

REPORT

CARBON FOOTPRINT OF A LARGE-SCALE RIGID AIRSHIP



CONCEPT

2025-10-01

MISSION

330419

Title of report: Carbon footprint of a large-scale rigid airship

Status: Conceptual

Date: 2025-10-01

PARTICIPATING

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1 Introduction

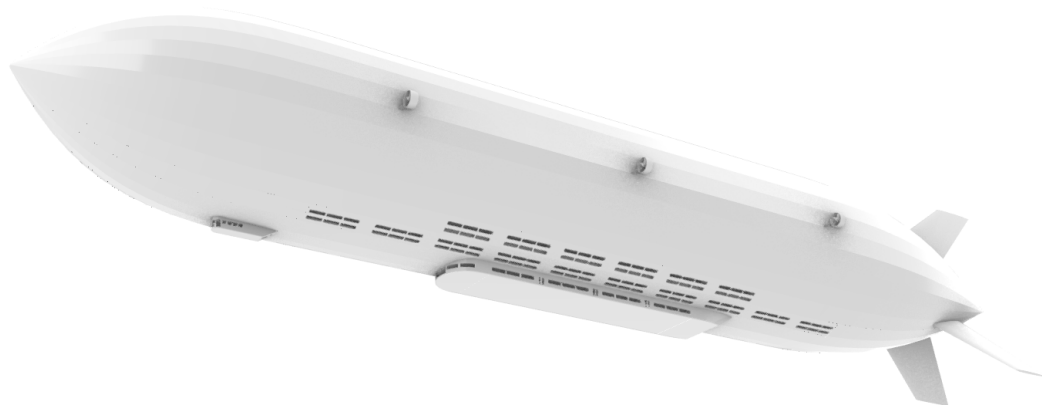
In today's society, we are increasingly aware of the challenges and pressures our planet faces due to human activity. With climate change posing one of the most tangible threats to the ecosystem and social stability, it becomes increasingly urgent to revise and reassess our technological and infrastructural choices. In this context, life cycle analysis emerges as a critical method to assess and understand the real consequences of our actions.

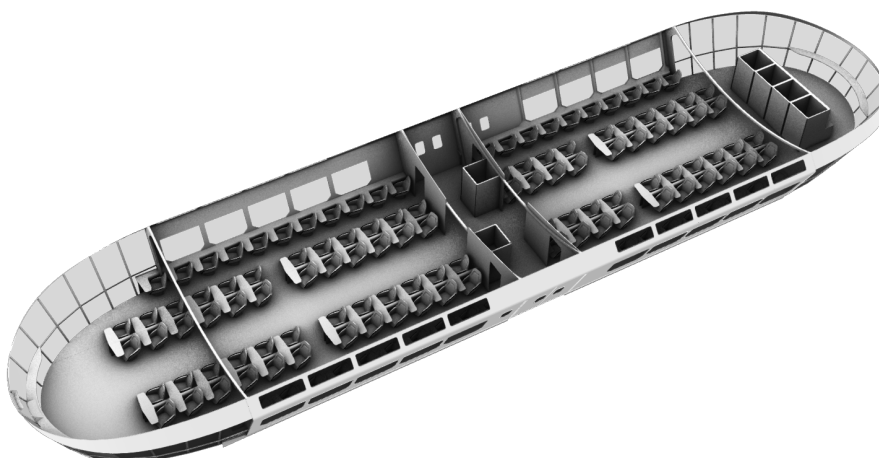
This report presents a carbon footprint assessment of the manufacturing and operation of a lighter-than-air technology vehicle, an airship, as well as a comparison between other modes of transport such as aviation, trains and road-bound vehicles.

1.1 Background

The airship used for reference in this study is a 100,000 m³ airship, approximately 200m in length and 30m in diameter, built with an internal rigid structure of carbon tubes. We reference this as the “studied airship”. The studied airship is a traditional rigid airship design using modern materials and manufacturing techniques, but lends its overall design philosophy to the Zeppelins of the 1920s and 30s, building on their proven technology and tested design.

The capacity of the airship mentioned above is derived from a weight and volume study combined with an interior layout design that determined the potential maximum configuration of the studied airship for passenger transport between 2021 and 2024.





This report's baseline is a hydrogen-propelled airship, with a fossil-fueled powertrain considered only for generic energy comparison. The business model's feasibility for the studied airship is outside this report's scope.

The airship industry widely considers hydrogen propulsion suitable and feasible for future large-scale airships. This is due to generous volume constraints allowing for significant hydrogen fuel storage for long-range capabilities. Hydrogen is also more energy-dense per unit weight than carbohydrates. Furthermore, airships' low power demand means a manageable number of fuel cells can be installed, keeping weight in check. Thus, a hydrogen-fuel cell drivetrain offers higher efficiency in electricity generation than diesel generators and lower fuel burn per unit weight.

An additional benefit of a hydrogen-fuel cell drivetrain is the continuous production of surplus water from the fuel cell's electrolysis. This water counterbalances the airship's fuel burn, maintaining neutral buoyancy.

Certifying hydrogen-fuel cell drivetrains for aviation presents a challenge that is beyond the scope of this report.

Airships utilise lighter-than-air technology, whose energy efficiency stems from two fundamental physical attributes:

1. **Lift Generation:** Airships generate lift through lifting gas (helium) rather than engine thrust.
2. **Reduced Drag:** Their slow travel speed minimises "parasite drag" or air resistance.

2 Goal and scope

This report aims to calculate the climate impact from the manufacturing and operation of the studied airship. A comparison with other modes of transport, such as aviation, train and road-bound traffic has also been performed. The geographical scope for manufacturing is the US. Sweden/Europe is used for the operational phase.

The climate impact from the construction of an airship field is also investigated, along with the potential for carbon storage from planting green structures in the area of the airship field.

It is important to highlight that the design of the airship and the airship field is still in a conceptual phase where material choices, fuel consumption, potential location etc, are still not fully known. Caution should therefore be exercised when interpreting the results.

3 Method

The climate impact from manufacturing the studied airship is calculated in the software SimaPro version 9.5.0.0. The LCA database used is Ecoinvent version 3.9.1, and the method used is IPCC 2021 GWP100 v.1.02. The infrastructure for the airship fields has been calculated with background data from the Swedish Transport Administration's climate software *Klimatkalkyl*. For other transport modes, the climate impact is based on literature studies.

In this report, the total carbon footprint is defined as the manufacturing of the airship, fuel production (Well to tank, WTT), fuel combustion (tank to wheel [propeller], TTW) and maintenance of the vehicle. The end-of-life stage of the airship is not included. The end-of-life describes the waste treatment of the vehicle.

The functional unit in this study is 1 pkm (passenger-km) for the operation of the airship. The results for the airship field are presented for the construction of one field.

When calculating the baseline scenario, generic LCA data from Ecoinvent have been used along with specific amounts for materials and energy consumption from information of airship manufacturers. When data has been missing, assumptions have been made to compensate for the absence of data. Generic ecoinvent data comprises a comprehensive collection of life cycle assessments (LCAs) for various products and processes. This database encompasses environmental impact information across different stages of a product's life cycle, including raw material extraction, manufacturing, distribution, use, and waste management. The data is considered "generic" as it does not pertain to a specific product or manufacturer but rather represents average or typical values for various industrial processes.

4 Life cycle inventory (LCI)

4.1 Life Cycle Inventory Airship

The calculation is based on the studied airship, which is designed for commercial certification. As the final design of the airship is still uncertain, assumptions and simplifications have been used when collecting data.

The studied airship is 200x30m, and the gondola is 46x12x3,9m. The maximum payload is approximately 17,000 kg, and the disposable load is approximately 20,500 kg. The number of passengers carried (pax) is 130.



Figure 1. The P1 proof of concept airship, a flight test vehicle measuring almost 124m, took flight in 2024 for the first time. (<https://ltaresearch.com/>) which represents the current forefront of the industry.

In Appendix 1, the life cycle inventory, as well as the used environmental data and assumptions, are presented for the studied airship.

Some of the more significant information and assumptions regarding the studied airship and airship fields are listed below.

- The studied airship has a capacity of 130 pax.
- The load factor of passengers is 80 % (same as for aeroplanes).
- The lifespan is 40 years (same as for aeroplanes).
- The total transport distance during the lifespan is roughly 19,000,000 km, which is based on 40 years, 320 days in the sky per year, 20 hours a day, with a speed of 40 knots.

- The main purpose of the aircraft is passenger transport, and therefore, the passengers are assumed to carry all the climate impact. The cargo does not carry any climate impact.
- The fuel consumption (LH₂) is 0,421 FF LH₂ kg/km or 0,78 FF LH₂ kg/nm at a ship heaviness of 750kg.
- A yearly loss of 10 % of lifting gas (Helium) is assumed.
- Maintenance includes replacement of canvas, electrical motors and generator sets/fuel cells after 20 years.
- A 200 kW electrical motor has been assumed to weigh 100 kg.
- The total weight of the fuel cell system is assumed to be approximately 2 tonnes with a maximum continuous rate of 1,600kW and a top rate of 2,400kW. The background data for modelling the hydrogen fuel cell production footprint is based on production data for a 10 MW diesel-electric generating set, for conservative reasons.
- Inventory and interior structures in the airship are assumed to consist of 50 % carbon fibre and 50 % aluminium.
- When calculating the fuel consumption for a diesel combustion engine, it has been assumed that it has 10 % lower efficiency and a 3.5X higher fuel burn compared to a hydrogen fuel cell.

For comparison with other modes of transport, the following assumptions have been made.

- A car is assumed to have a total mileage equivalent to 200,000 kilometres over its lifetime, carrying 3 persons per car.
- The climate impact from the manufacturing of a car is assumed to be 6,8 t CO₂e for a gasoline car, 7.1 t CO₂e for a diesel car and 13.7 t CO₂e for an electric car
- The life span for roads is assumed to be 40 years
- The life span for railways is assumed to be 40 years
- The life span for airports is assumed to be 100 years
- The life span for airship fields is assumed to be 40 years
- The allocation between road passenger transport and road goods transport is based on total transport distance.
- The allocation between passenger and goods railway transport is based on the number of vehicles.
- The average distance for travelling with an aircraft is assumed to be 3,500 km.

