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# Cost and Sustainability Comparison of Airship vs. Long-Haul Trucking for Cold Chain Vegetable Logistics in Europe

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**Abstract** In the pursuit of sustainable air cargo transport, an unmanned, hydrogen-lifted, hybrid solar-powered airship presents a groundbreaking solution for the transportation of fresh goods. This research examines the economic viability and environmental impact of this innovative transport method. By utilizing hydrogen for lift and incorporating a hybrid energy system, the airship ensures a cost-efficient power supply. The study specifically compares the operating costs for truck and airship fleet management along the Murcia to Munich route, highlighting key metrics such as cruise velocity, economic sustainability, and reduced greenhouse gas emissions. Additionally, the paper discusses the fleet sizing comparing actual truck fleet with modern airship scenario, demonstrating how these novel technologies could contribute to an improved quality and sustainability of perishable goods logistics.

**Keywords** *Airship, Hydrogen, Solar power, Sustainability, Economic analysis.*

## 1. Introduction

The growing concerns over climate change and environmental impact of freight transportation have led to an increased focus on developing sustainable solutions (Herold and Lee, 2017; Miklautsch and Woschank, 2022; Rossi et al., 2021). The logistics sector is a significant contributor to global greenhouse gas emissions, accounting for approximately 16.2% of the total (Bukhari et al., 2022; Evangelista et al., 2017). Traditional road freight, particularly long-haul trucking, is a major source of these emissions (Cui et al., 2023; Rossi et al., 2021). In recent years, the concept of using airships for cargo transport has gained renewed interest due to their potential for reduced environmental impact and increased energy efficiency (ARDEMA, 1977; Prentice and Knotts, 2020; Smokers et al., 2014). Compared to traditional air cargo, airships could offer several advantages, such as increased payload capacity, reduced or null fuel consumption, and the ability to achieve a faster transport of perishable goods in a controlled environment (Gallo et al., 2017). Moreover, the integration of hydrogen fuel cells and solar power can further reduce the operative cost enhancing the sustainability of airship operations and potentially outperforming conventional long-haul trucking (Adler and Martins, 2023; Zhang et al., 2018).

This paper presents a preliminary comparative analysis for cost and sustainability of airship and long-haul trucking transport over cold chain vegetable logistics. The analysis has been posed considering a reference case study for western Europe, but this could be a exportable benchmark for Middle East and Asia market.

## 2. Methodology

The study utilised a dual pronged research methodology to conduct a preliminary comparative analysis addressing the cost and emissions factors comparing airship and long-haul trucking transport for cold chain vegetable logistics. The methods encompassed mission profile selection, airship choosing and fleet size estimation. Lastly carbon emission quantification and preliminary transport cost evaluation.

## 2.1. Mission Profile

To establish the mission profile for the comparison, a concise economic survey of European trade patterns and the predominant freight transport modes employed for food commodities worldwide was undertaken. Upon confirming the market viability of the airship, a hypothetical route within Europe was plotted to gather data on the anticipated cargo volumes and, by extension, the requisite airship fleet size to service the route. Subsequently, information from both existing and newly developed airship designs was leveraged to estimate the projected cruising speed of the airship platform (Peelers et al., 1997).

When focusing on the regional grouping of the Sustainable Development Goal, Europe emerges as the largest contributor, accounting for 35.3% of total global trade. Furthermore, Europe's internal trade was valued at 11,517.4 billion US dollars (United Nations, 2023). As the designed airship will be used to transport food commodities, it is crucial to examine the trade landscape of this specific sector.

