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STRATEGIC AND ECONOMIC FEASIBILITY OF HYDROGEN INTEGRATION IN AIRPORTS: A CASE STUDY OF TIRANA INTERNATIONAL AIRPORT

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Abstract: *Hydrogen and fuel cell technologies are increasingly recognized as strategic tools for decarbonizing the aviation sector, offering not only environmental benefits but also operational and economic value. However, their effective integration within complex airport ecosystems remains underexplored, particularly concerning investment planning and infrastructure management. This study evaluates the technical, environmental, and economic feasibility of deploying hydrogen technologies at Tirana International Airport (TIA), focusing on both stationary and mobility applications powered by rooftop photovoltaic (PV) systems. Scenario-based modeling shows that allocating 25% of TIA's PV output could produce approximately 5,750 kg of green hydrogen annually—sufficient to supply 96 MWh of clean electricity or support 63,889 km of hydrogen-powered vehicle travel. The environmental assessment reveals a net annual* CO_2 *reduction of 58,576 kg, primarily from mobility uses, which alone account for 70,181 kg of avoided emissions. Economic analysis estimates the Levelized Cost of Hydrogen (LCOH) at €6.91/kg under current conditions, with potential to decline to €4.45/kg in a lower-CAPEX scenario. The corresponding cost for hydrogen mobility ranges from €1.16/km to €0.85/km, depending on technology and investment assumptions. These results highlight the importance of capital planning, utilization rates, and cost optimization strategies for real-world deployment. A SWOT analysis is used to identify strategic enablers and barriers, revealing key opportunities such as access to EU funding, public-private partnerships (PPPs), employment creation, and the potential to position TIA as a green infrastructure leader in the Western Balkans. The study concludes that hydrogen integration, if paired with targeted investment, institutional support, and coordinated stakeholder engagement, can significantly enhance airport resilience, energy autonomy, and economic competitiveness, aligning with both national policy priorities and broader European sustainability goals.*

Keywords: *Hydrogen Technologies, Economic Feasibility, Strategic Airport Management, Green Energy Transition, SWOT analysis*

1. INTRODUCTION

Air transport is a key driver of global socio-economic development, generating direct, indirect, and induced economic impacts through employment, service provision, and supply chains (Dimitrios & Maria, 2018, p. 285; Cristureanu & Bobircă, 2007, p. 34). The expansion of airport infrastructure not only supports the aviation industry but also stimulates regional economic growth, enhances connectivity, and improves access to global markets (Zhang & Graham, 2020).

Albania has seen a significant surge in air passenger traffic, with over 10 million passengers processed at Tirana's "Mother Teresa" International Airport in 2024 (Tirana International Airport, 2024). Following its planned expansion, the airport aims to handle up to 15 million passengers annually, reinforcing its role as a key regional hub. According to ACI Europe (2023), the total economic impact of airports in Albania—including direct, indirect, induced, and catalytic effects—contributes approximately €0.4 billion to the national GDP and supports around 6,500 jobs. However, the rapid growth of tourism brings challenges related to safety, operational costs, and energy efficiency (Baroutaji et al., 2019, p. 35). Airports are high-energy consumers (Ortega Alba & Manana, 2017, p. 5), and as operations expand, so do carbon emissions due to increasing power demands from terminals, ground vehicles, and infrastructure (El Zein et al., 2025, p. 1363).

To reduce their climate footprint, airports are adopting sustainability strategies focused on decarbonization, energy efficiency, and green infrastructure (Degirmenci et al., 2023, p. 6). Tirana International Airport (TIA) has embraced this transition by installing solar panels, replacing traditional lighting with LEDs, incorporating electric vehicles, and deploying energy-efficient systems (Farabbi, 2024, pp. 6-8). Given their scale and energy demand, airports are well-positioned to adopt next-generation clean technologies. Among these, hydrogen and fuel cell systems are emerging as promising solutions for decarbonizing operations. With global hydrogen demand expected to increase nearly eightfold by 2050 (Rasul et al., 2015, p. 112), these technologies offer advantages such as high energy density, improved efficiency, and minimal noise, making them ideal for reducing emissions in airport environments (Wu et al., 2025, p. 715). Growing research highlights the feasibility of hydrogen and fuel cell systems in airport settings, including fixed installations such as microgrids and ground operations, as well as mobile applications like hydrogen-powered aircraft. Studies explore energy efficiency, emissions reductions, infrastructure needs, and cost-effectiveness. For instance, Zhou (2022) investigates hydrogen storage for low-carbon airport systems, while Xiang et al. (2021) propose a hydrogen-solar microgrid for electrification. Gu et al. (2023) address infrastructure needs for hydrogen-fueled aircraft, and Testa et al. (2014) document environmental benefits in ground handling. Degirmenci et al. (2023) assess the sustainability and cost structure of hydrogen supply chains, and Baroutaji et al. (2019) provide a comprehensive review of aviation-related hydrogen technologies. Recent literature also emphasizes the broader economic, innovation, and policy contexts driving such technological transitions. Abbasov (2024) and Korohod (2023) underline the importance of green economy frameworks and decarbonization strategies in addressing global environmental and energy challenges. Živanović et al. (2023) highlight the role of innovation management in improving sustainability performance and business excellence, while Hysaj and Sulçaj (2024) demonstrate the positive impact of infrastructure-focused innovation on economic growth in the Western Balkans.