4.2 Life cycle inventory Airship field

The concept of the airship field is not comparable to a traditional airport. The idea of the field is to minimise the need for hardened surfaces, such as asphalt and buildings and maximise green structures and surfaces in the area.

Within the landing zone, see the light green circle in Figure 2, the surface is reinforced with permeable grass reinforcement. The outer areas (meadow, bush, and forest) do not include any infrastructure for the airship field, but is the space required for operational safety to land the airship. The bush and forest zones are planted with vegetation to act as carbon storage and improve the safety of ground operations.

In Appendix 2, the life cycle inventory, as well as environmental data and assumptions, are presented for the airship field.

Some of the more significant information and assumptions are listed below.

- The terminal is assumed to be 3,225 m². This assumption is based on data for Umeå airport with a capacity of 980,000 pax per year. The capacity of the airship field is assumed to be 3,000 pax a day for 365 days a year, 1,095,000 pax per year.
- The number of parking slots is assumed to be 900.
- The road from the terminal to the landing zone is assumed to be 800 m long and equivalent to a pedestrian and bicycle road.
- No excavation or filling with bulk material is assumed to be needed in the landing zone. The grass reinforcement is assumed to be able to handle the required weight.
- Only energy use in terminal buildings and mowing/clearing of vegetation in the grass and meadow areas are included as maintenance/operation.
- A hangar for airship maintenance and an air traffic control tower are not included in the analysis.
- Infrastructure for fuel supply and storage is not included in the analysis.
- Stormwater treatment, ground stabilisation measures or potential remedial measures for soil and groundwater pollution are not included in the analysis.
- No demolition work is assumed to be required before construction.
- No environmental impact has been attributed to the planting of trees and bushes.
- Trees have been assumed to have a potential for carbon storage of 8 kg CO₂e/tree and year, and bushes have been assumed to have a potential of 12 kg CO₂e/m² and year (Råberg, 2022). There are 24 trees per hectare in the forest zone and a 12 % coverage of land area in the bush zone.

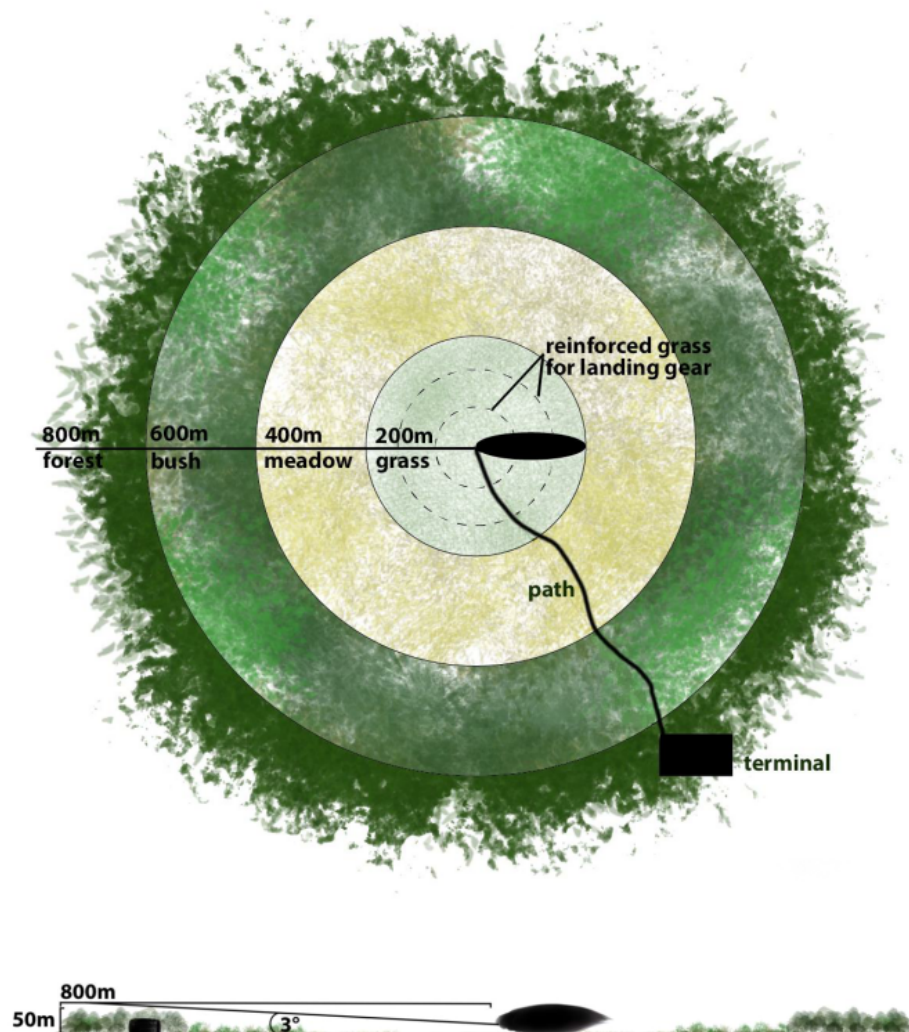


Figure 2. Airship field, concept idea.

5 Results

This chapter accounts for the findings of the study. The results for the airship (chapter 5.1) present the results per transported person kilometre, and the results for the airship field (chapter 5.2) present the results for the construction and maintenance of one airship field.

5.1 Results Airship

The fossil climate impact from the manufacturing and operation of the studied airship is 10 g CO₂e/pkm, and the energy consumption is 0,10 kWh/pkm. The consumption of LH₂ in operation is the single most significant contributor to carbon emissions, accounting for 81 % of the total emissions per pkm. The manufacturing of the airship accounts for 14 % of the total carbon emissions, and the maintenance (including replacements and the lifting gas helium) accounts for the remaining 5 %, see Figure 3.

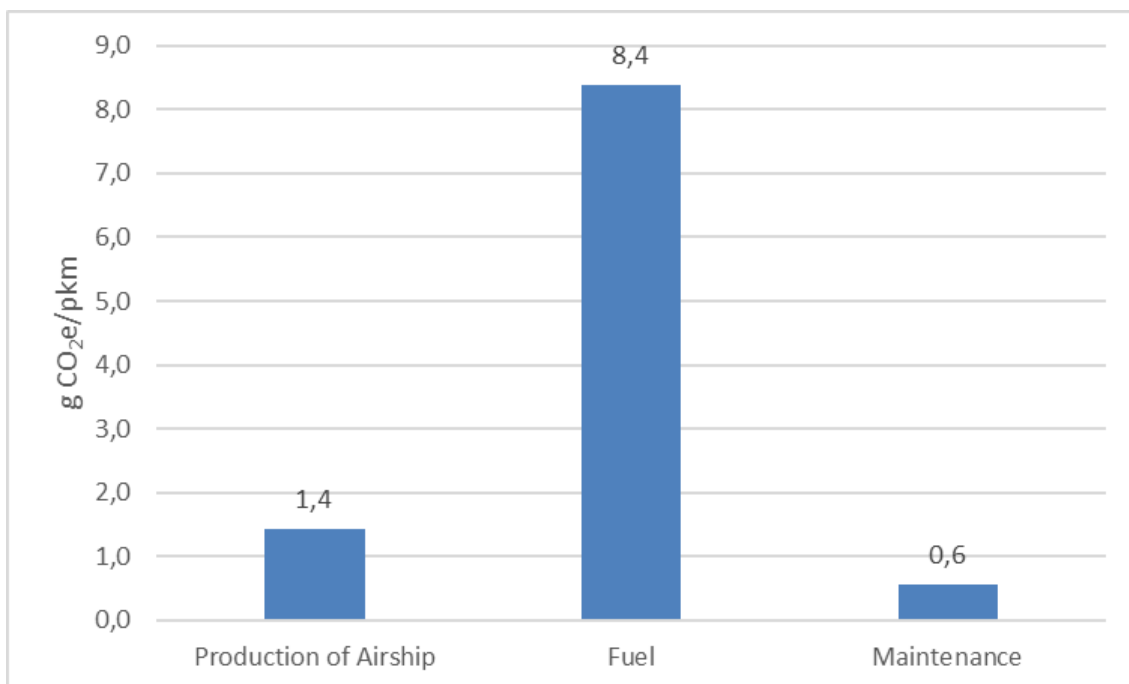


Figure 3. Carbon emissions per pkm for the studied airship.

The manufacturing of the airship brings 1,4 g CO₂e/pkm or 2,800 tons CO₂e per produced airship. In Figure 4, the percentage of carbon emissions from the manufacturing stage is presented per component, part, or activity. The majority of the impact is related to the manufacturing of the carbon fibre tube framework (56 %), which consists of 10 tons of carbon and 5 tons of titanium. Other significant contributions include the manufacturing of the gondola (23 %) and the fuel tanks (15 %). The canvas structure accounts for approximately 3 % of the carbon emissions from the manufacturing of the airship.

