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Ecological Comparison of Airships to Other Types of Transport

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ABSTRACT

Airships are lighter-than-air vehicles that rely on buoyant gases like helium or hydrogen to generate lift, which is achieved through static buoyancy, unlike aircraft that use aerodynamic lifts. In comparison to traditional modes of transport, such as trucks, trains, and aircraft, airships have the potential to fill niche roles in freight logistics, particularly in regions with congested or underdeveloped infrastructure. In this study, a hybrid airship, named Dynalifter, is compared to traditional transport modes such as rail, electric trains, aircraft, and airships. Its large transport capacity over long distances, combined with its ability to land on smaller airfields, positions it as a complement to existing modes of transportation, particularly for oversized or remote cargo deliveries. It offers unique advantages in operational flexibility, reduced infrastructure requirements, and suitability for cargo transport. The analysis shows that although airship emissions are not the most environmentally friendly in terms of emissions per ton-kilometer, they offer significant flexibility in operational conditions and cargo capacity, making them a viable option for specific types of cargo. Further research into hydrogen propulsion and advances in airship technology could improve their environmental performance, potentially making them a competitive alternative for low-emission cargo transportation.

1. Introduction

The production and use of airships are currently limited primarily to sightseeing flights. However, several manufacturers aim to change this trend by developing airships for cargo transport. Some of these designs promise payload capacities of more than hundreds of tones, with hull lengths reaching hundreds of meters. As these airships are mostly in the prototype stage, their functionality and practicality cannot yet be verified with certainty.

The practical significance of airships lies in their potential to replace certain aircraft operations or land transports. Although airships are relatively slow for air transport, they can land much closer to the destination or directly at the target location. This reduces the need for intermediate handling and onward transport, thus cutting excess CO_2 emissions. Furthermore, airships could help alleviate the congested transport infrastructure in Europe by offering an alternative for oversized shipments that

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are currently transported by specialized trucks and ships over long periods. Airships can in these scenarios reduce such transport times from months to days.

Airships are lighter-than-air (LTA) vehicles that rely on buoyant gases like helium or hydrogen to generate lift, which is achieved through static buoyancy, unlike aircraft that use aerodynamic lifts. Some manufacturers, like Ohio Airship [1] and AT2 Aerospace (originally Lockheed Martin [2,3] combine static and aerodynamic lift to create hybrid airships (HAs), which increase stability and eliminate the need for ballast systems. Other manufacturers, like Aeros [4] and Atlas LTA [5], planned to build airships based only on static lift.

A significant advantage of airships is their minimal need for ground infrastructure, allowing them to land in unpaved or remote areas. Dynalifter, which is solved in this work, requires basic airfield infrastructure but can operate on minimal runways and land at smaller airfields. This feature is then a fundamental advantage over large transport aircraft.

2. Dynalifter and Traditional Types of Transport

2.1 Dynalifter

The Dynalifter is not the largest airship in Ohio Airship's portfolio, but it is projected to be the most practical due to its size and operational costs [1]. The basic parameters are shown in Table 1. The cargo hold has a capacity of 72.58 tons and a transport volume of 1,108.40 m^3. This makes it suitable for handling large and oversized cargo over long distances in record time with reduced infrastructure requirements compared to traditional transport.

Table 1
Dynalifter basic parameters [1]

Parameters	Values
Travel speed [km/h]	**185.20**
Payload [t]	**72.58**
Range [km]	**5,926.40**
Fuel	**Aviation gasoline (AvGas)**
Dimensions Overall (LxWxH) [m]	**231.95 x 109.42 x 30.48**
Dimensions Hull (LxWxH) [m]	**231.95 x 39.01 x 28.04**
Dimensions CargoBay (LxWxH) [m]	**30.48 x 7.93 x 4.57**

2.2 Traditional Types of Transport

Traditional modes of transport considered in this study are presented in Table 2, as traditional types of transport are trucks, aircraft, and trains in various modifications. This table contains details about types of fuel that are traditional and nontraditional like hydrogen. Next, this information is their payload capacities. These transport modes are diverse in infrastructure needs and operational efficiency, which makes them relevant benchmarks against airships.

Other methods of freight transport not included in this article are jet air vehicles and boats. The issue of water transport is not addressed in this article due to several factors. Firstly, the speed of water transport is relatively low. Secondly, water transport has significantly higher capacities than other forms of transport. On the other hand, jet air vehicles are the opposite of water transport. Planes are very fast, but they can not carry much cargo and are much less fuel-efficient.