Framing hydrogen deployment at TIA through the lens of the enterprise ecosystem further reinforces its strategic relevance. As Nahara (2024) explains, enterprise ecosystems grounded in sustainable development promote cross-sectoral collaboration, knowledge exchange, and flexible innovation pathways. These ecosystems enable autonomous actors, such as airports, energy providers, and public institutions, to cooperate dynamically, thereby maximizing synergy and accelerating green transformation. Positioning TIA as a hub within such an ecosystem highlights its potential to contribute not only to Albania's decarbonization efforts but also to regional innovation and resilience.

This study aims to explore the potential integration of hydrogen and fuel cell technologies within the Tirana International Airport (TIA) ecosystem. Specifically, it assesses the technical, environmental, and economic feasibility of applying hydrogen solutions for both stationary and mobile airport operations. Additionally, a SWOT analysis is conducted to evaluate the strategic strengths, weaknesses, opportunities, and threats associated with hydrogen deployment at TIA.

2. METHODOLOGY

This study applies a quantitative, scenario-based methodology to evaluate the feasibility, sustainability, and strategic implications of hydrogen and fuel cell deployment at Tirana International Airport (TIA). The approach integrates technical modeling, environmental performance analysis, and economic feasibility assessments to explore the potential of green hydrogen use in stationary and mobility-related airport operations. Specifically, the methodology includes:

- Energy modeling to estimate hydrogen production from photovoltaic (PV) systems and its conversion efficiency via proton exchange membrane (PEM) fuel cells.
- Emissions analysis to quantify avoided CO_2 emissions compared to diesel-based mobility and grid-based electricity.
- Levelized Cost of Hydrogen (LCOH) and cost-per-kilometer indicators to assess economic viability under different capital expenditure (CAPEX) scenarios.
- Strategic evaluation tools, including a SWOT analysis, to capture the broader operational, regulatory, and investment dimensions relevant for airport management and policy planners.

By combining techno-economic metrics with scenario planning and strategic analysis, this methodology provides not only a sustainability assessment but also decision-support insights for infrastructure managers, energy planners, and investors evaluating green transitions in the airport sector.

2.1.Hydrogen production modelling

Hydrogen production from the airport's rooftop photovoltaic (PV) system is estimated using the following relationship:

$$\mathrm{H_2\ produced} = \frac{\mathrm{E_{PV,allocated}}}{\mathrm{EC_{H_2}}} \qquad \text{(Eq. 1)}$$

Where: $E_{PV,allocated}$ - Annual PV energy allocated for electrolysis (kWh/year); EC_{H_2}- Specific energy consumption of the electrolyzer (kWh/kg H_2)

The hydrogen production potential was estimated based on the annual output of Tirana International Airport's rooftop photovoltaic (PV) system (Figure 1), which generates approximately 1,334 MWh/year.

Figure 1. *Solar panels installed on the roof of a building at Tirana International Airport. Tirana International Airport.*

Source: Vega Group

For modeling purposes, it was assumed that 25% of the airport's energy consumption could be diverted to power an electrolyzer for green hydrogen production. This allocation was informed by an analysis of the official flight departure schedule for Tirana International Airport, which highlighted periods of reduced operational activity, particularly between 10:00 and 15:00. During these hours, the number of departing flights decreases significantly, as confirmed by a detailed breakdown of hourly flight data. These midday hours also align with peak solar photovoltaic (PV) generation, presenting a strategic window in which surplus solar electricity can be utilized without impacting critical airport operations. To estimate hydrogen output, the specific energy consumption of the electrolyzer was set at 58 kWh per kilogram of hydrogen, encompassing both stack performance and auxiliary system loads. In low-temperature electrolyzers like ALK, PEM, and AEM, energy consumption of about 55–60 kWh is expected per kg of hydrogen produced (Franco and Giovannini, 2023, p. 7).

