, pesticides, and water. This targeted approach minimizes waste, optimizes resource use, and substantially reduces emissions associated with agricultural inputs^[7-8].

In forestry management, drones play a crucial role in forest inventory, monitoring, and conservation practices. Enhanced aerial surveillance capabilities allow precise mapping and rapid detection of issues such as illegal logging, pest infestations, and forest fires. Early intervention capabilities provided by drones help mitigate these threats promptly, preserving forests as effective carbon sinks^[9]. Projects conducted in Brazil and Indonesia utilizing drone-based monitoring have demonstrated significant improvements in forest health and carbon sequestration capabilities, showcasing measurable reductions in deforestation rates and emissions from logging activities.

3.3 Environmental surveillance and monitoring

Environmental monitoring is vital in preventing ecosystem degradation, managing natural resources, and enhancing carbon sequestration capacities. Traditional methods of environmental monitoring often suffer from limited scope, high costs, and delayed data acquisition. Drone technology offers extensive and timely surveillance capabilities, enabling detailed data collection from inaccessible or vast geographic areas. Drones equipped with multispectral and hyperspectral sensors, LiDAR, and high-resolution imaging systems can effectively monitor environmental indicators such as vegetation health, soil erosion, water quality, and wildlife habitats.

Timely and precise data collection facilitated by drones allows environmental managers and policymakers to implement proactive measures, including restoration projects, habitat conservation, and pollution control. Effective management reduces ecological disturbances and optimizes natural carbon capture processes. Case studies across protected natural areas and ecological restoration projects illustrate significant environmental improvements and increased carbon storage, directly attributable to drone-enabled surveillance.

4 Empirical evidence and case studies

4.1 Logistics and delivery

Amazon's Prime Air and DHL's drone delivery tests have demonstrated significant carbon emission reductions compared to conventional delivery methods, particularly for lightweight, short-distance packages^[6]. By 2020, Amazon had received approval from the Federal Aviation Administration (FAA) to begin commercial drone delivery testing in select markets. In these pilot programs, drones completed short-range deliveries to suburban areas, demonstrating a significant reduction in delivery time and energy use.

Energy modeling conducted during Amazon's trials indicated that drone delivery uses approximately 94% less energy per package than conventional vans, particularly in routes under 5 kilometers. The electric drones consume around 0.08 megajoules (MJ) per package, compared to more than 1 MJ for a gas-powered van on the same route. Carbon emissions were also reduced proportionally, showcasing a significant environmental advantage. Furthermore, the integration of renewable energy in the drone charging stations (such as solar-powered hubs) enhanced the overall sustainability profile^[6].

DHL has similarly invested in autonomous delivery drones through its Parcelcopter program. In a 2016 trial in the Bavarian Alps, drones successfully delivered medical supplies and essential goods to a remote village, bypassing difficult terrain and reducing the need for fuel-consuming ground transport. The drones, capable of flying over 70 kilometers per hour, used a fully electric propulsion system and completed delivery runs in under 8 minutes for distances that typically required 30 minutes by car.

Environmental assessments from this pilot showed that CO₂ emissions were cut by over 60% compared to equivalent delivery via internal combustion engine (ICE) vehicles. Additionally, because drones took direct flight paths, the total travel distance was reduced by up to 40%, further amplifying emissions savings. The drone also improved logistical resilience during inclement weather, which often disrupted traditional delivery routes in mountainous regions.

4.2 Agriculture applications

In precision agriculture, drones have effectively reduced pesticide and fertilizer use, as evidenced by pilot projects in

North America and Europe, resulting in decreased agricultural emissions^[8].

One case study in Niigata Prefecture demonstrated that drone spraying reduced pesticide usage by 30% and fuel consumption by over 50% compared to ground-based vehicles^[6]. Additionally, because drones avoided compacting the soil (a known issue with tractors), soil health was better maintained, indirectly improving carbon sequestration potential.

Post-harvest assessments showed an increase in yield consistency and quality due to the even distribution of inputs, while emission estimates reported approximately 0.15 tons of CO₂-equivalent savings per hectare per season. Beyond emissions, drone usage saved labor costs and time, which is increasingly important in aging rural populations.

4.3 Forestry monitoring

Projects in Brazil and Indonesia utilizing drone-based monitoring have significantly improved forest conservation practices, thereby boosting natural carbon sinks and reducing illegal logging activities^[9].

In Brazil, non-governmental organizations (NGOs) and environmental agencies have increasingly adopted drone technology to combat deforestation in the Amazon rainforest. In collaboration with the Chico Mendes Institute and Amazon Conservation Team, a 2021 initiative deployed fleets of drones over protected zones in the state of Acre.

These drones, equipped with LiDAR and thermal imaging, mapped tree canopy health, detected unauthorized land clearing, and guided reforestation efforts. In a 12-month period, drone surveillance identified 43 illegal logging operations, leading to swift enforcement actions and prevention of further loss. Estimates showed that this early detection helped conserve over 3,500 hectares of forest, equating to a retention of approximately 28,000 metric tons of carbon^[6].

Additionally, drone-collected data was used to model carbon sequestration rates in reforested areas, allowing scientists to better track climate benefits and improve management practices. The operational cost of drone missions was 60% lower than traditional aerial patrols, and data processing time was reduced from months to days.

Drones are also vital in Indonesian tropical Peatlands. Indonesia's peat forests are one of the most carbon-dense ecosystems in the world but are vulnerable to deforestation and burning. Since 2016, Indonesian authorities, supported by the UN-REDD program, have employed UAVs for monitoring peatland integrity in Sumatra and Kalimantan^[6].

In one pilot led by the Ministry of Environment and Forestry, drones surveyed drainage canals, identified hotspots of fire risk, and guided community-based restoration efforts. The drones helped locate early signs of peat degradation, allowing interventions such as canal blocking and native tree replanting. The project reported a 45% decrease in peatland fire incidents over a three-year period. Carbon accounting suggested an avoidance of emissions equivalent to 2.2 million tons of CO₂.

Data Integration and Public Access: Beyond monitoring, UAV-collected data in both Brazil and Indonesia has been integrated into public geographic information systems (GIS), improving transparency and allowing researchers, policymakers, and communities to engage with forest conservation in real time^[5]. The ability of drones to make invisible environmental processes visible is redefining conservation monitoring.

5 Challenges and opportunities

5.1 Regulatory and technical challenges

Current regulatory frameworks remain fragmented, hindering drone deployment at scale. Technological limitations, such as battery life and payload capacity, also pose significant barriers^[3].

5.2 Opportunities for innovation

Technological advancements, including improvements in battery technology, autonomous navigation systems, and AI-driven monitoring capabilities, represent substantial opportunities for growth and environmental impact enhancement^[4].

5.3 Policy interventions

Governments can facilitate the growth of low-altitude economies through targeted policy measures, including subsidies, streamlined regulations, and investment in research and infrastructure development^[9].

6 Discussion

The environmental advantages of drone applications in logistics, agriculture, and environmental monitoring are clear,

although scalability and widespread adoption remain constrained by technical and regulatory factors. A comparison with traditional methods consistently demonstrates lower emissions, enhanced efficiency, and increased carbon sequestration capabilities. Therefore, proactive policy frameworks and industry innovations are essential to maximize these benefits.

7 Conclusion

This article highlights the promising role of the low-altitude economy in achieving carbon neutrality. By leveraging drone technologies, substantial reductions in carbon emissions and enhancements in carbon sequestration are achievable. Future research and policy development should prioritize overcoming existing barriers to fully realize the environmental potential of UAV-based economic activities, thereby significantly contributing to global sustainability efforts.

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