Table 2
Other types of transport [1, 6-8]

Type of transport	Fuel	Payload [t]	Weight [t]
Electric truck	**Electric**	**2.25**	**4.50**
Hydrogen truck	**Hydrogen**	**2.25**	**4.50**
Hydrogen truck	**Hydrogen**	**6.00**	**12.0**
Hydrogen truck	**Hydrogen**	**15.50**	**31.0**
Diesel truck	**Diesel**	**16.79**	**33.58**
C 130 Hercules	**AvGas**	**19.09**	**69.75**
Diesel train 2ES5	**Diesel**	**3,370.00**	**5,570.0**
Electric train 2ES5	**Electric**	**3,370.00**	**5,570.0**

3. Comparison of Emissions as a Function of Transport Performance

In the context of environmental comparison, it is necessary to look at emissions as a function of transport. Based on ecological comparison in CO_2 emissions, we need to include the weight of cargo and transport distances. The standard unit is defined as tonne-kilometres (tkm). The overall ratio is, therefore, a definer as grams CO_2 equivalent per tonne-kilometers (gCO_2e/tkm).

Two basic parameters are important for emission calculations:

i. Emissions from fuels and transport,
ii. Transport vehicle emissions.

3.1 Emissions from Fuels and Transport

According to Table 1 and Table 2, there are four basic types of fuel: AvGas, diesel, electric, and hydrogen. The selected fuels considered in this paper are shown in Table 3. The emissions in this comparison are converted to the power consumed, where a correction can then be made for the required distance and load. Fuel is the primary source of the emissions we associate with transport. This issue, such as the type of fuel and its emissions, is addressed by technical standard EN 16 258, which defines 14 basic fuel types, but only two of them will be used in this article [8]. This standard in the English version is no longer valid, but the national standard ČSN EN 16 258, which adopts this standard, is valid in the Czech Republic and will therefore be used in this work [9]. The original norm is from 2012, it is currently insufficient and does not represent the most ecological type of fuel which are electricity and hydrogen.

Within total emissions, it is also important to distinguish where these emissions originate. In terminology, the direct conversion phase from fuel to energy is called Tank to Wheels (TTW). However, this phase is preceded by production and transport called Well to Tank (WTT). Full emissions production is called Well to Wheels (WTW). It follows that:

$$\boldsymbol{TTW + WTT = WTW} \tag{1}$$

Since the fossil fuel standard is from 2012, the WTT should already be lower. This statement would be valid if the transport process from existing sources were improved. However, in today's geopolitical situation emissions associated with transporting fuel to the EU are significantly increased and therefore the values in this standard are used for this thesis.

Table 3
Selected fuel types [8, 10-11]

Fuel types	TTW [gCO₂/kWh]	WTT [gCO₂/kWh]	WTW [gCO₂/kWh]
AvGas	**254.16**	**51.12**	**305.28**
Diesel	**268.20**	**57.24**	**325.44**
Electricity CZE 2014	**0.00**	**555.01**	**555.01**
Electricity EU 2014	**0.00**	**364.32**	**364.32**
Electricity India 2014	**0.00**	**885.43**	**885.43**
Hydrogen optimistic	**0.00**	**69.01**	**69.01**
Hydrogen pessimistic	**0.00**	**192.02**	**192.02**

3.1.1 Electricity

Electricity only has emissions associated with generation (WTT), but these are heavily skewed by the energy mix of individual countries. For this reason, Figure 1 shows the evolution of emissions from electricity production in chosen countries.