2.2.Energy recovery and mobility estimation

Following the estimation of hydrogen production potential, this section evaluates two key application pathways for the generated hydrogen: stationary energy recovery and airport ground mobility. Each pathway is analyzed to estimate the energy output, operational implications, and corresponding environmental benefits.

Hydrogen produced on-site can be converted back into electricity during periods of peak demand or grid instability using proton exchange membrane (PEM) fuel cells. The energy recovered from hydrogen is calculated using the following relationship:

$$E_{recovered} = \eta_{FC} \times H_2\,produced \times LHV_{H_2} \qquad \text{(Eq. 2)}$$

Where: $E_{recovered}$ - Electrical energy recovered (kWh/year); η_{FC} - Electrical efficiency of the fuel cell (assumed 50%); $H_2\,produced$ - Annual hydrogen production (kg/year); LHV_{H_2} - Lower heating value of hydrogen (kWh/kg)

Hydrogen is also considered a clean fuel alternative for ground support equipment (GSE) such as passenger transport buses, baggage tugs, and service vehicles, which are currently powered by diesel. The annual driving range achievable with the available hydrogen is estimated using:

$$Mobility\ Range_{H_2} = \frac{H_2\,produced \times 100}{C_{veh}} \qquad \text{(Eq. 3)}$$

Where: $Range_{H_2}$- Total driving range (km/year); C_{veh} - Average hydrogen consumption per 100 km (kg H_2/100 km)

For the mobility analysis in this study, performance assumptions for hydrogen refueling stations (HRS) and fuel cell buses (FCBs) were drawn from established industry expectations. A specific fuel consumption of 9 kg H_2 per 100 km was used as the median value for estimating the annual driving range of hydrogen-powered airport vehicles (Buss et al., 2022). The availability of the bus fleet was assumed to be 90%, ensuring consistent service levels comparable to conventional systems. Refueling operations were modeled with a 10-minute average fill time, aligning with operational demands in airport environments.

2.3. Levelized cost of hydrogen (LCOH) calculation

The Levelized Cost of Hydrogen (LCOH) is determined by assessing all costs incurred over the lifetime of a hydrogen production system, including capital expenditures (CAPEX), fixed and variable operational expenditures (OPEX), and electricity costs, relative to the total hydrogen produced over the system's operational period (Equation (1)).

$$LCOH = \frac{LHV}{\eta_{sys,LHV}} + \left(\left(\frac{\left(\frac{i}{100} * \left(1+\frac{i}{100}\right)^n\right)}{\left(1+\frac{i}{100}\right)^n - 1} + \frac{OPEX}{100} \right) \frac{CAPEX}{\tau} + E \right) \qquad \text{(Eq. 4)}$$

Where LCOH: Levelized Cost of Hydrogen [€/kgH_2]; LHV: Lower Heating Value [kWh/kgH_2]; i: Discount Rate [%]; n: Lifetime [a]; E: Electricity Costs [€/kWh]; ηsys, LHV: System Efficiency related to the LHV; τ: Full Load Hours [h]; OPEX: Operational Expenditures [CAPEX/a]; CAPEX: Capital Expenditures [€/kW]

The LCOH was calculated using the Umlaut & Agora Industry Excel tool (v1.0, 2023). The analysis assumes a capital expenditure (CAPEX) of €1,970/kW (Clean Hydrogen Joint Undertaking, 2024), annual operation and maintenance (O&M) costs equal to 3.5% of CAPEX, a 20-year system lifetime, and a 5% discount rate. To reflect real-world infrastructure conditions, an additional 15% of CAPEX was included to cover civil works, such as installation, site adaptation, safety systems, and integration.