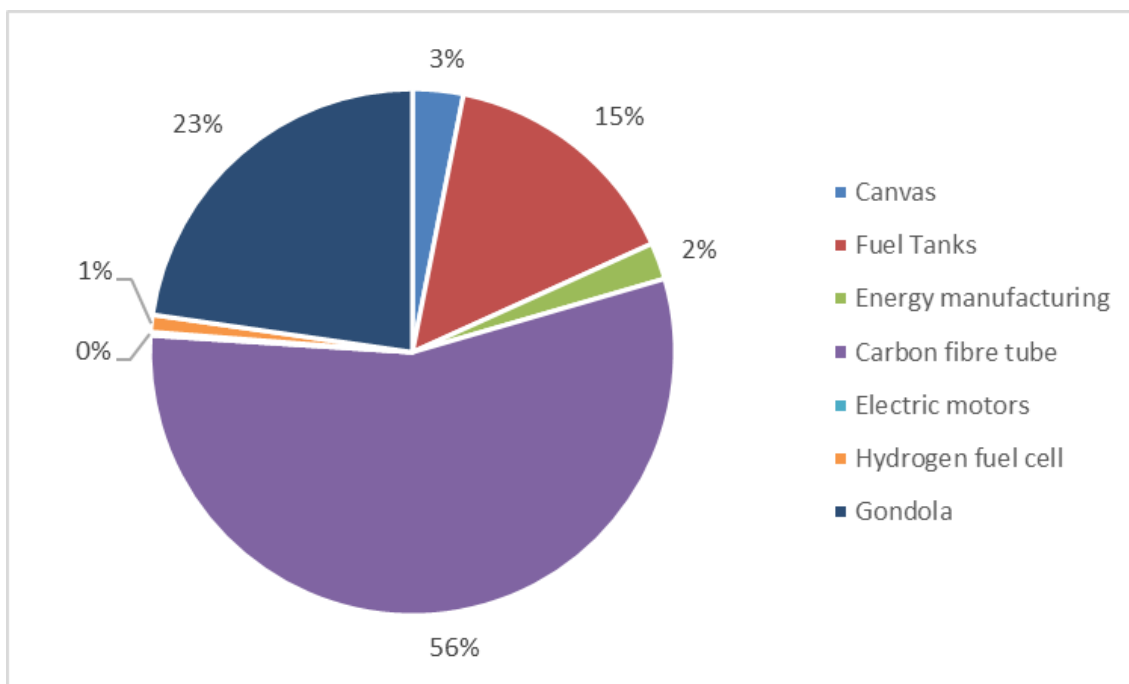


Figure 4. Material contribution to carbon emissions from the manufacturing of airships.

5.2 Results Airship field

The fossil climate impact from establishing an airship field is roughly 2,250 tons of CO₂e. The landing zone consists of plastic (steel can also be used) grass reinforcement, with 55 % of the total carbon emissions from the airship field. The terminal building accounts for 34 %, the parking area 7 %, and the access road, as well as maintenance and operation, contribute 2 % each of the total carbon emissions from the airship field.

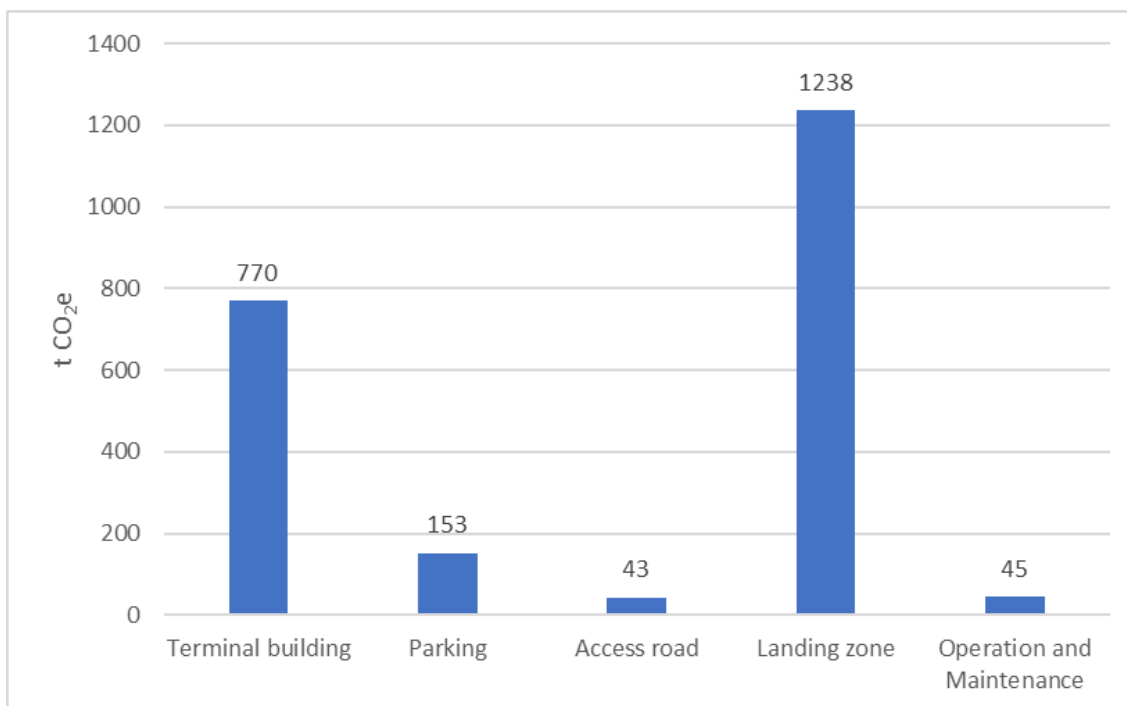


Figure 5. Carbon emissions from an airship field, presented in tonne CO₂e.

The potential for carbon storage from planting vegetation within the area for the airship field has also been explored. Vegetation such as trees and bushes has the potential to store carbon emitted to the atmosphere as long as the tree/bush is still alive. The forest zone (see Figure 2) has the potential to store roughly 17 tonnes of CO₂e a year or 676 tonnes of CO₂e over the lifetime of the airship field (40 years). The bush zone (see Figure 2) has the potential to store roughly 904 tonnes of CO₂e a year or 36,173 tons of CO₂e over the lifetime. In Figure 6, the potential for carbon storage for trees and bushes combined is illustrated over the lifespan of 40 years. For an airship field, the annual potential carbon storage will be 865 tonnes CO₂e/year, when the lifetime is 40 years and 899 tonnes CO₂e/year if the lifetime is 100 years.

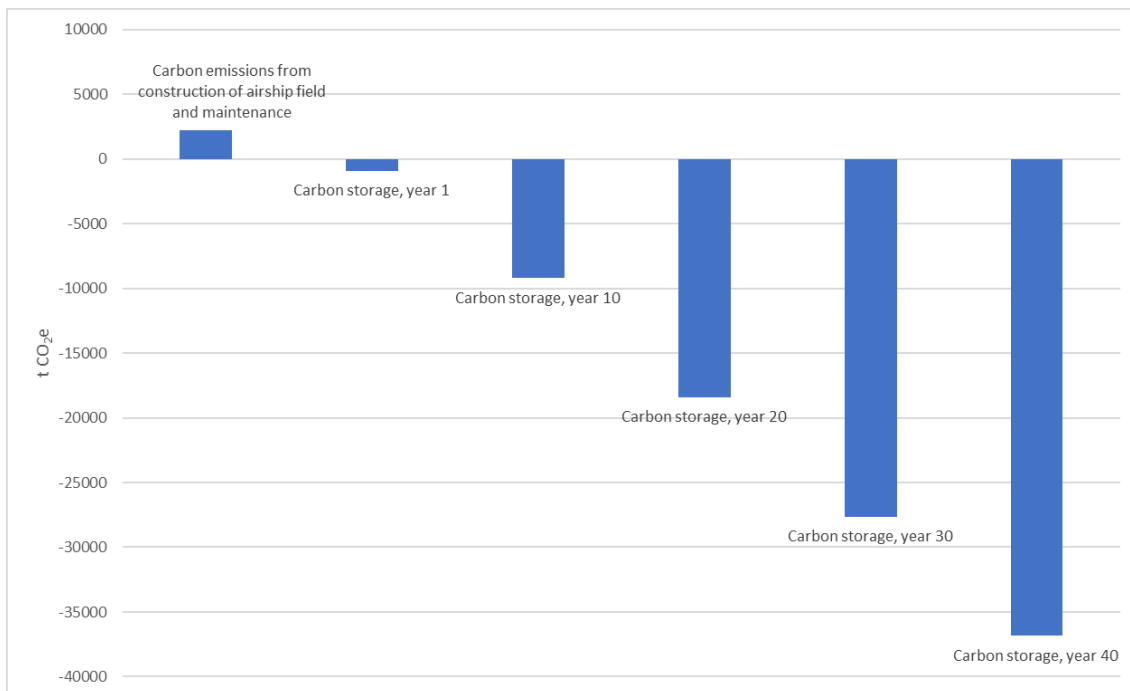


Figure 6. Potential for carbon storage in vegetation in an airship field.

6 Sensitivity analysis

In this chapter, a sensitivity analysis has been carried out to highlight how different aspects of the assessment contribute to the results.

6.1 Sensitivity analysis Airship

The life cycle inventory data for the airship is based on very rough assumptions for material use and operation. As the design of the airship is not yet finished, it is important to update the analysis when more information on material choices and data regarding operation is available. To address the importance of data quality and verification of results, a sensitivity analysis has been conducted on the fuel, load factor, replacements and distance.

6.1.1 Fuel consumption

The fuel consumption of LH₂ in the operation of the airship contributes to the majority of the carbon emissions. The data used in the analysis is based on generic Ecoinvent data for the production of hydrogen. The energy used in the production of hydrogen plays a significant role in its potential climate impact. In Figure 7, this is illustrated by the carbon emissions per pkm from liquid hydrogen produced with different energy sources and assumptions. As seen in the figure, the baseline scenario used in this analysis is approximately 10 g CO₂e/pkm. If the LH₂ had been produced with 100 % renewable energy, the climate impact would have been 3 g CO₂e/pkm or 242 g CO₂e/pkm if the LH₂ had been produced entirely of natural gas or biomethane with 20% upstream leakage (Mukhopadhyaya, J & Rutherford, D., 2022). This illustrates a best- and worst-case scenario but highlights the significance of upstream emissions along the supply chain and the importance of setting requirements for fuel suppliers.