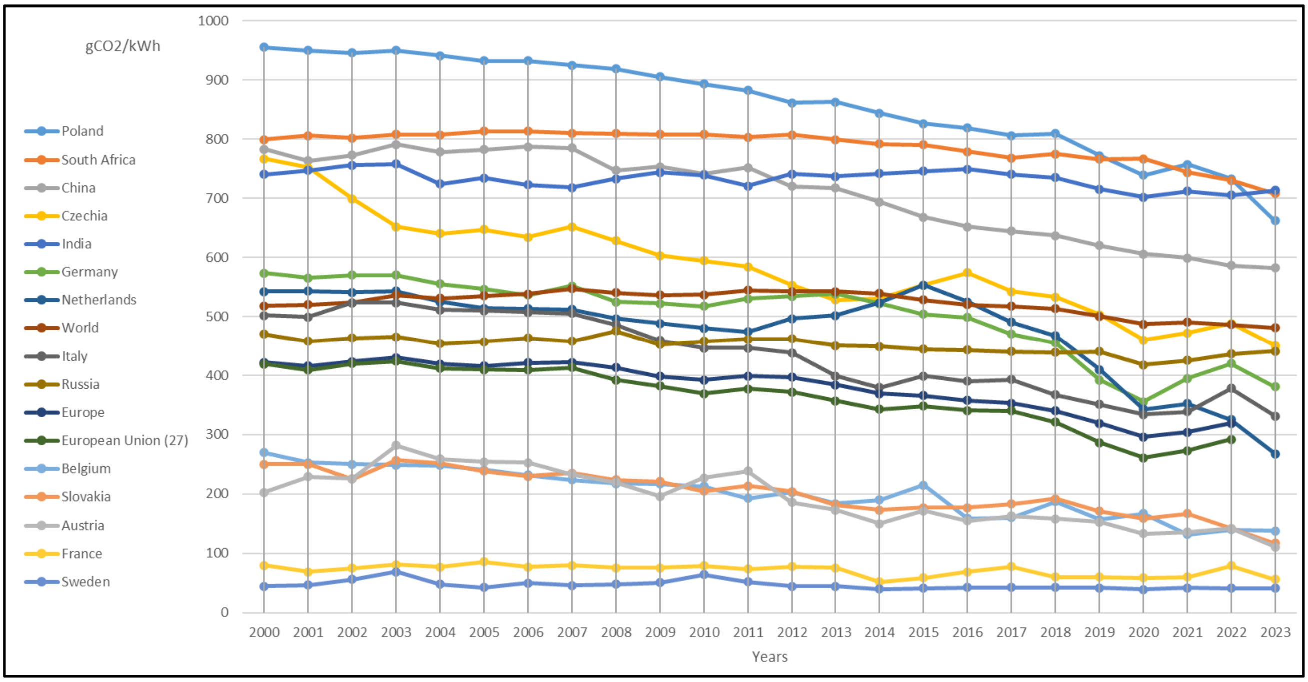

Fig. 1. Emissions from electricity [11]

The energy must get to its destination, which is through the power system. However, there are losses in this system, which are due to the efficiency of the transformers and the losses on the lines. The power losses on the lines in each chosen country are shown in Figure 2.