Global trade data indicates that agricultural products, including fresh vegetables, must be transported to meet consumer demand. Research conducted in 2018 by Joseph Poore and Thomas Nemecek (Poore, 218AD) examined the modal split of food transport in tonne-kilometres, revealing that the majority, 58.97%, was undertaken by sea freight, while 30.97% was transported via road, 9.9% by rail, and a smaller proportion by air. As this study focuses on intra-European Union trade, the analysis will concentrate on road-based transportation, which is extensively used for the distribution of refrigerated produce within Europe. In fact the vast majority of vegetables transport (around 70%) are transported via refrigerated trucks (Pérez-Mesa et al., 2020). The proposed airship solution aims to replace these road-based logistics methods for international trade within the region, connecting the highest-producing areas to the largest consumer markets. According to data from the Spanish Federation of Fruit, Vegetable, Flower and Live Plant Exporter Associations, in 2023 Spain exported 87% of its agricultural production, equating to 9.4 million tonnes. The primary exporting regions within Spain were identified as Andalusia, Valencia, Murcia, and Catalonia (Informations-Gesellschaft mbH, n.d.) Furthermore, EUROSTAT statistics indicate that the Murcia region extensively utilises road transport for intra-European trade, with 13,000 tonnes transported via this mode in 2022 (Antonella de Ciccio, 2018). Conversely, Germany has emerged as the largest recipient of Spanish fruits and vegetables, receiving 3.12 million tonnes at a cost of 4.91 million Euros. Additionally, Germany has been identified as the region transporting goods over the longest distances by road and the second-largest in terms of cargo quantities (Pérez-Mesa et al., 2021, 2020, 2019). Based on these findings, the proposed airship route would connect the Murcia region of Spain to Munich, Germany. The route can be covered with 1934 km of highway by trucks or with a direct flight of 1527 km.

## 2.2. Airship dimension and fleet estimation

To determine the requisite number of airships needed to service the specified route, the daily volume of transported goods must be estimated. It is known that in 2023, Spain exported 3.12 million tonnes of perishable products to Germany. According to Fepex data, the Murcia region accounted for approximately 23% of these shipments, implying that 718,000 tonnes of produce were moved from Murcia to Germany (Pérez-Mesa et al., 2020).

Assuming, as a first simplification, that these goods are all routed through a consolidation facility in Munich and evenly distributed throughout the year, a daily transport volume of 1,970 tonnes can be inferred. An analysis of the transportation practices of prominent German supermarket chains, such as EDEKA and Lidl, reveals that EDEKA has recently acquired numerous refrigerated Iveco

Euro 6 trucks with a net capacity of 22.5 to 26 tonnes. Lidl's Hollfeld facility on the other end is projected to handle 70-85 trucks per day, processing 3 to 6 trucks hourly (Schmid et al., 2018). The computed time to reach the final destination, comprehensive of regular stops, from Murcia to Munich is equal to 27.18 hour. Based on the provided data and the estimated daily cargo volume of 1,970 tonnes per day, the analysis suggests that a fleet of 228 trucks would be required to service the route between Murcia and Munich to ensure a continuous and robust feedline of vegetables. This figure find correspondence with the anticipated average processing capacity of the logistics facilities, assuming an average throughput of around 4 trucks per hour operating continuously over a 24-hour period all year long. These parameters have been used as the baseline to determine the carbon emission and the cost for the transportation as is.

Obviously, the deployment of airships with an equivalent payload capacity and equivalent average cruise velocity would not be economically viable. As a result, the study has considered the existing cargo airship as benchmark involving a payload capacity comparable to three trucks, and two cruise speed achievable: 120 and 185 km/h.

### **2.3. Airship developing scenario**

The proposed airship is based on the development specifications of modern airships such as the Atlant 100 by LTA Advanced Technology and the ML866 by Aeros. The Atlas 100 is a recent lightweight dirigible concept with a cargo capacity of 66 tons, a cruising speed of 110 km/h, and a range of 4,500 km (Joner and Schneider, 1975), (Pukshansky et al., 2016). The ML866, on the other hand, is a large modern airship designed for cargo transport, with a volume of 866,000 cubic meters, a payload capacity of 240 tonnes, and a range of 5,200 km at a cruising speed of 185 km/h (Metlen et al., 2016). Considering the available cargo capacities of these designs, the proposed airship for the European cold chain vegetable logistics would have a capacity of 66 metric tons, a cruising speed of 110 km/h, and a range of 4,500 km. This airship size is intended to directly replace the capacity of three standard refrigerated trucks for the identified route between Murcia and Munich.

The current state of the art in developing transport airship indicates that these vehicles can be economically viable for freight transport applications, with the potential to offer significant advantages over traditional road-based transportation. Despite the two main manufacturers does not unveil yet a date-to-market the pilot projects presented confirm the solution and pave the way for the commercialization of this lighter-than-air vehicle typology in the next decade.