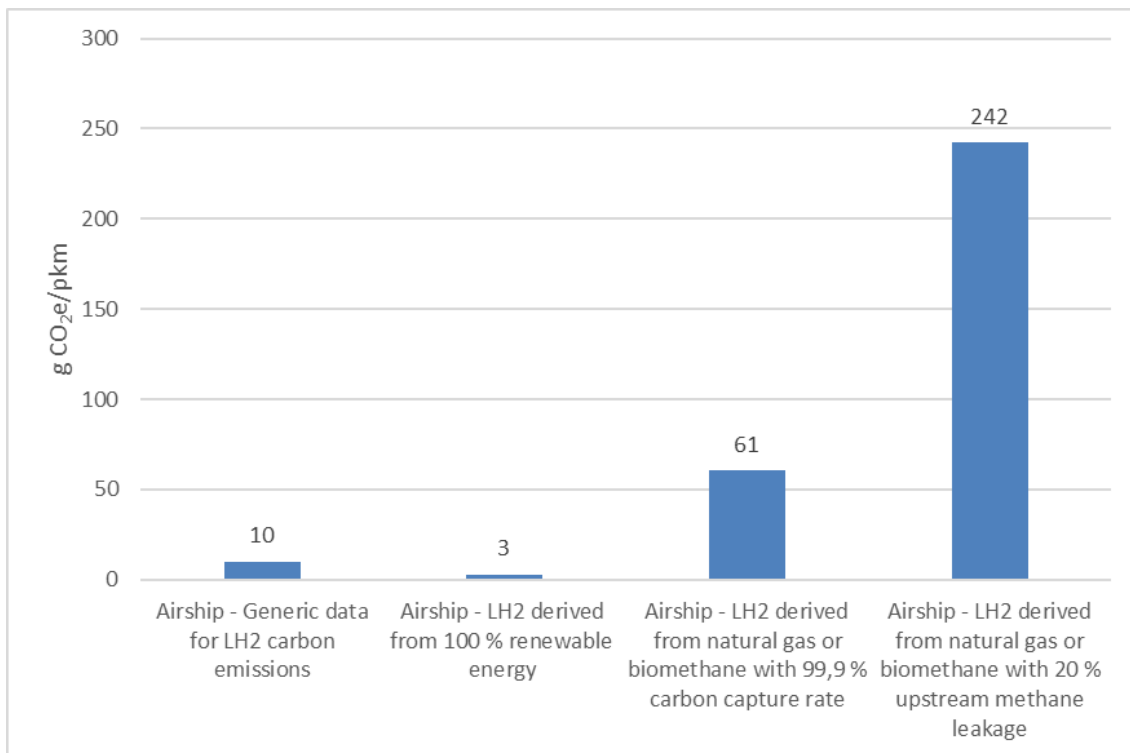


Figure 7. Carbon emissions per pkm with different data for LH₂.

6.1.2 Other operational aspects

To investigate other potential aspects that impact the analysis results, an additional sensitivity analysis was conducted. Given that the production of the airship has a relatively minor impact compared to fuel consumption during the operational phase, the primary contributors to the climate impact are associated with the operational aspects of the airship. The focus of the sensitivity analysis has subsequently been on operational aspects.

- Changing the load factor from 80 % to 50 % translates to an increase of the potential climate impact by 60 % compared to the baseline scenario.
- If the passenger capacity had been 65 pax instead of 130 pax, with a load factor of 80 %, the climate impact would increase by 100 %.
- Changing the technical lifespan of the airship from 40 years to 20 years resulted in a 14 % increase in carbon emissions per pkm.
- Changing the technical lifespan of replacement parts (hydrogen fuel cell, electric motors, and canvas) from 20 years to 5 years gives a 4 % increase in carbon emissions per pkm.
- Changing the yearly distance [utilisation] of the airship to half of the baseline scenario brings a 19 % increase in carbon emissions.
- If the fuel consumption per km is increased by 20 %, the climate impact per pkm will be 16 % higher than the baseline scenario.

- In the baseline scenario, a yearly loss of 10 % of lifting gas is assumed. If 100 % of the lifting gas must be replaced every year, this would result in a 35 % increase in carbon emissions per pkm.
- If the fuel is switched from hydrogen to diesel, the fossil climate impact would increase by 472 %.
- If the speed of the airship were to increase from 40 kts to 50 kts, the fuel consumption would increase from 0,421 kg LH₂/km to 0,616 kg LH₂/km, but the total distance per year would also increase from 474,112 km to 592,640 km. This change would increase the carbon emission per pkm by 34 %.

In Figure 8, the different aspects of the sensitivity analysis are presented.

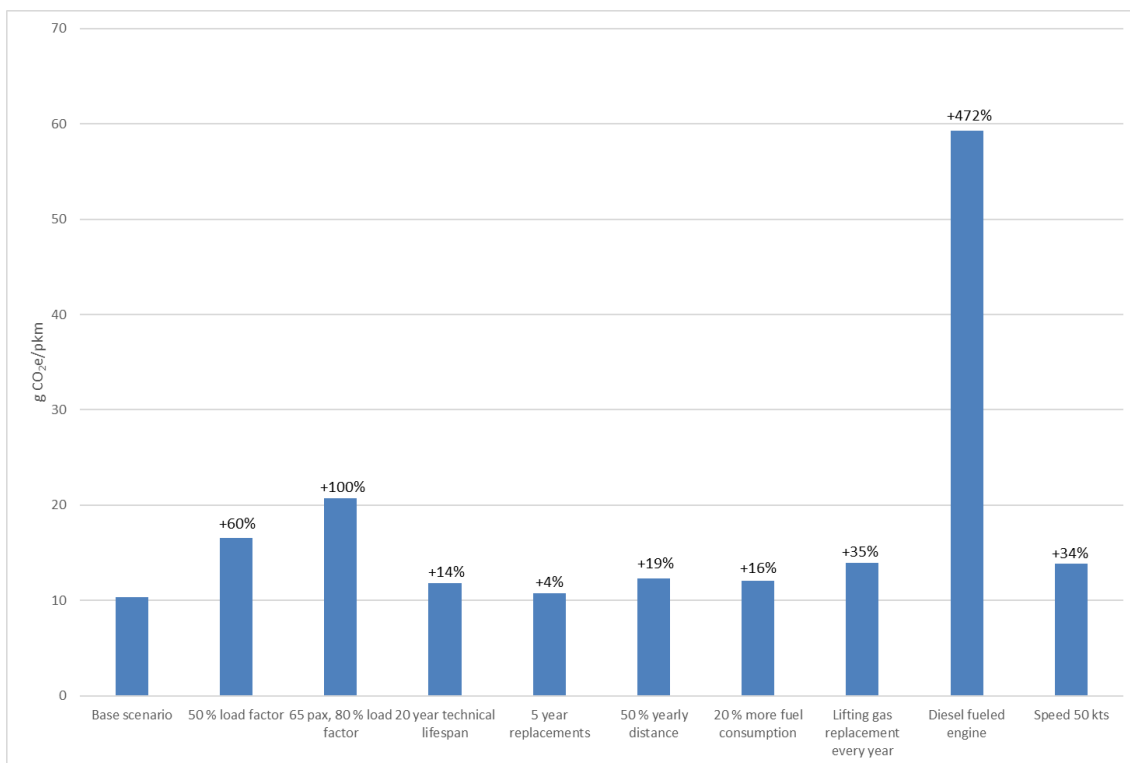


Figure 8. Sensitivity analysis airship, g CO₂e per pkm.

6.2 Sensitivity analysis Airship field

The climate impact related to the airship field is mainly influenced by the terminal building and the landing zone. In Figure 9, the following scenarios have been evaluated for the sensitivity analysis:

- If it is assumed that 0,4 m of the landing zone would have to be excavated and filled with bulk material for stabilisation purposes, this would bring an increase of 46 % of the total climate impact from the airship field.
- In the baseline scenario, it is calculated with 50 mm grass reinforcement. If 40 mm grass reinforcement could be used, there is potential to reduce the impact from the airship field by 25 % compared to the baseline scenario.

- A 50 % smaller or bigger terminal would result in a 17 % reduction or addition compared to the baseline scenario.
- 50 % more or less parking slots would result in +/- 3 % climate impact to the baseline scenario.