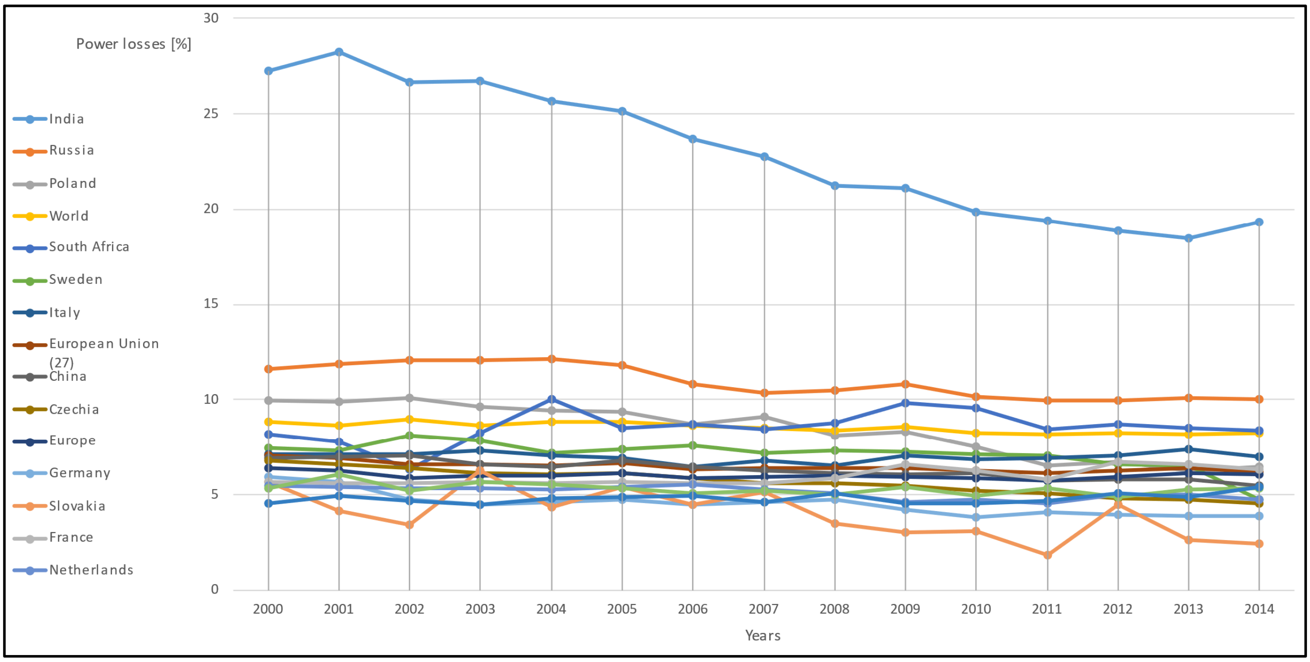

Fig. 2. Electricity transmission and distribution power losses [12]

If we apply these losses to the transmission of electricity to the destination in each period, then we get the data shown in Table 3, where CO_2 emissions are therefore increased by the level of losses.

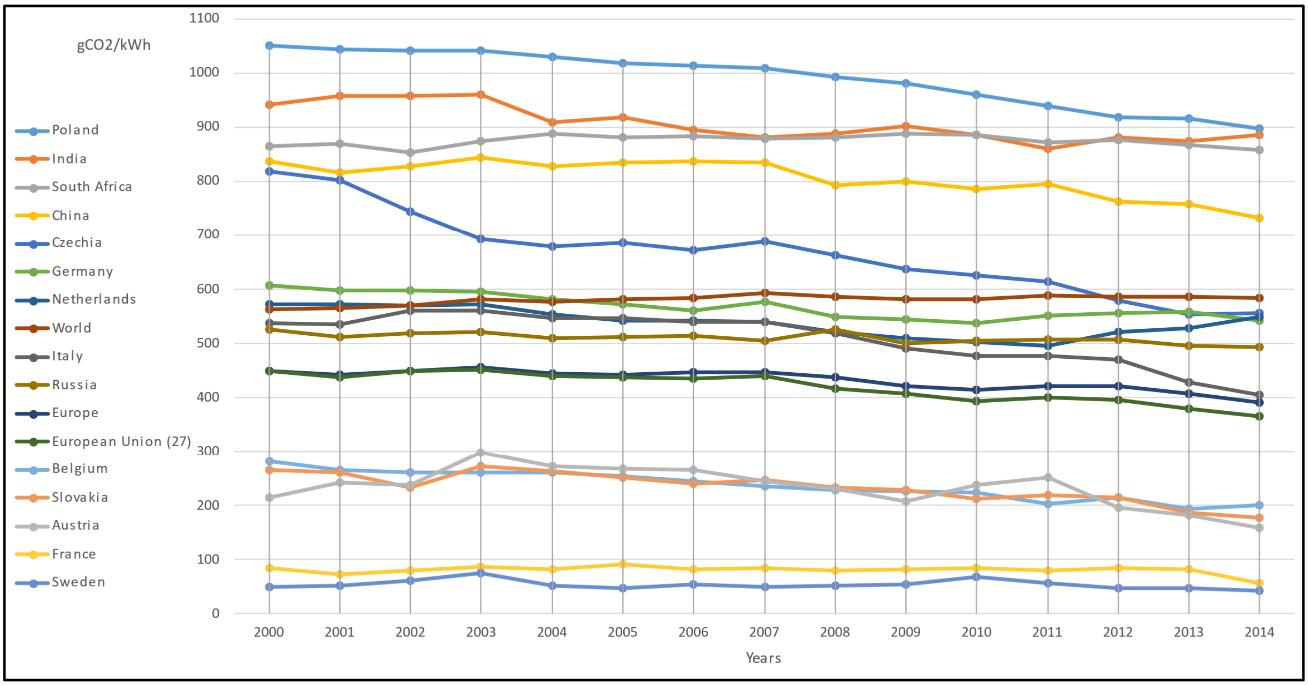

Fig. 3. Emissions from electricity with transmission

Since the data for transmission losses are only up to 2014, these values will be used, which are also closer to EN 16258. It will not be possible to reduce losses in the transmission and distribution system below a certain level.