### **2.4. Carbon emission estimation**

The carbon emission estimation for the road-based truck transport has been assessed using the Clean Fleet Toolkit, a free tool instrument developed by the United Nations Environment Programme to evaluate the environmental impact of vehicle fleets (“<https://www.unep.org/resources/toolkits-manuals-and-guides/clean-fleet-toolkit>,” 2024). A general and optimistic assumption has been made that a modern fleet of all EURO 6 diesel and ammonia-powered trucks has been used considering the EU market a standard diesel with sulphur content equal to 10ppm. Each truck is equipped with an auxiliary diesel unit of 35 Hp dedicated to the continuous refrigeration of the truck during the leg between Murcia and Munich. The return track did not involve any fuel consumption associated to the refrigerator unit.

The direct carbon emissions of the airship can be negligible in first instance given the hybrid powering (solar and fuel cell). The emission implicated with the generation of gaseous hydrogen has been quantified the 2030 scenario proposed by International Energy Agency (Energy Agency, n.d.) (IEA).

## 2.5. Preliminary transport cost estimation

An investigation was conducted among service providers in 2024 and a review of relevant literature and reports to evaluate the transport cost for refrigerated truck transport. The analysis revealed an average cost of 0.07 € per ton-kilometre for the road-based transport of refrigerated agricultural produce in Europe (Meng et al., 2021; Piala et al., 2017). This cost estimate accounts for factors such as fuel consumption, vehicle maintenance, labour, and other operational expenses associated with operating a fleet of refrigerated trucks for cold chain logistics within the European Union.

Regarding the cost of airship transport, the authors have developed a model based on the outcomes provided by a similar study (B. E. Prentice, 2021). This previous research examined the economic feasibility of utilising airships lifted with hydrogen and solar powered for the transportation of cargo, including perishable agricultural goods, and offered a framework for estimating the operational and capital costs involved in deploying an airship-based logistics system. The authors have leveraged the insights and data from this prior research to inform their own cost analysis and comparisons between the airship and truck-based transport alternatives.

## 3. Results and discussion

This section will present the comparative analysis of the costs and sustainability aspects between the airship and long-haul trucking transport options for the cold chain vegetable logistics in Europe. Firstly, the fleet size will be evaluated and then outputs in carbon emissions and operational cost will be provided.

### 3.1. Fleet comparison

The mission profile outlined in Section 2.1 indicates that the journey from Murcia to Munich would take, with a standard truck approximately 27 hours, factoring in regular stops and an average speed of 80 km/h. Additionally, 2 hours have been allocated for the loading and unloading processes at the destination. Based on these assumptions and a simplified assessment of the transport capacity, a total of 57 teams, each comprising 4 trucks, have been determined as necessary. This equates to a fleet of 232 trucks covering a total distance of approximately  $1.35 \times 10^8$  km annually.

Alternatively, transporting goods via airship would be more direct, avoiding highway fixed routing and following a straighter path. This would lead to a reduction of up to 1,527 km in the distance travelled per segment. Assuming a cruising speed of 120 km/h, comparable to the Atlant airship, the flight duration would be reduced by up to 12 hours compared to the road-based journey. Considering the higher-performance ML866 airship with a cruise speed of 185 km/h, the flight time would be further reduced by up to 8 hours. Accounting for the longer stops required for landing, unloading, and recharging the airship, estimated at 3 hours, the total fleet required would be 30 airships in the first scenario and 22 in the second, representing a significant reduction in the number of vehicles compared to the truck-based fleet needed to service the same transport demand.



(a)



(b)

**Figure 16:** Modern Cargo Airship: (a) Atlant 100 (“[https://atlas-ita.com/atlant\\_cargo\\_airship/](https://atlas-ita.com/atlant_cargo_airship/),” 2024); (b) ML866 (“<https://aeroscraft.com/aeroscraft/>,” 2024)

### 3.2. Carbon emissions

The road-based transport of the required refrigerated freight volume from Murcia to Munich using a fleet of 228 Euro 6 diesel and ammonia-powered trucks is estimated to result in approximately 45,091 tonnes of diesel fuel consumption per year over the entire fleet. the CO<sub>2</sub> equivalent emission associated with this fuel usage is estimated at 182,523 tonnes annually with the 75% associated with the truck movement and 25% from the refrigeration unit. The carbon monoxide emitted would be equal to 139 ton per year and the NO<sub>x</sub> emission at 386.15 ton per year.