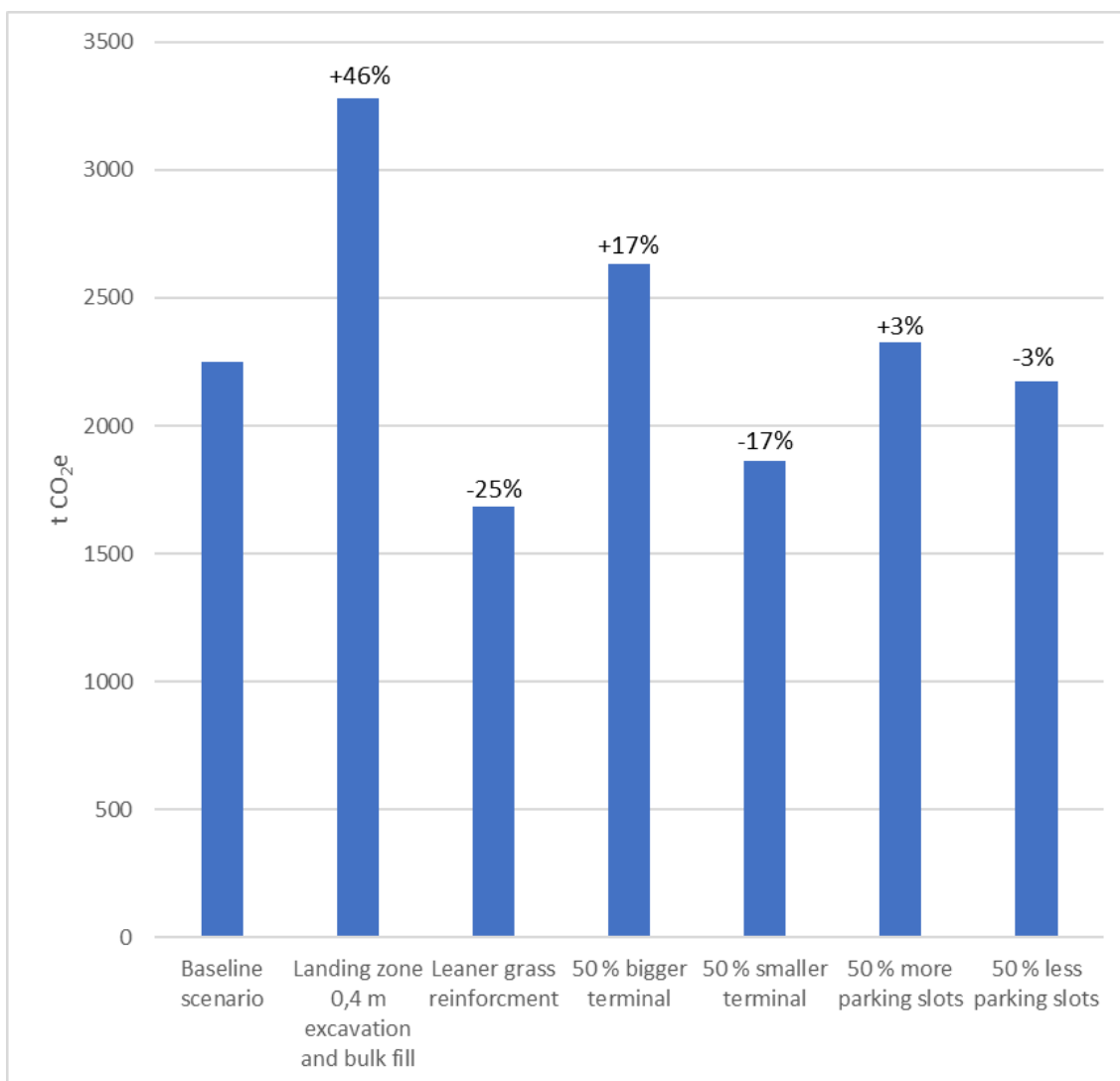


Figure 9. Sensitivity analysis airship field.

6.3 Comparison to other modes of transport

The results in this study have been compared to other modes of transport, as seen in Figure 10.

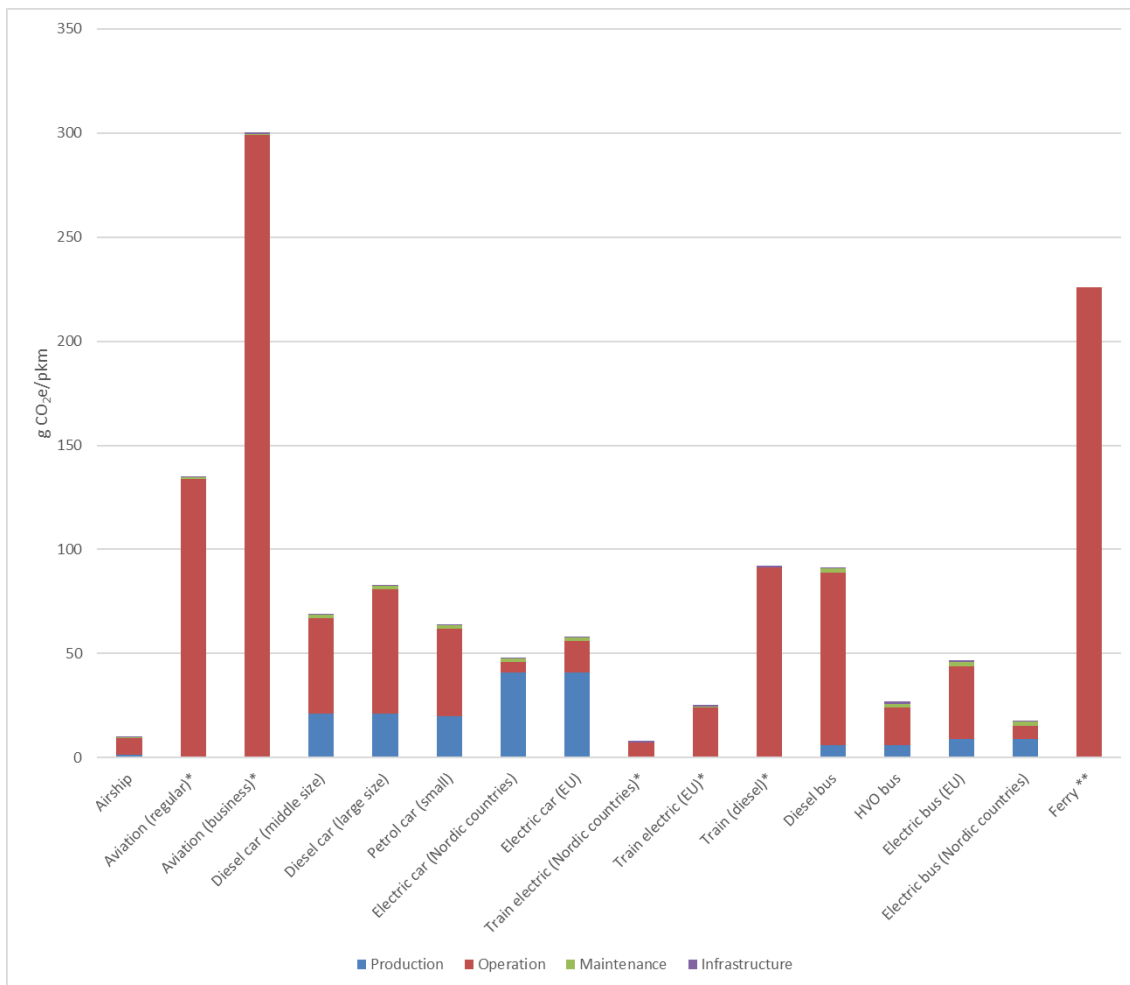


Figure 10. Comparison between different modes of transport, g CO₂e/pkm.

*Maintenance is not included.

** Construction, maintenance and infrastructure are not included.

The baseline scenario for the airship results in a climate impact of 10 g CO₂e/pkm. As a comparison, a traditional aircraft has a climate impact between 133 and 298 g CO₂e/pkm (Larsson, J & Kamb, A., 2022), depending on whether it is a regular or business flight. Few studies include the production of aircraft; two studies have been found. The environmental impact of construction varies between 0.77-7.7 g CO₂e/pkm (EPD International, 2024a). In this study, the production of an aircraft is assumed to be 0.77 gCO₂e/pkm. This value was chosen to have a reliable and conservative comparison between the modes of transport.

Travel by electric train in the Nordic countries brings the lowest climate impact per pkm (7g CO₂e/pkm). The reason for this is the share of renewable electricity that is used in these countries. A European electrical train has a climate impact of 24 g CO₂e/pkm, and a diesel train has a climate impact of 91 g CO₂e/pkm. In Europe, there is often a mix of electric and diesel trains, but the majority is assumed to be electric. The construction of the train is based on 8 studies where the result varies between 0.003 g CO₂e/pkm and 1.2 g CO₂e/pkm (EPD International, 2024b). The value in Figure 10 is the median for the 8 studies, 0,91g CO₂e/pkm.

Travel by ferry brings a climate impact of 226g CO₂e/pkm. The information about the ferry's climate impact is scarce. One reason for the high result is that the load factor is 40 %, and the area per passenger is larger for ferries than for other transport modes. Many ferries contain restaurants, tax-free stores, and sun decks. The result for ferries does not include the construction of the vehicle or maintenance, due to no study having been found.

Travel by electric car entails a climate impact of 46-56 g CO₂e/pkm, depending on the origin of the electricity used; the operational phase constitutes 11-27 % of the emissions. A car with a combustion engine has a climate impact between 62-81 g CO₂e/pkm, depending on the type of fuel used and the size of the car. Unlike aircraft, trains or boats, the construction of the vehicle plays a bigger part in the total carbon emissions per pkm for cars, as the total distance over its lifetime is significantly shorter in comparison.

When comparing the climate impact of bus travel, the results vary depending on the literature used. Larsson, J & Kamb, A. (2022) declare a climate impact of 25 g CO₂e/pkm for the operational phase of a diesel-driven bus and Nordelöf et. Al (2017) declares a climate impact of 83 g CO₂e/pkm for the operational phase of a traditional diesel bus. The climate impact from the construction of a bus with a combustion engine is 6 g CO₂e/pkm. An electric bus has a climate impact of 15-44 g CO₂e/pkm, depending on the origin of the electricity used, where 9 g CO₂e/pkm is derived from the construction of the electric bus.

6.4 Comparison to an airport

A comparison between the construction of an airship field and a traditional airport has also been carried out. Data for the traditional airport is sourced from Ecoinvent, based at Zurich Airport. The Ecoinvent data has been adjusted to be more comparable to the airship field. The impact of the airport clearance has been removed, and the energy has been substituted with district heating and electricity in Sweden. The data has been scaled on the number of passengers travelling to and from Zürich airport in the year 2019 (Zürich Airport, 2024). The airship field is assumed to have a capacity of 3,000 passengers per day, 365 days a year.

The result of the comparison illustrates that the construction of an airship field entails significantly less carbon emission compared to the construction of a traditional airport (see Figure 11). The total amount of area required for building purposes for the airship field is substantially smaller compared to a traditional airport. Roughly 60 % of the carbon emissions related to the construction of the airport originate from electricity and heating for operational purposes. As the built-up area is significantly larger for the airport, the need for electricity and heating also increases. The traditional airport also includes more sealed surfaces compared to the airship field.

It is hard to determine the system boundary and scope of the results for the airport; thus, there is an overwhelming risk of overestimating the differences between constructing an airship field and an airport. This is because the data for the airport might include infrastructure and maintenance necessary for the airship field as well. As the data quality for the airship field is still low and under development, these results should be treated with caution.