3.1.2 Hydrogen

Another fuel mentioned above is hydrogen, which is normally locally emission-free. However, hydrogen production produces between 0.8 and 4.6 kg CO_2 per kg of hydrogen [10]. Hydrogen transport then produces between 1.5-1.8 kg CO_2 per kilogram of hydrogen [10]. The resulting emissions are then expressed by summing these two variables. As this is a paper published in 2024 and the previous data are from 2012 and 2014, the least optimistic option is probably closer to reality 10 years ago.

3.2 Transport Vehicle Emissions

As common methods of freight transport methods, this article considers the following:

i. Turboprop air vehicles,
ii. Train,
iii. Trucks.

3.2.1 Turboprop Air Vehicles

Based on internal information from Ohio Airships Corporation [1], Dynalifter will be powered by Allison T56 engines, which are also used by the now legendary C130 Hercules. The problem with these vehicles is estimating the average burn, which is dependent on several factors that cannot be controlled and therefore each flight is an original. These factors are, for example, weather, wind direction, and exclusion zones. For this reason, the maximum possible flight time is considered for this calculation, which is given by the airship manufacturer [1] and practical operating experience. In this comparison, the more modern type of engine is considered, namely the Series IV [6]. Table 4 shows the basic parameters.

Table 4
Turboprop basic parameters [1, 6]

Parameters	Dynalifter	C 130 H
Engine	**Allison T56**	**Allison T56**
Engine power [kW]	**3,914.93**	**3,914.93**
Number of engines [Pieces]	**8.0**	**4.0**
Fuel	**AvGas**	**AvGas**
In-flight engine load [%]	**33.33**	**56.94**

The calculation is based on the knowledge of fuel consumption at a certain power and power required in flight. These data are retrieved from an E-2C aircraft performing a four-hour test flight [6]. These consumption percentages are directly assigned to the C130H aircraft and indirectly to the airship, where the power usage percentages are taken from the manufacturer. Formula (1) is for Dynalifter:

$$\boldsymbol{E_{tkm1}} = \frac{\boldsymbol{E_{AvGas}} * \boldsymbol{C_p} * \boldsymbol{n_1} * \{2 * (\boldsymbol{P_{GP}} * \boldsymbol{t_{GP}} + \boldsymbol{P_{MP}} * \boldsymbol{t_{MP}} + \boldsymbol{P_{LP}} * \boldsymbol{t_{LP}}) + \boldsymbol{P_{MP}} * \boldsymbol{\eta_1} * [\boldsymbol{t_{MAX}} - 2(\boldsymbol{t_{GP}} + \boldsymbol{t_{MP}} + \boldsymbol{t_{LP}})]\}}{\boldsymbol{m_1} * \boldsymbol{l_1}} \quad (2)$$

and Formula (2) is for C 130 H:

$$\boldsymbol{E_{tkm2}} = \frac{\boldsymbol{E_{AvGas}*C_p*n_2*\{P_{GP}*t_{GP}+P_{MP}*t_{MP}+P_{LP}*t_{LP}+P_{MP}*\eta_2*[t_{MAX}-(t_{GP}+t_{MP}+t_{LP})]\}}}{\boldsymbol{m_2*l_2}} \quad (3)$$

where fuel consumption is C_p =288.90 mg/Wh; fuel emission is E_{AvGas}=3.76 kgCO_2e/kg; maximum distance is l_1=5,926.40 km; maximum cargo weight is m_1=72.58 t; numbers of engines are n_1=8.0 pcs and n_2=4.0 pcs; maximum distance is l_2=1,944.60 km; maximum cargo weight is m_2=19.09 t; engine power for ground operations is P_{GP}=969.00 kW; engine power for landing operations P_{LP}=969.0 kW; engine maximum power is P_{MP}=3,914.93 kW; time of ground operations is t_{GP}=0.16 h; time of landing operations is t_{LP}=0.08 h; maximum flight times are t_{MAX1}=32.0 h and t_{MAX2}=3.30 h; time of maximum engine power is t_{MP}=0.40 h; and in-flight engine loads are η_1=33.33 % and η_2=56.94 %. Therefore, we get:

$$E_{tkm2} = \frac{3.76*288.90*8.0*\{2*(969.00*0.16+3{,}914.93*0.40+969.0*0.08)+3{,}914.93*33.33*[32.0-2(0.16+0.40+0.08)]\}}{72.58*5{,}926.40}$$

=882.87 gCO_2e/tkm,

$$E_{tkm2} = \frac{3.76*288.90*4.0*\{969.0*0.16+3{,}914.93*0.40+969.00*0.08+3{,}914.93*56.94*[3.30-(0.16+0.40+0.08)]\}}{19.09*1{,}944.60}$$

=904.99 gCO_2e/tkm.