In comparison, the hydrogen-powered airship with the larger capacity would emit zero direct emissions during operation, as the only emissions would be from the production of the hydrogen fuel. The amount of hydrogen estimated with ranges between 1849 and 1684 tonnes annually, depending on the airship cruise speed model adopted. Considering the 2030 scenario proposed by IEA(Energy Agency, n.d.) of 6-7 kg of CO<sub>2</sub> equivalent emitted per kg of Hydrogen produced via water electrolysis using renewable electricity, the indirect emissions from the hydrogen production for the airship would be approximately 11,094 to 10,108 tonnes of CO<sub>2</sub> equivalent per year. This value, lower of more than 1 order of magnitude compared with the one emitted with truck transport with the 2050 scenario proposed by IEA could be further reduced up to a factor of 6.

Description	Value	Unit
Diesel Fuel	45'091.14	Ton/Year
Carbon Dioxide (CO <sub>2</sub> ) Truck	138'634	Ton/Year
Carbon Dioxide (CO <sub>2</sub> ) Cooling Unit	43'890	Ton/Year
Total Carbon Dioxide (CO <sub>2</sub> )	182'523.59	Ton/Year
Carbon Monoxide (CO)	139.55	Ton/Year
Volatile Organic Compound (VOC)	33.87	Ton/Year
Nitrogen Oxides (NO <sub>x</sub> )	386.15	Ton/Year
Sulfur Dioxide (SO <sub>x</sub> )	1.35	Ton/Year
Particles Smaller than 10 µm (PM10)	1.81	Ton/Year

**Table 7:** Emission with truck transport.

### 3.3. Cost comparison

The estimated operating cost per ton-kilometre for the refrigerated truck transport, obtained through inquiries with local transport providers and market research, is equal to 0.07 \$. The economic model adopted for the comparison takes a conservative approach, considering that both the truck and airship are solely utilised for the transportation of vegetables from Spain to Germany, and thus

return empty. This assumption leads to the calculation of the transport cost for both modes to include the cost of the return journey. Assuming that trucks operate at full loading capacity, this results in a total shipping cost for the current truck-based solution of 0.36 \$ per kilogram on this route.

4. The operating scenario adopted for airship cost estimation has been reported in Table while the input cost obtained as benchmark between cargo companies are reported in Table 2: Operating scenario.
5. . Table 8: Input Cost.
6. reports the fixed operating cost and, finally. Table 9: Fixed Cost and Table 10: Case Study with 120km/h cruise speed.

evidences the variable and total cost for the two cruise velocity scenarios, 120 and 185 km/h.

The observed difference in energy costs between the slower and faster airship configurations, as shown in Tables 5 and 6, can be attributed to the hydrogen consumption model employed in this study. This model approximates hydrogen consumption mainly as a function of flight hours, with lower dependence with different cruise speeds. As a result, the slower airship configuration requires approximately 135 flight hours per week, while the faster ML866 needs only 123 flight hours per week to transport the same quantity of goods. Consequently, despite its higher cruising speed, the faster airship incurs a lower annual energy cost due to the reduced total flight hours. Summarizing the shipping cost evaluated per kilogram of payload for the airship case ranges between 0.52 \$ and 0.39 \$ per kilogram, depending on the achievable cruise speed.

Observing the breakdown of the cost model it can be stated that the large amount of the total cost is connected with the annual fixed cost of the airship itself, which account for between the 84 and 85 percent of the total cost. This fact highlights the need to maximise the airship utilisation through higher deployment hours or additional revenue streams to improve the overall cost competitiveness against truck transport.

These results indicate that the hydrogen-powered airship could potentially offer a cost-effective and sustainable transportation solution compared with long-haul refrigerated truck transport for cold chain logistics, in the route examined in this study. While the airship transport costs are currently estimated to be slightly higher than the truck-based mode, the significant reduction in carbon emissions and the potential for further cost optimisation through technological and operational improvements make airships a promising alternative that warrants further investigation.