2.4.Emission reduction potential

Both application pathways—stationary energy recovery and hydrogen-powered mobility—contribute to the reduction of carbon dioxide (CO_2) emissions at Tirana International Airport (TIA). This section outlines the methodological approach used to quantify these environmental benefits.

a) Avoided emissions from grid electricity replacement

When hydrogen is used in fuel cells to generate electricity on-site, it can reduce reliance on grid-supplied electricity. The emissions avoided from displacing grid electricity are estimated using the following equation:

$$CO_{2,avoided}^{grid} = E_{recovered} \times EF_{grid} \quad \text{(Eq. 5)}$$

Where: $CO_{2,avoided}^{grid}$ - Annual avoided emissions from grid electricity substitution (kg CO_2/year); $E_{recovered}$ - Annual energy recovered via hydrogen fuel cells (kWh/year); EF_{grid} - CO_2 emission factor for diesel combustion (3.622 kg CO_2/l), based on Eco Cost Value Idemat 2025RevA6.xlsx database.

This method provides a conservative estimate, as grid emission factors are subject to change depending on the energy mix and seasonal hydropower availability.

b) Avoided emissions from diesel replacement in mobility

Replacing diesel-powered ground support vehicles (GSE), such as airport buses and baggage tractors, with hydrogen-powered alternatives significantly reduces emissions from combustion. Avoided emissions from this substitution are calculated using:

$$CO_{2,avoided}^{diesel} = Fuel_{displaced} \times EF_{diesel} \quad \text{(Eq. 6)}$$

Where: $CO_{2,avoided}^{diesel}$ - Annual CO_2 reduction from diesel fuel replacement (kg CO_2/year); $Fuel_{displaced}$ - Diesel fuel equivalent (liters or kg) replaced by hydrogen use; EF_{diesel} - CO_2 emission factor for diesel combustion (3.622 kg CO_2/l), based on Eco Cost Value Idemat 2025RevA6.xlsx database.

The equivalent diesel displacement is estimated by comparing the hydrogen-based driving range with the average diesel fuel consumption of GSE operating under similar load conditions.

2.5.SWOT evaluation

To assess the strategic feasibility of integrating hydrogen and fuel cell technologies at Tirana International Airport (TIA), a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis was conducted. This approach was chosen to systematically identify internal capabilities and external conditions that may influence the success of hydrogen deployment across both stationary and mobile airport applications. Insights were informed by previous SWOT analyses published in various international contexts (Ren et al., 2015; Bednarczyk et al., 2022; Khan & Kamdi, 2023; Bayssi et al., 2024; Furuncu, 2025), offering valuable comparative perspectives on hydrogen market dynamics, implementation challenges, and strategic opportunities relevant to TIA's case.

3. RESULTS

3.1. Hydrogen yield and operational potential

Table 1 summarizes the key energy conversion outcomes from the modeled integration of hydrogen systems at Tirana International Airport. Based on the assumption that 25% of the airport's rooftop photovoltaic (PV) output—equivalent to 1,334 MWh/year—is allocated to hydrogen production, approximately 333.5 MWh/year is available for electrolysis. Using an electrolyzer with a specific energy consumption of 58 kWh per kilogram of hydrogen, the estimated annual hydrogen output is 5,750 kg H_2. Assuming a 50% electrical efficiency for proton exchange membrane (PEM) fuel cells and a lower heating value (LHV) of hydrogen of 33.3 kWh/kg, the recoverable energy from hydrogen is approximately 96 MWh/year. For mobility applications, with an average consumption of 9 kg H_2 per 100 km, the produced hydrogen could enable an annual driving range of approximately 63,889 km.

Table 1. *Summary of Hydrogen production, energy recovery, and mobility potential at Tirana International Airport*

Parameter	Value	Unit
PV energy allocated for electrolysis	333.5	MWh/year
Total hydrogen production yield	5,750	kg H_2/year
Recoverable energy from hydrogen (as electricity)	96	MWh/year
Estimated annual driving range (mobility)	63,889	km/year