3.2.2 Trains

The energy consumption of a full freight train is calculated from an empty train written by [7] that has a certain efficiency and its consumption at that efficiency is known. Furthermore, the nominal efficiency of a fully loaded train is known and therefore a conversion to a fully loaded train of nominal weight is made. Emissions from electricity are different in each country, but emissions in the Czech Republic, India, and the EU are taken as a representative sample. The diesel freight train is then based on the premise of equal power requirement per weight and consumption per efficiency.

Table 5
Train basic parameters [7]

Engines	**Electric**	**Diesel**
Weight with cargo [t]	**5,570.0**	**5,570.0**
Weight without cargo [t]	**2,200.0**	**2,200.0**
Engine power [kW]	**5,504.17**	**5,504.17**
Effectivity [%]	**86.25**	**33.0**
Distance [km]	**108.0**	**108.0**

The calculation of the electric train neglects the transmission losses between the trolley and the pantograph. At the same time, these losses are highly dependent on the structural conditions and the contact force, leading to different line and transition resistances.

$$\boldsymbol{E_{E/Dtkm}} = \frac{\boldsymbol{E_{E/D}*\frac{P_{E2E}}{\eta_{E/D}}*\frac{m_F}{m_E}}}{\boldsymbol{l*(m_F-m_E)}} \quad (4)$$

where electric emission is E_E=364.32 gCO_2e/kWh; diesel emission is E_D=325.44 gCO_2e/kWh; distance is l=108.0 km; train weight with cargo is m_F=5,570.0 t; train weight without cargo m_E=2,200 t; energy consumption without cargo is P_{E2E}=2,174.0 kWh; electric transmission efficiency is η_E=86.25 %; and diesel transmission efficiency is η_D=33.0 %. Therefore, we get:

$$E_{Etkm} = \frac{364{,}32*\frac{2{,}174.00}{0.86}*\frac{5{,}570.00}{2{,}200.00}}{108.00*(5{,}570.00-2{,}200.00)} = 6.39 \text{ gCO}_2\text{e/tkm},$$

$E_{Dtkm} = \frac{325.44 * \frac{2,174.00}{0.33} * \frac{5,570.00}{2,200.00}}{108.00 * (5,570.00 - 2,200.00)}$=14.91 gCO_2e/tkm.

3.2.3 Trucks

It was determined that half the weight of the car is the weight of the consignment. See Table 6 for total weight and shipment weight along with engine power.

Table 6
Trucks basic parameters [13-14]

Fuels	Diesel	Hydrogen			Electric
Weight [t]	**33.58**	**4.50**	**12.0**	**31.0**	**4.50**
Cargo weight [t]	**16.79**	**2.25**	**6.0**	**15.50**	**2.25**
Engine max power [kW]	**330.0**	**60.0**	**80.0**	**160.0**	**60.0**

Table 7 shows the emissions from the theoretically calculated methods and laboratory operation with a comparison to the real emissions from a specific route. These data are reserved for suburban traffic and combine trips in cities, but also in adjacent areas and on highways. When comparing with air transport, it is necessary to consider long transport routes, as urban transport is more environmentally burdensome than motorway driving, so it can be assumed that the resulting emissions will be lower in the case of motorway driving than is the case here. For this reason, the FIGE method is chosen as it shows the lowest emissions per kilometer.

Table 7
Diesel truck emissions [13]

Type	FIGE	WHVC	RDC	REAL
Emissions [gCO2/km]	**671.80**	**771.3**	**689.0**	**1,118.8**

Table 8 shows the estimated hydrogen and electricity consumption for each vehicle. The mean value of the consumption is then chosen for the calculations.