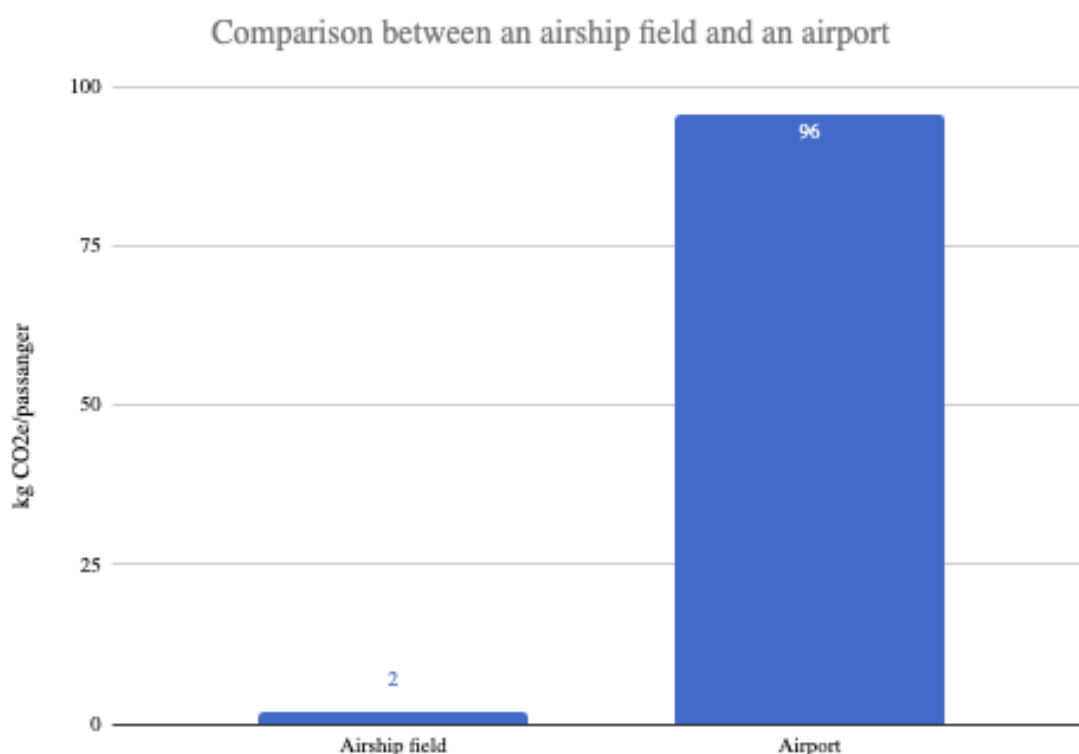


Figure 11. Emission comparison per passenger from the infrastructure construction and operation during lifetime (100 years) between an airship field and an airport, the result presented as kg CO₂e per [airport/field] passenger (carbon sequestration not accounted for).

6.5 Comparison of the climate impact of infrastructure

Few studies have been found that include climate impact from infrastructure, i.e. construction of roads, railways and airports. The calculation regarding the environmental impact of the infrastructure is based on a Swedish context, statistics from Swedish agencies and assumptions.

According to the Swedish Transport Administration, the annual climate impact from road infrastructure is 1.8 million tons CO₂e (Swedish Transport Administration, 2022). In the year 2022, 95% of all road transport in Sweden was made by a passenger car (Trafa, 2024a), and the total passenger kilometres were 110 billion passenger kilometres. Based on the assumptions above, the climate impact from the road infrastructure is assumed to be 0.22 g CO₂e/pkm, which is around 0.3 - 0.5 % of the total climate impact.

The annual climate impact from railway infrastructure is 0.6 million tons of CO₂e (Swedish Transport Administration, 2022). The allocation between passenger transport and goods transport is based on the number of vehicles. 80 % of the trains are used for transporting passengers (Trafa, 2024b), and the total amount of passenger kilometres is 5,679 million pkm (Trafa, 2024c). Based on the assumption above, the climate impact from railway infrastructure is assumed to be 0.91g CO₂e/pkm, which is between 1% and 11% of the total climate impact for railways.

The climate impact for aviation infrastructure construction is based on the results in 6.4, where the maintenance and operation of the airport have been removed for comparison reasons. The lifespan for an airport is assumed to be 100 years, and the average transport distance is assumed to be 3,500 km. The climate impact from aviation infrastructure is assumed to be 0.20 g CO₂e/pkm, which stands for around 0.1 % of the total climate impact for aviation.

The climate impact of airship infrastructure is based on the same assumption as for aviation. The climate impact for airship infrastructure construction is 0.01g CO₂e/pkm, which is 0.1 % of the total climate impact.

The potential of the airship field to sequester carbon has not been accounted for in the calculations of the airship's CO₂e per pkm to remain conservative.

Figure 12 shows the climate impact of infrastructure for different modes of transport.

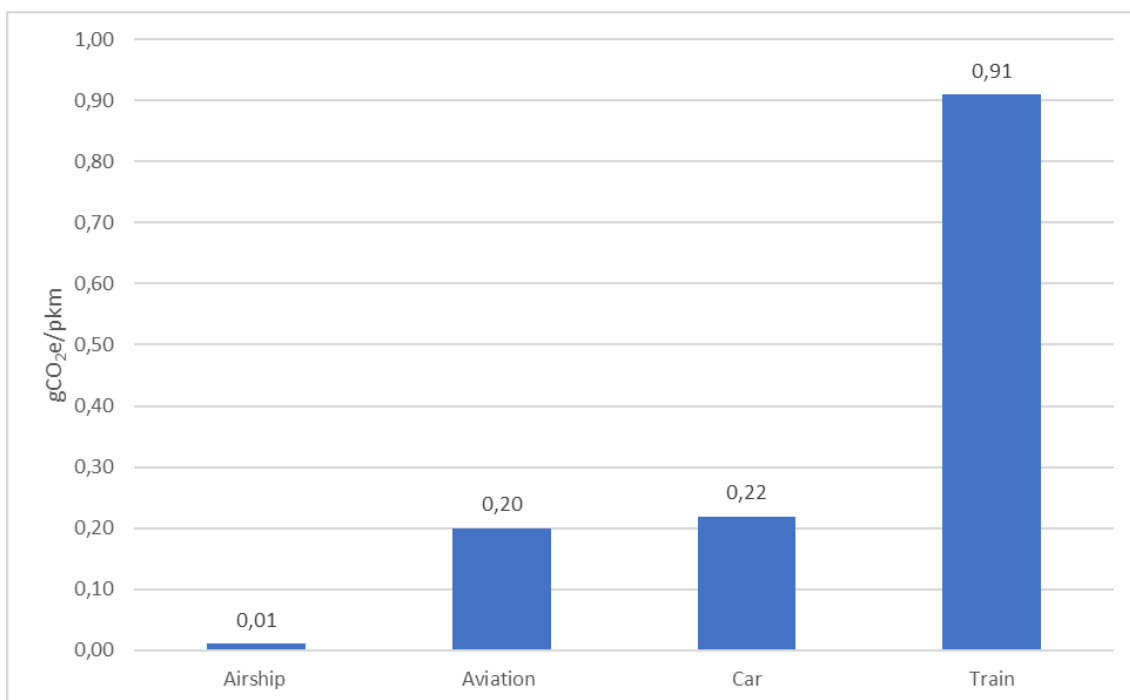


Figure 12. Comparison of infrastructure construction emissions for different modes of transport

The climate impact from infrastructure contains great uncertainties due to a lack of information and assumptions regarding, e.g. lifespan and total number of passengers. Information about the construction of each mode of transport has been poor, which makes it difficult to evaluate if each source has the same scope and system boundary. The assumption regarding lifespan, allocation between goods and passengers and total number of passengers during the lifespan of the infrastructure has an impact on the results. These assumptions are difficult to ensure, and therefore, the result varies between studies. Due to this, the result for the infrastructure should be treated with caution.

7 Discussion and conclusion

The technology for airship travel is not new; however, there is a lack of information and literature regarding the climate impact of this mode of travel. With the rising threat of exceeding thresholds and climate tipping points for global warming, the need for alternative aerial modes of transport other than aeroplanes might be needed.

As seen in this study, airship travel could play a part in reducing the climate impact related to travel. The sourcing of the hydrogen fuel used to operate the airship has a decisive role in the climate impact. As hydrogen is energy-intensive to produce, renewable energy must be used in the production. Otherwise, there is an imminent risk of suboptimisation, where the carbon emissions take place in the energy production instead of when combusted in an engine.

The passenger capacity of the airship also plays a decisive role in the climate impact per pkm. The impact can be seen in the sensitivity analysis in section 6.1.2, when changing the load factor from 80 % to 50 % or adjusting the number of passengers carried (pax) from 130 to 65, the climate impact significantly increases. To minimise the carbon emissions per pkm, it is therefore important to increase the load factor and create opportunities for as many passengers as possible on each flight.

As the final design of the airship is not yet finished, there are uncertainties related to the manufacturing of the airship and its components. In this study, rough assumptions regarding inventories and components have been made; for example, a 50/50 share of aluminium and carbon fibre has been presumed for all components in the interior (except for windows). Even if the vast majority of the climate impact is related to the operation of the aircraft, there are big incentives to update the climate calculation as more detailed data is available to minimise the carbon emissions arising from the material acquisitions.

The concept idea for the airship field is comparable to a train station where you arrive at the station, enter your train and leave. The result of this study reflects a very slim design of the airship field. The landing zone and the terminal building cause most of the climate impact from the airship field. However, the need for stabilisation measures could be of significant importance if it is needed. The results include a terminal building, access road, grass reinforcements for the landing zone, parking, and some minor maintenance. As this constitutes a very rough estimation, it is advised to update and complement the calculation when more detailed data is available.

The area suitable for the field is old industrial areas that could be used without claiming any virgin land. As the area requirements for the airship field are considerable, feasible areas could be hard to find. The results regarding the potential for carbon storage in vegetation reflect a condition where no green structures are claimed, with an advantage for the airship field. If trees and bush vegetation were to be cut down to make room for the field, the results presented in Figure 6 would be the opposite, due to the potential for carbon storage to be removed, and the carbon stored in the vegetation would be released into the atmosphere. The clearing of trees and bushes would also have an environmental impact from the activities connected to the felling of trees.

The climate impact from infrastructure for airports and airship fields has the lowest impact of all modes of transport. Other environmental advantages for airports and airship fields are that they use less area than roads and railways, which means that less

forest and nature have been affected. Roads and railways also have created barrier effects in nature, which means that animals and vegetation have more difficulty moving freely in nature.