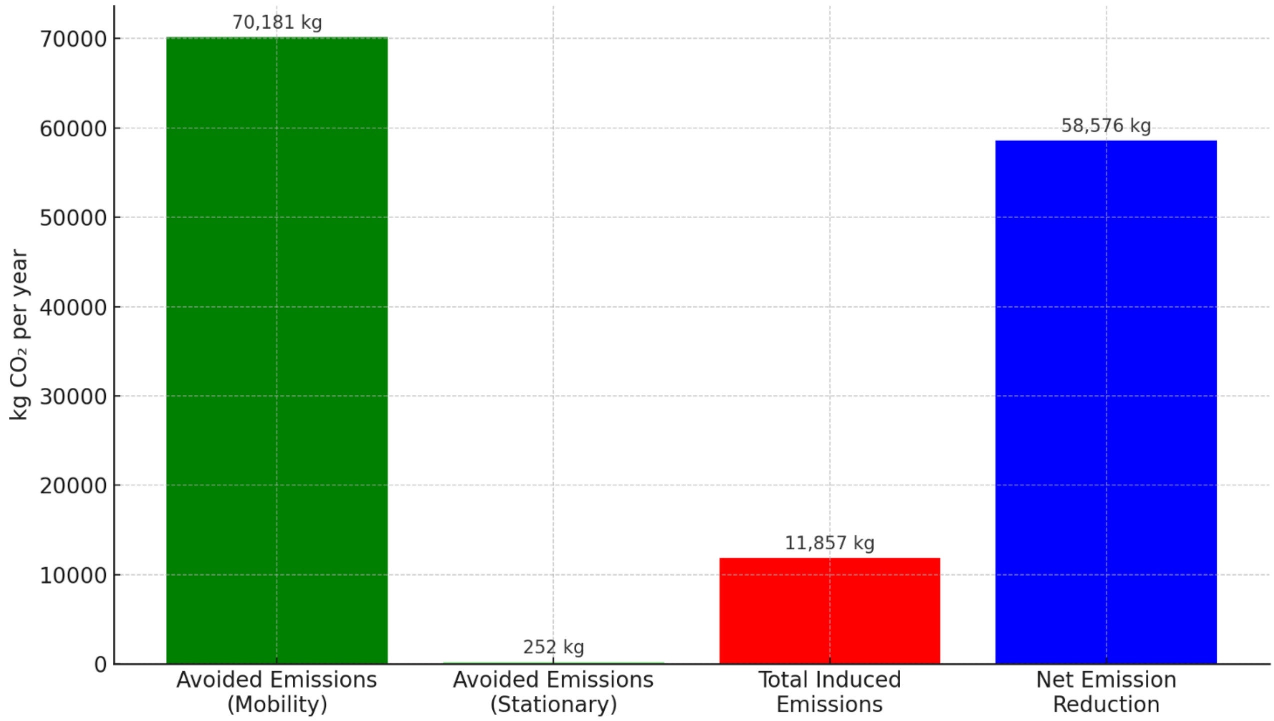
Source: Elaborated by authors

3.2. Environmental feasibility

Figure 2 shows a comparison between avoided and induced CO_2 emissions resulting from hydrogen deployment at Tirana International Airport (TIA). The environmental feasibility analysis indicates that hydrogen application at TIA offers significantly greater potential in mobility compared to stationary energy recovery. Specifically, using hydrogen for on-site electricity generation via stationary fuel cells leads to a relatively modest annual reduction of approximately 252 kg of CO_2, primarily due to Albania's already low-emission electricity mix. In contrast, replacing approximately 19,378 liters of diesel fuel used in airport ground transport yields a much larger emissions reduction of around 70,181 kg of CO_2 per year. This highlights the significantly higher environmental value of prioritizing hydrogen for transport applications at TIA.

Hydrogen production using photovoltaic (PV) sources induces emissions of approximately 2.062 kg of CO_2 per kilogram of hydrogen, resulting in a total of roughly 11,857 kg of CO_2 per year. These emissions stem mainly from upstream electricity-related processes. Literature indicates that solar-powered PEM electrolysis systems yield global warming potentials ranging from 0.61 to 2.8 kg CO_2-equivalent per kilogram of hydrogen, depending on regional and operational conditions (Ajeeb et al., 2024, p. 9). Despite these induced emissions, the overall environmental balance remains strongly favorable. Comparing the total avoided emissions (70,433 kg CO_2/year) with the induced emissions results in a net annual reduction of approximately 58,576 kg of CO_2. This outcome further reinforces the environmental feasibility and strategic advantage of emphasizing hydrogen integration in mobility solutions at TIA.