Table 8
Hydrogen and electric truck consumption [14-15]

Types	Consumptions
Hydrogen 4.5t [g/km]	**33.0–43.0**
Hydrogen 12t [g/km]	**56.0–71.0**
Hydrogen 31t [g/km]	**98.0–125.0**
Electric 4.5t [kWh/km]	**0.41–0.45**

Figure 4 shows the average energy loss within the charging of an electric vehicle, but these losses are measured for an 11 kW charger, which is quite slow. For comparison, the most powerful chargers are around 400 kW. From electrotechnics, the losses will be increased with more power consumption. For the next calculation will be used energy loss for charging between 20% and 100%.

$$\boldsymbol{E_{Dtkm}} = \frac{\boldsymbol{E_{Dkm}}}{\boldsymbol{m_D}} \tag{5}$$

$$\boldsymbol{E_H} = \frac{\boldsymbol{E_H * C}}{\boldsymbol{m_H}} \tag{6}$$

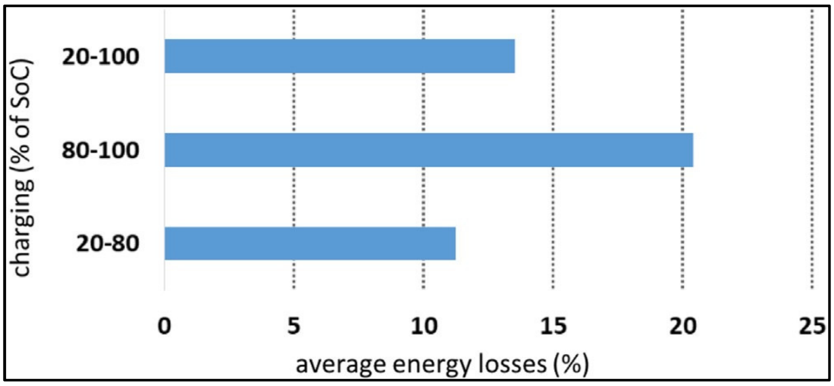

Fig. 4. Electric vehicle charging losses

$$E_{Etkm} = \frac{E_E * C * \eta_E}{m_E} \quad (7)$$

where electric consumption is C_E=0.43 kWh/km; hydrogen consumption is C_H=38.0 g/km; diesel emission is E_{Dkm}=671.80 gCO_2/km; emissions from hydrogen are E_H=6.40 gCO_2e/gH2; electric emission is E_E=364,32 gCO_2e/kWh; diesel cargo weight is m_D=16.79 t; electric and hydrogen cargo weight is $m_{H/E}$=2.25 t; electric charging efficiency is η_E=86.47 %. Therefore, we get:

$E_{Dtkm} = \frac{671.80}{16.79}$ =40.01 gCO_2e/tkm,

$E_{Htkm} = \frac{6.40*38.0}{2.25}$ =40.01 gCO_2e/tkm,

$E_{Etkm} = \frac{364.32*0.43*0.8647}{2.25}$ =79.05 gCO_2e/tkm.

4. Results

Figure 5 provides an overview of the emissions associated with each transport mode, expressed in grams of CO_2 equivalent per ton-kilometer (gCO_2e/tkm). The results show that electric and hydrogen-powered trucks are still affected by infrastructure limitations and fuel production methods. The Dynalifter, while not the most environmentally efficient in terms of emissions per ton-kilometer, offers significant flexibility in operational conditions and cargo capacity, making it a viable alternative for oversized and special freights. The comparison also highlights the substantial differences between rail and air transport. Rail, especially electric trains, consistently outperform other modes in terms of CO_2 emissions.

The carbon footprint described in this document is partly different from common beliefs. These differences are due both to the age of the data and the relatively large infrastructure requirements that new transport modes require. However, the results are not generally valid but only for conditions in this paper.

5. Discussion

The analysis shows that although airships produce higher emissions than trains and trucks, they offer greater operational flexibility and lower infrastructure requirements than C130H. This makes them particularly suitable for regions with limited transport infrastructure or for specialized freight operations. Furthermore, the potential to power airships with hydrogen could significantly reduce their emissions, positioning them as a more sustainable alternative in the future. While this technology is still in its early stages, advancements in hydrogen production and storage could improve the environmental performance of airships even further.