Description	Value	Unit
Cruising Speed	120	km/h
Cargo Capacity	78	ton
Useful Operating Life	25	years
Loading/unloading	3	hours/day
Cargo utilization	100	
Crew Size	2	

**Table 2:** Operating scenario.

Description	Value	Unit
Insurance	3,500,000.00	\$/year
Crew wages	100,000.00	\$/year/person
Fuel Cost	1.00	\$/litre
Maintenance & Inspection	1,000,000.00	\$/year
Ground handling	1,000,000.00	\$/year
Airship purchase	80,000,000.00	\$/year

**Table 8:** Input Cost.

Description	Value	Unit
Aircraft amortization (25 year @ 4.25%)	5,200,000.00	\$/year
Insurance	3,500,000.00	\$/year
Maintenance & Inspection	1,000,000.00	\$/year
ground handling	1,000,000.00	\$/year
Total Annual Fixed Cost	10,700,000.00	\$/year

**Table 9:** Fixed Cost.

Description	Value	Unit
Crews	200,000.00	\$/year
Energy Cost	1,849,040.16	\$/year
Total Annual Variable Cost	2,049,040.16	\$/year
Total Cost	12,749,040.16	\$/year
Cost per kg	0.52	\$/kg

**Table 10:** Case Study with 120km/h cruise speed.

Description	Value	Unit
Crews	200,000.00	\$/year
Energy Cost	1,684,681.03	\$/year
Total Annual Variable Cost	1,884,681.03	\$/year
Total Cost	12,584,681.03	\$/year
Cost per kg	0.39	\$/kg

**Table 11:** Case Study with 185 Km/h mission profile.

## 7. Conclusion and further developments

This study provides a comprehensive comparative assessment of the cost and sustainability implications of utilizing hydrogen-powered airships versus long-haul refrigerated trucks for cold chain vegetable logistics between Murcia, Spain, and Munich, Germany. The findings indicate that hydrogen-powered airships could yield substantial environmental benefits, reducing carbon emissions by over 90% compared to the existing truck-based logistics system. This significant reduction underscores the airship's potential to contribute to sustainable freight transport, not only in cold chain logistics but across various goods that are traditionally transported by truck, sea, and air.

While the current analysis primarily focuses on the transportation of perishable goods, the advantages of airships extend beyond this scope. The unique capabilities of airships, such as reduced fuel consumption, lower environmental impact, and the ability to bypass conventional ground-based transportation infrastructure, position them as a viable alternative for a broad range of cargo types. Airships could offer a more sustainable solution for transporting goods over challenging terrains, remote areas, and regions with underdeveloped infrastructure, where

conventional transport modes are less efficient or more costly. However, the higher initial operating costs associated with airship deployment remain a significant barrier. The cost per kilogram of transported goods via airship currently ranges from \$0.39 to \$0.52, which, while competitive, still surpasses the cost of truck transport at \$0.36 per kilogram. These findings suggest that while airships offer a promising alternative from an environmental standpoint, their economic viability requires further optimization, particularly concerning the high fixed costs of airship operations. To unlock the full potential of airship technology across different cargo types, several challenges must be addressed:

- **Infrastructure Development:** Establishing dedicated airship docking and handling facilities is critical for efficient operations.
- **Technological Advancements:** Further technological improvements in propulsion systems, energy storage, and materials are essential to enhance performance and reduce costs.
- **Regulatory Hurdles:** Integrating airships into the existing logistics network will require overcoming regulatory challenges related to airspace management, safety standards, and unmanned civil operations.
- **Market Acceptance:** The perception of higher costs and the novelty of the technology may hinder market adoption.

Future research should focus on overcoming the economic and operational hurdles associated with airship deployment. This includes exploring strategies for cost reduction, such as economies of scale in airship production, and investigating alternative business models that integrate airships into multimodal logistics networks. Additionally, pilot projects and real-world trials could provide valuable data to refine the technology and assess its performance under various operating conditions.

In conclusion, hydrogen-powered airships represent a promising yet complex solution for sustainable logistics across various sectors. Their potential environmental benefits make them an attractive option for future development, but overcoming the associated challenges will require continued innovation, collaboration, and investment. As the logistics sector continues to evolve, airships could play a crucial role in shaping a more sustainable and efficient global supply chain.

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