Figure 2. *Comparison of avoided and induced CO_2 emissions from Hydrogen deployment at TIA*



Source: Elaborated by authors

3.3.Economic feasibility

The economic feasibility of hydrogen production at Tirana International Airport (TIA) was assessed by calculating the Levelized Cost of Hydrogen (LCOH) and the Levelized Cost of Electricity (LCOE) for hydrogen-powered stationary applications. The analysis assumes that 25% of the airport's rooftop photovoltaic (PV) system's annual output is allocated to an on-site electrolyzer operating for approximately 2,190 hours per year. Based on a 155-kW modular electrolyzer functioning at 25% utilization, the LCOH was estimated at €6.91 per kilogram of hydrogen. This figure underscores the sensitivity of hydrogen production costs to utilization rates and infrastructure investment. Under more favorable capital expenditure (CAPEX) conditions—such as €1,300 per kW—the LCOH could decrease to approximately €4.45/kg H_2, highlighting the potential for cost reductions through technological advancements, economies of scale, or improved operational efficiency. In parallel, the LCOE was calculated for electricity generated by converting hydrogen back into power using proton exchange membrane (PEM) fuel cells operating at 50% electrical efficiency. Based on a recoverable energy output of 96 MWh/year, and applying the same cost structure as the LCOH scenario, the resulting LCOE was €0.41/kWh in the base case. While this is relatively high compared to current grid prices, it provides a valuable benchmark for assessing the potential role of hydrogen as a clean, dispatchable, and locally produced energy source within airport operations.

It is important to note that the full hydrogen-to-electricity conversion process at TIA requires two distinct systems: a PEM electrolyzer for hydrogen production and a PEM fuel cell for electricity generation. While the LCOH reflects only the cost of hydrogen production, the LCOE incorporates both the cost of hydrogen and the capital and operational expenses associated with the fuel cell system. This dual-system configuration highlights the need for optimized system integration, cost-effective design, and high utilization rates to ensure the overall economic viability of hydrogen deployment within airport infrastructure.

Table 2. *Summary of Levelized Cost of Hydrogen (LCOH) under different CAPEX scenarios*

Scenario	CAPEX (€ / kW)	Annual Cost (€)	LCOH (€/kg H_2)	LCOE (€/kWh)	Hydrogen Mobility Cost (€/km)
Base Case (High CAPEX)	1,970	34,561	6.91	0.41	1.16
Optimistic Case (Lower CAPEX)	1,300	22,472	4.45	0.26	0.85

Source: Elaborated by authors

In addition to stationary applications, the study also evaluated the economic feasibility of hydrogen for mobility. Based on an average consumption of 9 kg of H_2 per 100 km and the previously calculated LCOH values, the fuel cost alone was estimated at €0.62 per km in the base case and €0.40 per km in the optimistic scenario. To provide a more comprehensive cost assessment, additional factors were considered: the capital cost of a hydrogen fuel cell bus (assumed at €650,000 in the base case and €500,000 in the optimistic case), depreciation over a 12-year operational lifespan with an annual mileage of 60,000 km, and maintenance costs estimated at approximately €0.15 per km.

When all cost components are included, the total economic cost of hydrogen mobility is estimated at €1.16 per km in the base case and €0.85 per km in the optimistic scenario. These figures underscore that hydrogen-fueled mobility remains capital-intensive, particularly during the early stages of deployment. Nevertheless, it offers significant operational benefits in airport environments, including fast refueling, zero local emissions, and low noise levels, making it an attractive option for fleet decarbonization, especially in contexts where vehicle range and operational uptime are critical.

3.4.SWOT attributes

Table 3 illustrates the strategic potential of integrating hydrogen technologies at Tirana International Airport (TIA). The integration of hydrogen technologies at Tirana International Airport (TIA) presents several notable strengths, including compatibility with solar energy, enhanced energy independence, reduced operating costs, and rapid refueling capabilities with high efficiency. The development of green aviation infrastructure promises long-term savings and delivers both environmental and public health benefits (Yusaf et al., 2022, p. 5). Hydrogen can complement solar energy systems, enabling a more sustainable energy mix for airport operations (Zhou et al., 2022, p. 7). This potential is reinforced by the recent doubling of TIA's photovoltaic (PV) system capacity from 1 MW to 2 MW, enhancing the airport's ability to support on-site green hydrogen production and reduce grid dependency. It can further reduce reliance on conventional fossil fuels, enhancing energy security. Over time, hydrogen's efficiency and scalability can lower operational expenses. Hydrogen allows for faster refueling compared to battery-electric alternatives, making it suitable for aviation needs. Refueling a hydrogen tank only takes minutes, whereas fully charging a battery may take hours, depending on the battery technology and the local electrical power limitation (Offer et al., 2010, p. 28).