Comparing train, car, and air transport by passenger kilometres is not always accurate since aircraft always take the linear distance while the road and train must follow the existing infrastructure. For example, to travel between Stockholm in Sweden and Helsinki in Finland, the flight distance is 437 kilometres, while going by car makes it a 1,760-kilometre journey around the Bothnian Bay.

The construction of an airship field entails significantly fewer carbon emissions compared to the construction of a traditional airport, given that the need for buildings with sealed-up surfaces and energy use is minimised. The airship field illustrated in this study is a very slim design where passengers are only intended to arrive at the airship field to board or exit the airship, much like the design of an average train station. The same goes for the land claim in the immediate area around the airship field, which is only a landing zone covered with grass reinforcement and an access road surrounded by meadow, bush and tree vegetation. Consequently, it is important to acknowledge that any further land claims or built-up environment would increase the potential carbon emissions related to the airship field.

In summary, the airship has one of the lowest climate impacts when compared to different modes of transport. This statement is, however, dependent on the sourcing of hydrogen fuel, as the climate impact from the production of hydrogen fuel varies depending on the source of electricity. Significant consideration should therefore be granted to the sourcing and supply chain of the fuel. As the project is still in a conceptual stage, where many aspects are still undecided, it is recommended to update and complement the carbon footprint when more detailed data is available.

Within the scope of this report, we have used the largest modern airship that was available to produce reliable data. However, the rigid airship used in this study is “only” a bit more than 100,000m³, which is to be considered a first generation of modern large-scale airships, but built on a design platform to scale up the volume and size. As airships scale up in size, their capacity increases exponentially relative to the increase in length and drag (fuel consumption), thus presenting a potential to significantly reduce the climate footprint further. It is therefore recommended to study an LCA on a larger airship for a better assessment of what lighter-than-air technology can offer in terms of clean and efficient aerial transportation for the future.

8 References

Ecoinvent, < <https://ecoinvent.org/the-ecoinvent-database/> >

Ecoraster reinforcement grid (2018). EDP S-P-03450. EPD International AB

EPD International 2024a, Aircrafts

[Data \(environdec.com\)](#)

<https://api.environdec.com/api/v1/EPDLibrary/Files/27187d7a-d95c-452f-acdd-4a38e453c50e/Data>

EPD International 2024b, Trains

<https://api.environdec.com/api/v1/EPDLibrary/Files/df3e74c2-35ca-4e03-9397-69e15f18e3e9/Data>

<https://api.environdec.com/api/v1/EPDLibrary/Files/0a46c383-a599-4c99-9fb0-1d9683d64bf7/Data>

<https://api.environdec.com/api/v1/EPDLibrary/Files/a85c7146-02c0-4510-afa6-4407c9e12796/Data>

<https://api.environdec.com/api/v1/EPDLibrary/Files/e0941e44-2243-44b6-029f-08da0ca8bd08/Data>

<https://api.environdec.com/api/v1/EPDLibrary/Files/34038dda-107e-499e-bad0-cb4f9a35ad83/Data>

<https://api.environdec.com/api/v1/EPDLibrary/Files/122f36f9-7fe7-4b7b-a38d-abf3be9c559d/Data>

<https://api.environdec.com/api/v1/EPDLibrary/Files/a85c7146-02c0-4510-afa6-4407c9e12796/Data>

<https://api.environdec.com/api/v1/EPDLibrary/Files/5890c5b1-b935-40c9-b40f-b633d86f2b1e/Data>

<https://api.environdec.com/api/v1/EPDLibrary/Files/d861a36f-8ab0-4538-b804-311ea6ac52e3/Data>

Flying Whales

Larsson, J & Kamb, Anneli (2022). Metodrapport för www.klimatsmartsemester.se Version 3.0. Chalmers tekniska högskola.

ZLT Zeppelin Luftschifftechnik GmbH & Co.

LTA Research & Exploration

Mukhopadhyaya, J & Rutherford, D (2022). PERFORMANCE ANALYSIS OF EVOLUTIONARY HYDROGEN-POWERED AIRCRAFT. White Paper.

Nordelöf. A., Romare. M & Tivander. J (2017). Miljöpåverkan från elektriska stadsbussar. Chalmers tekniska högskola. Rapport nr. 2017:9 (2).

OceanSky AB

PowerCell AB

Råberg, T. (2022). Potentiella kolsänkor i Malmö stad. Miljöförvaltningen Malmö.

Swedish Transport Administration (2022). TRAFIKVERKETS MILJÖRAPPORT 2021, Publication number 2022:008

[Trafikverkets Miljörapport 2021 \(diva-portal.org\)](https://diva-portal.org/trafikverkets-miljorapport-2021)

The Swedish Transport Administration, Klimatkalkyl 7.0

Trafa, 2024a Road transport

[korstrackor-2022---2023-09-22.xlsx \(live.com\)](#)

Trafa, 2024b Amount of passenger and goods trains.

<https://www.trafa.se/globalassets/statistik/bantrafik/bantrafik/2020/bantrafik-2020.pdf>

Trafa, 2024c Passenger kilometre for railways.

<https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.trafa.se%2Fglobalassets%2Fstatistik%2Fbantrafik%2Fjarnvagstransporter%2F2022%2Fjarnvagstransporter-2022-kvartal-4.xlsx&wdOrigin=BROWSELINK>

Trafa, 2024d Allocation between passenger and freight

[luftfart-2022---korr.-2024-03-15.xlsx \(live.com\)](#)

Volkswagen (2024). Vägen mot en klimatneutral elbil. Available at: <https://www.volkswagen.se/sv/elbilar/miljo/livscykelanalys.html>. Gathered: 2024-02-05.

Zürich airport (2024). Traffic volumes Zurich. Available at: <https://report.flughafen-zuerich.ch/2022/ar/en/traffic-volumes-zurich/>. Gathered 2024-01-22.

Appendix 1 - LCI data Airship

Component	Unit	Amount	LCA data	Comment
Airship				
Carbon fibre tube	ton	5	Titanium {GLO} titanium production Cut-off, U	
	ton	10	Carbon fibre reinforced plastic, injection moulded {GLO} carbon fibre reinforced plastic, injection moulded Cut-off, U	
Electric motor (200 kW)	pc	12	Electric motor, vehicle {GLO} market for electric motor, vehicle Cut-off, U	One 200 kW electric motor is assumed to have a weight of 100 kg.

Diesel generator set/Hydrogen fuel cell <i>ZeroAvia SuperStack – framtidens 600 kW-system</i> <i>Total effekt: 400 kW kontinuerligt per modul, till totalt upp mot 600 kW i ZA600</i> <i>Systemnivå-effekttäthet: > 1,5 kW/kg (inkluderar balanskomponenter såsom kylning och DC/DC-konvertering) .</i> <i>En full 600 kW-uppsättning (2x300 kW moduler?) skulle väga cirka 400 kW ÷ 1,5 ≈ 267 kg, men med alla komponenter och totala systemvikten landar det troligen högre.</i> <i>ZA600 SuperStack (modul) 400 kW ~267 kg (400/1.5) m ~300-400 kg inkl. BoP (Balance of Plant = alla kringssystem som behövs för att bränslecellerna ska producera optimalt)</i>	pc	1	Total weight of 10 000 kg 4 % Steel, chromium steel 18/8, hot rolled {GLO} market for steel, chromium steel 18/8, hot rolled Cut-off, U 9 % Copper-rich materials {GLO} market for copper-rich materials Cut-off, U 87 % Steel, low-alloyed, hot rolled {GLO} market for steel, low-alloyed, hot rolled Cut-off, U 9170 kWh Electricity, medium voltage {US} market group for electricity, medium voltage Cut-off, U 90 000 MJ Heat, district or industrial, natural gas {GLO} market group for heat, district or industrial, natural gas Cut-off, U	The total weight of the generator set is assumed to be 10 000 kg. Ecoinvent data for <i>Diesel-electric generating set, 10MW {RoW} production / Cut-off, U</i> have been used for proportions of ingoing materials. The energy consumption for the production process is assumed to be the same per kg as the energy consumption for the production of an Internal combustion engine, passenger car.
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Canvas				
Polyester heat shrinkable (75 denier) 200 PPI:200EPI	m ²	20903	Fibre, polyester {GLO} market for fibre, polyester Cut-off, U	Max weight of material according to manufacturer = 160 g/m². The individual layers have been assumed to have an equal share of this weight. Coatings and exterior films have been excluded from the analysis.
200 denier vectran weave fabric 45 EPI:32 PPI, PVF exterior lamination, PU coated			Nylon 6-6 {RoW} market for nylon 6-6 Cut-off, U	
Carbon Dyneema non-woven, 1400 denier per inch, PVF (Tedlar) exterior film			50 % Nylon 6-6 {RoW} market for nylon 6-6 Cut-off, U 50 % Carbon fibre reinforced plastic, injection moulded {GLO} market for carbon fibre reinforced plastic, injection moulded Cut-off, U	
Aramid spread fibre non-woven 1200 denier per inch, tedlar film exterior			Nylon 6-6 {RoW} market for nylon 6-6 Cut-off, U	
Polyurethane adhesive	kg	6 270	Polyurethane adhesive {GLO} market for polyurethane adhesive Cut-off, U	Assumed 100 g of polyurethane adhesive per m ² (between all four layers).