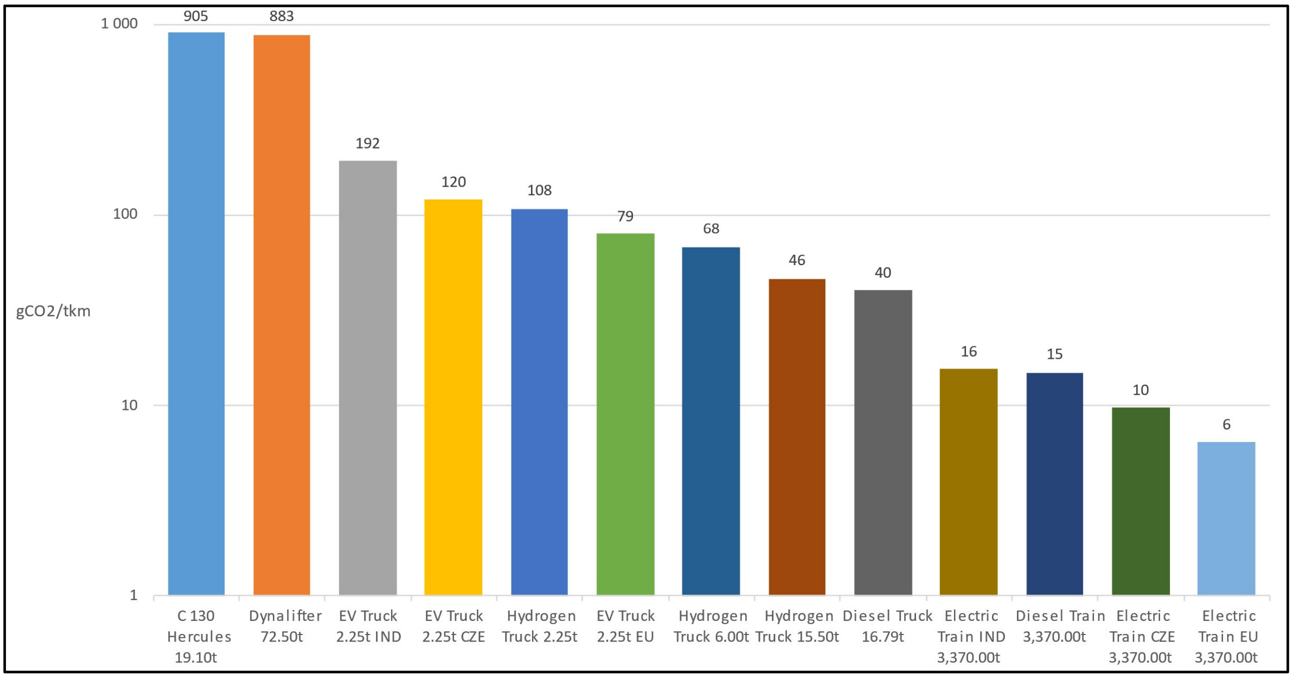

Fig. 5. Emissions per performance

When the comparison is made against a jet-powered aircraft, it can be concluded that turboprop engines are much more fuel-efficient than jet engines. For example, the B747F has a fuel consumption of approximately 11.18 t/h [16] whereas the Dynalifter has a fuel consumption at ideal conditions of 3.16 t/h (9.05 t/h with maximum power). This is a consumption almost four times higher in ideal condition and 20% more when all motors run on maximum whole travel time.

The question is whether the transition to local zero-emission mobility is efficient enough to have a real effect when all factors are considered [17-18]. The only area where a switch to zero-emission local transport is likely to be mandatory is the EU. It accounts for 8% of the world's total human emissions according to [19], and of that, transport is 22%. However, this is 1.76% of total human emissions. If non-human emissions were included, this percentage would be even lower. Looking further at other circumstances of CO_2 production, some works have estimated that emissions associated with large-scale military operations far eclipse those from regular transportation [20].

6. Conclusion

This study demonstrated that while hybrid airships like Dynalifter were not the most efficient in terms of emissions per ton-kilometer, they offered unique advantages in operational flexibility, reduced infrastructure needs, and suitability for oversized cargo transport. In comparison to traditional modes of transport, such as trucks, trains, and aircraft, airships have the potential to fill niche roles in freight logistics, particularly in regions with congested or underdeveloped infrastructure.

Further research into hydrogen propulsion and advancements in airship technology could enhance their environmental performance, potentially making them a competitive alternative for low-emission cargo transport. However, the success of airships in the broader market will depend on continued innovation and improvements in fuel efficiency and primally cost-effectiveness.

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