Table 3. *SWOT Analysis of Hydrogen integration at Tirana International Airport (TIA)*

STRENGTHS	**WEAKNESSES**
• **Renewable Energy Integration** – On-site solar PV (1→2 MW), potential for wind energy, enabling 24/7 green hydrogen via electrolysis • **Energy Resilience** – Reduced grid dependence, hydrogen storage for backup power during outages • **Operational Advantages** – Faster refueling (3–5 min), longer range and uptime for ground support equipment, lower maintenance than diesel • **Environmental Benefits** – Zero operational emissions, noise pollution reduction, improved air quality around the airport • **Policy Alignment** – Matches EU Green Deal, supports Albania's NDC, complies with CORSIA • **Scalability** – Modular hydrogen systems allow for phased expansion as demand grows	• **Infrastructure Gaps** – No existing hydrogen production, storage or refueling systems; high capital investment required • **Regulatory Barriers** – Lack of mature hydrogen safety standards and limited regulatory experience • **Technical Expertise** – Shortage of skilled workforce for hydrogen system operation and maintenance • **Economic Feasibility** – High hydrogen cost and uncertain return on investment in current market conditions • **Limited Domestic Supply Chain** – Dependence on foreign equipment and expertise increases implementation complexity
OPPORTUNITIES	**THREATS**
• **Renewable Expansion** – Potential for hybrid solar-wind systems to power hydrogen production continuously • **Smart Energy Systems** – Implementation of energy management systems to optimize supply-demand and resilience	• **Market Uncertainty** – Slow adoption of hydrogen-powered aircraft may delay infrastructure utilization • **Safety Perceptions –** Public concerns over hydrogen safety may affect acceptance and implementation

• **Health & Community Benefits** – Reduction in NOx and particulate matter; improved health outcomes and public support • **Strategic Partnerships** – Collaborate with Airbus and EU hydrogen initiatives for co-development and visibility • **Branding & Marketing** – Position TIA as a Balkan "Green Hub" to attract green tourism and eco-conscious airlines • **Funding & Incentives** – Access to EU climate finance and support through public-private partnerships • **Technology Demonstration** – Use the airport as a showcase for clean hydrogen technologies in the region	• **Technology Competition** – Battery-electric and sustainable aviation fuel (SAF) technologies may become more dominant • **Supply Chain Risks** – Dependency on imported hydrogen tech and potential delivery delays • **Policy & Bureaucracy** – Delays or reversals in national policy, limited government support or changing priorities

Source: Elaborated by authors using

The advantages of a hydrogen economy are counterbalanced by significant weaknesses, such as high initial investment requirements, safety and security concerns, and the current absence of a hydrogen distribution network. Developing hydrogen infrastructure requires substantial upfront costs, including storage and distribution systems (Ngyon & Darekar, 2024, p.7). Hydrogen is highly flammable and requires stringent safety measures for storage and handling. Safety concerns are among the major barriers to the broad application of H2 as a fuel source (Lavanya et al., 2024, p.3). In the production of green hydrogen, one of the main challenges is reducing the number of accidents, which are mainly related to electrical risk and oxygen contamination of hydrogen (Calabrese et al., 2024, p.9). Additionally, limited expertise, lack of financial incentives, and low public awareness present further barriers. The Western Balkans, especially Albania, face a major skills gap in hydrogen technologies due to limited technical expertise, low public awareness, and inadequate VET and reskilling programs (Radovanovic and Stevanovic Carapina, 2024, p. 5).