Gondola - Structure				
Windows (polycarbonate 3 mm)	m ²	190	Window frame, aluminium, U=1.6 W/m²K {RoW} window frame production, aluminium, U=1.6 W/m²K Cut-off, U Polycarbonate {RoW} polycarbonate production Cut-off, U	The window frame is assumed to be 10 cm wide. Total frame area per m² window = 0,36 m² Density of polycarbonate is assumed to be 1,2 kg/m²/mm. Glass thickness = 3 mm. Total glass area per m² window is assumed to be 0,64 m².
Floors	Kg	467	Carbon fibre reinforced plastic, injection moulded {GLO} market for carbon fibre reinforced plastic, injection moulded Cut-off, U Aluminium, cast alloy {GLO} market for aluminium, cast alloy Cut-off, U	50 % is assumed to be Carbon fibre and 50 % aluminium
Bulkheads + internal walls	Kg	300	Carbon fibre reinforced plastic, injection moulded {GLO} market for carbon fibre reinforced plastic, injection moulded Cut-off, U Aluminium, cast alloy {GLO} market for	50 % is assumed to be Carbon fibre and 50 % aluminium

			aluminium, cast alloy Cut-off, U	
Ceiling	Kg	73	Carbon fibre reinforced plastic, injection moulded {GLO} market for carbon fibre reinforced plastic, injection moulded Cut-off, U Aluminium, cast alloy {GLO} market for aluminium, cast alloy Cut-off, U	50 % is assumed to be Carbon fibre and 50 % aluminium
Structure	Kg	6000	Carbon fibre reinforced plastic, injection moulded {GLO} market for carbon fibre reinforced plastic, injection moulded Cut-off, U Aluminium, cast alloy {GLO} market for aluminium, cast alloy Cut-off, U	50 % is assumed to be Carbon fibre and 50 % aluminium

Inventory	Kg	1705	Carbon fibre reinforced plastic, injection moulded {GLO} market for carbon fibre reinforced plastic, injection moulded Cut-off, U Aluminium, cast alloy {GLO} market for aluminium, cast alloy Cut-off, U	50 % is assumed to be Carbon fibre and 50 % aluminium Sum of indata from Weight budget for: 4.2 Panoramic lounge 4.3 Restaurant 4.4 Toilet 4.5 Vestibules 4.6 Multifunctional studio 4.7 Reception 4.8 Entertainment lounge 4.9 Panoramic observatory (excl. curtains)
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Gondola - Trough-floor connections

Stairs	Kg	150	Carbon fibre reinforced plastic, injection moulded {GLO} market for carbon fibre reinforced plastic, injection moulded Cut-off, U Aluminium, cast alloy {GLO} market for aluminium, cast alloy Cut-off, U	50 % is assumed to be Carbon fibre and 50 % aluminium
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Elevator	Kg	150	Carbon fibre reinforced plastic, injection moulded {GLO} market for carbon fibre reinforced plastic, injection moulded Cut-off, U Aluminium, cast alloy {GLO} market for aluminium, cast alloy Cut-off, U	50 % is assumed to be Carbon fibre and 50 % aluminium
Dumbwaiter (lift)	Kg	45	Carbon fibre reinforced plastic, injection moulded {GLO} market for carbon fibre reinforced plastic, injection moulded Cut-off, U Aluminium, cast alloy {GLO} market for aluminium, cast alloy Cut-off, U	50 % is assumed to be Carbon fibre and 50 % aluminium
Spiral staircase	Kg	30	Carbon fibre reinforced plastic, injection moulded {GLO} market for carbon fibre reinforced plastic, injection moulded Cut-off, U Aluminium, cast alloy {GLO} market for aluminium, cast alloy Cut-off, U	50 % is assumed to be Carbon fibre and 50 % aluminium

Gondola - Upper deck				
Partition	Kg	2649	Carbon fibre reinforced plastic, injection moulded {GLO} market for carbon fibre reinforced plastic, injection moulded Cut-off, U Aluminium, cast alloy {GLO} market for aluminium, cast alloy Cut-off, U	walls, floors, ceiling 50 % is assumed to be Carbon fibre and 50 % aluminium
Passenger cabins	Kg	862	Carbon fibre reinforced plastic, injection moulded {GLO} market for carbon fibre reinforced plastic, injection moulded Cut-off, U Aluminium, cast alloy {GLO} market for aluminium, cast alloy Cut-off, U	Bench, seat, bed, cabinet, handrail 50 % is assumed to be Carbon fibre and 50 % aluminium
Crew quarters	Kg	600	Carbon fibre reinforced plastic, injection moulded {GLO} market for carbon fibre reinforced plastic, injection moulded Cut-off, U	Beds, furniture 50 % is assumed to be Carbon fibre and 50 % aluminium

			Aluminium, cast alloy {GLO} market for aluminium, cast alloy Cut-off, U	
Kitchen	-	-	-	Kitchen has been excluded from the analysis.
Toilets	Kg	222	Carbon fibre reinforced plastic, injection moulded {GLO} market for carbon fibre reinforced plastic, injection moulded Cut-off, U Aluminium, cast alloy {GLO} market for aluminium, cast alloy Cut-off, U	Chemical toilet, sinks, shower 50 % is assumed to be Carbon fibre and 50 % aluminium

Transports

Carbon fibre tube (Titanium)	km	500	Transport, freight, lorry >32 metric ton, EURO5 {RoW} market for transport, freight, lorry >32 metric ton, EURO5 Cut-off, U	Titanium from China. Transport in CN from factory to harbour. Assumed distance.
	km	19850	Transport, freight, sea, container ship {GLO} market for transport, freight, sea, container ship Cut-off, U	Titanium from China. Transport from CN to the US. Assumed distance.
	km	1600	Transport, freight, lorry >32 metric ton, EURO5 {RoW} market for transport, freight,	Titanium from China. Transport from harbour US to Akron, Ohio. Assumed distance.

			lorry >32 metric ton, EURO5 Cut-off, U	
Carbon fibre tube (Carbon fibre)	km	1000	Transport, freight, lorry >32 metric ton, EURO5 {RoW} market for transport, freight, lorry >32 metric ton, EURO5 Cut-off, U	CF tube from the US. Transport in the US. Assumed distance.
Electric motor (200 kW)	km	627	Transport, freight, lorry >32 metric ton, EURO5 {RER} market for transport, freight, lorry >32 metric ton, EURO5 Cut-off, U	Electric motor from Slovenia. Transport from Slovenia to harbour in Italy. Assumed distance.
	km	7565	Transport, freight, sea, container ship {GLO} market for transport, freight, sea, container ship Cut-off, U	Electric motor from Slovenia. Transport from Italy to the US. Assumed distance
	km	1600	Transport, freight, lorry >32 metric ton, EURO5 {RoW} market for transport, freight, lorry >32 metric ton, EURO5 Cut-off, U	Electric motor from Slovenia. Transport in the US from harbour to Akron, Ohio. Assumed distance
Diesel generator set/Hydrogen fuel cell	km	500	Transport, freight, lorry >32 metric ton, EURO5 {RER} market for transport, freight, lorry >32 metric ton, EURO5 Cut-off, U	Hydrogen fuel cell from Sweden. Transport to harbour in Germany. Assumed distance
	km	6400	Transport, freight, sea, container ship {GLO} market for transport, freight,	Hydrogen fuel cell from Sweden. Transport from Germany to the US. Assumed distance

			sea, container ship Cut-off, U	
	km	1000	Transport, freight, lorry >32 metric ton, EURO5 {RoW} market for transport, freight, lorry >32 metric ton, EURO5 Cut-off, U	Hydrogen fuel cell from Sweden. Transport in the US from the harbour to Akron, Ohio. Assumed distance

Production

Energy use at the production site	kWh	94 143	Electricity, medium voltage {US} market group for electricity, medium voltage Cut-off, U	Energy for production in Akron, Ohio
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Use

Fuel (LH ²)	kg	7 680 614	Hydrogen, liquid {RER} market for hydrogen, liquid Cut-off, U	The fuel consumption for the airship is 0,75 kg LH ₂ /nm or 0,405 kg LH ₂ /km. Total distance over lifetime of 40 years = 18 964 480 km.
Lift gas (Helium)	m ³	477 500	Helium {GLO} market for helium Cut-off, U	Total amount of lifting gas required is 95 500 m ³ . A yearly loss of 10 % has been assumed over the technical life span. Density of Helium 0,1785 kg/m ³ .

Replacements	pc	1	Canvas	Canvas is assumed to be replaced after 20 years.
	pc	1	Electrical motors	Canvas is assumed to be replaced after 20 years.
	pc	1	Generator set	Canvas is assumed to be replaced after 20 years.

Additional data		
Passenger capacity	pax	130
Load factor	%	80
Technical life span	years	40
Transport distance per year	km	474 112

Appendix 2 - LCI data Airship Field

Infrastructure	Unit	Amount	LCA data	Comment
Terminal building	m2	3 225	Klimatkalkyl 7.0. Stationsbyggnad (6.2)	Terminal building is assumed to have similar climate impact as a station building for trains per m2.
Parking	m2	11 250	Klimatkalkyl 7.0. Gång- och cykelväg (6.4)	Assumed 900 parking slots. The area for 1 parking slot is assumed to be 12,5 m2 (2,5x5 m).
Access road	m2	3 200	Klimatkalkyl 7.0. Gång- och cykelväg (6.4)	Assumed width of 4 m.
Landing zone	m2	126 000	Ecoraster reinforcement grid E50 (EPD S-P-03450)	Assumed wall height of 50 mm (conservative approach). The EPD has expired but no alternative products have been identified.
	km	1 400	Transport 20-26 t (NTM, 2024)	Weight per m2 Ecoraster 9,55 kg.
Operation	kWh/year	63	Klimatkalkyl 7.0. Drift Stationsbyggnader El	Yearly energy use for terminal building collected from Operation and maintenance-schablons in Klimatkalkyl 7.0 (118+108 MJ/year). Climate impact from electricity collected from Klimatkalkyl (0,054 kg CO ₂ e/kWh)

Maintenance	Hours/ year	11	Klimatkalkyl 7.0. Röjning/Slätter	Assumed 20 km/h for cutting/clearing grass and meadow 4 m width = 80 000 m²/h. Area for grass+meadow = 502 655 m² Area for grass = 125 663 m². The meadow area is assumed to be cut once a season and the grass area is assumed to be cut four times per season.
Carbon storage in trees	Kg CO ₂ e/ year	16 900	Råberg, T (2022)	Forest area = 88 ha. Trees per ha = 24 pc Total amount of trees = 2112 pc. 8 kg CO₂e/tree and year
Carbon storage in bushes	Kg CO ₂ e/ year	904 300	Råberg, T (2022)	Bush area = 628 000 m² Bush coverage = 12 % Total bush area = 75 360 m² 12 kg CO₂e/m² bush
Technical lifespan	Years	40	-	-