Despite these challenges, there are multiple opportunities to strengthen the initiative, including positioning TIA as a green airport, generating new employment, reducing the airport's carbon footprint, and integrating with sustainable public transport systems. Integrating hydrogen technologies into this ongoing effort would mark a significant step forward in decarbonizing airport infrastructure. The expanded PV system also increases resilience, enabling more stable and reliable hydrogen production from renewable sources. Hydrogen can serve as a clean energy source for ground support equipment, shuttle buses, and potentially even short-haul aircraft in the future, further enhancing TIA's environmental credentials. Fuel cell electric vehicles emit only water vapor and warm air, producing no harmful tailpipe emissions. The development of hydrogen technology can also act as a powerful driver of economic growth and job creation. It opens up employment opportunities across a broad spectrum of sectors, including engineering, system design, installation, maintenance, logistics, and operations. As the hydrogen and fuel cell industries expand, a wide array of new jobs will emerge, ranging from high-tech positions to vocational and skilled trades, spanning different skill levels, tasks, and income brackets (Bezdek, 2018, p. 9). This can support just transition strategies, particularly for workers from traditional fossil fuel industries. To help cover the substantial investment costs associated with hydrogen integration, TIA can leverage access to EU and international funding instruments, such as the European Green Deal, Horizon Europe, and the Connecting Europe Facility, all of which prioritize investments in sustainable transport and clean energy infrastructure. Additionally, the airport could benefit from the formation of Public-Private Partnerships (PPPs), which unite government agencies, private investors, and technology developers to co-finance infrastructure, share financial risks, and accelerate implementation. PPPs are increasingly recognized as crucial for fostering the development of emerging technologies, such as hydrogen applications (Pinilla-De La Cruz et al., 2023, p. 6). These funding avenues and collaborative models offer a viable path to reduce the financial burden on TIA, making the project more feasible while supporting both environmental goals and long-term economic resilience.

Nevertheless, external threats such as economic viability concerns, competition from other renewable technologies (e.g., solar + battery systems and sustainable aviation fuels), technical and regulatory challenges, public safety perceptions, and fluctuating energy markets may hinder implementation and long-term success.

4. CONCLUDING REMARKS

This study explored the feasibility of integrating hydrogen and fuel cell technologies at Tirana International Airport (TIA), with a focus on both stationary and mobility-related applications powered by rooftop photovoltaic (PV) energy. The results confirm that even partial use of available solar capacity (25%) could produce approximately 5,750 kg of hydrogen annually, enabling the generation of 96 MWh of electricity or powering more than 63,000 km of zero-emission vehicle travel. These findings align with earlier studies on hydrogen's potential in airport ecosystems (Wu et al., 2025; Rasul et al., 2015). From an environmental perspective, the analysis shows a clear advantage for mobility applications. While stationary hydrogen fuel cells offer modest emissions savings (252 kg CO_2/year), mobility uses deliver a significantly greater reduction (approximately 70,181 kg CO_2/year), primarily through diesel displacement. Even after accounting for induced emissions from PV-powered electrolysis (~11,857 kg CO_2/year), the net reduction remains substantial—58,576 kg CO_2 annually—confirming the environmental feasibility of mobility-focused hydrogen strategies. Beyond technical and environmental performance, the economic and management dimensions are critical to the real-world viability of hydrogen integration. The Levelized Cost of Hydrogen (LCOH) was calculated at €6.91/kg under current CAPEX and utilization conditions, with potential to decrease to €4.45/kg in more favorable investment scenarios. For airport operators, these values highlight the importance of system optimization, financial planning, and policy alignment to improve cost-effectiveness. Moreover, the Levelized Cost of Electricity (LCOE) for hydrogen-generated power was estimated at €0.41/kWh—relatively high, but strategically valuable for peak shaving or emergency backup applications. In the case of mobility, total cost per kilometer was estimated at €1.16 in the base scenario and €0.85 in the optimistic scenario. While hydrogen vehicles remain capital-intensive during early-stage adoption, operational advantages such as fast refueling, reduced noise, and zero local emissions make them attractive for airport fleet management, especially for ground support equipment with high uptime requirements.

From a management perspective, this transition requires coordinated investment planning, infrastructure phasing, and workforce development. The SWOT analysis illustrates both opportunities (e.g., access to EU funding, branding as a green hub, job creation) and risks (e.g., skills shortages, regulatory gaps, and uncertain ROI). Hydrogen integration should therefore be framed not just as a technological innovation but as a strategic infrastructure investment, requiring involvement from airport leadership, public agencies, and private partners. Strategically, hydrogen deployment positions TIA within a broader enterprise innovation ecosystem (Nahara, 2024), where cross-sectoral collaboration, modular design, and flexible financing mechanisms—particularly public-private partnerships (PPPs)—are essential. This aligns with Živanović et al. (2023), who emphasize the need for innovation management structures that support business excellence and long-term sustainability goals. Additionally, evidence from the Western Balkans shows that infrastructure innovation contributes positively to economic growth (Hysaj & Sulçaj, 2024), reinforcing the strategic value of this investment for Albania's green economy transition.

In sum, while technical and environmental metrics confirm the feasibility of hydrogen systems at TIA, long-term success will depend on addressing economic barriers, leveraging funding instruments, and embedding the project within a strategic airport management framework.

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