RAPPORT

eFlight: Socio-economic analysis

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Executive summary

Today, one of the fast-growing sources of greenhouse gas emissions is the aviation industry, which accounts for 3% of the EU's total greenhouse gas emissions. The strategy of the EU is focused on reducing aviation emissions in Europe and globally. In this context, electric aviation is seen as a future of the aviation industry because it can offer a cleaner and more environmentally friendly way to travel. Electric aviation is an innovative technology and first commercial flights in Sweden are expected by 2026. That is why it is critical to understand effects that electric aviation may cause. The implemented pre-study was focused on the following objectives:

- To develop a simple tool calculating direct costs and benefits, such as environmental impact, travel time, and other related costs (total cost, e.g., personnel cost, energy cost, airport and infrastructure cost where available) for 10 routes that would include an electric flight option.
- To identify and analyse related indirect socio-economic and environmental impacts.

In order to reach these objectives, we have performed a quantitative and qualitative analysis. Quantitative analysis involves evaluation of environmental impact, related costs, travel time, and distance. We have used qualitative analysis to discuss expected costs of electric aviation in comparison to traditional and other direct and indirect effects of electric aviation for passengers, regional airports, environment, municipalities, and regions. Qualitative analysis is based on primary data collected through interviews with experts working in the areas of electric aviation and climate research.

Our major findings show that:

1. Electric flight can offer considerable *time savings* and fast connections between destinations located in remote and sparsely populated areas, where existing transport alternatives are very time-consuming.
2. Electric aviation can connect destinations using *the shortest distance*.
3. Among the analised alternatives, electric aviation produces *the lowest CO2 emissions per passenger per trip.*
4. Electric aircrafts are expected to produce *little noise*. This will result in a more pleasant travel experience for passengers. At the same time, adding more regional aviation routes might produce more noise in general at airports.
5. Electric aviation has a potential to have a *lower cost per passenger per trip* in comparison to traditional aviation.
    a. *Production costs* of electric aircrafts are 10–15% lower in comparison to traditional aircrafts because a smaller factory is needed, and the labour costs are lower as well.
    b. *Maintenance costs* of electric planes are expected to be 20% to 50% lower in comparison to traditional combustion engine planes of the same size.
    c. *Personnel costs* of electric aircraft are expected to be the same as for traditional aviation, however, the navigation of electric aircrafts is expected to be easier for pilots.

   d. Electric aviation implies certain *same or lower cost for using aviation infrastructure* for airline companies.
   e. Electric aviation is expected to have *lower direct operating costs* than traditional combustion engine aircraft of the same size because the fuel cost is lower by 50% to 80%.
6. Electric aviation can provide *a better accessibility* to remote and sparsely populated regions via direct flights.
7. Electric aviation may have a number of *positive effects for regional airports* in terms of increased revenues, new business areas, making use of airports not used for commercial flights today. However, there is a need of a certain investment in charging infrastructure.
8. Electric aviation may have a number of *positive effects for regions and municipalities* by creating a perception of destinations as environmentally friendly and sustainable and boosting tourism by this. Electric aviation can connect the direction east-west in a better way and open completely new routes. Electric aviation may foster interregional business development, new logistics opportunities, which would make remote destinations an attractive place to live and work.

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Table of Contents

1 Introduction

Today, one of the fast-growing sources of greenhouse gas emissions is the aviation industry. The share of CO_2 emissions created by aviation "accounts for about 3 percent of the EU's total greenhouse gas emissions and more than 2 percent of global emissions" (EU, n.a.). The strategy of the EU is focused on reducing aviation emissions in Europe and globally. In this context, electric aviation is seen as a future of the aviation industry because it can offer a cleaner and more environmentally friendly way to travel. In addition, it offers a better and faster connection between regions, lower price, and leads to new concepts of quieter and smaller airports with shorter runways.

Electric aviation is an innovative type of aviation, which is still in the development phase. In Sweden, the first electric planes used for commercial flights are expected by 2026 (heartaerospace.com, 2020). Electric planes will be able to cover a distance of 400 km. This promises a better and faster connection between regions and development of regional aviation.

This pre-study has two objectives. One objective is *to develop a simple tool calculating direct costs and benefits*, such as environmental impact (CO2 emissions), travel time, and other related costs (total cost, e.g., personnel cost, energy cost, airport, and infrastructure cost where available) for a trip that would include electric flight option. To achieve this, we have performed qualitative analysis and collected data needed for analysis. Analysis is focused on 10 routes, which are important for the Green Flyway project. The calculations are provided in a separate Excel file and the key results are summarised in this report.

The second objective is *to identify and analyse the indirect socio-economic and environmental impacts*. To achieve this, we have conducted interviews with the key stakeholders including representatives of transport authorities, regional airports, municipalities, project managers and researchers involved in electric aviation projects. The summary of these interviews is provided in this report.

The key findings of this study show that the introduction of electric aviation has a number of socio-economic benefits for different actors:

- For passengers: considerable time savings and a fast and direct connection between destinations located in sparsely populated areas, better accessibility, lower noise in the cabin, and integration of electric aviation into the public transport system.
- For regional aviation: new areas of activities and increase in revenues, one-time investment in infrastructure, meeting electricity demand, reduced noise, use of airports not used for commercial aviation today, and changed security procedure for regional flights.
- For the environment: lowest level of CO2 emissions per passenger per trip emissions in comparison to traditional aviation.
- For municipalities and regions: positive climate and environmental impact related to use of fossil fuel free transport, perception of destination as environmentally friendly, better connections between east and west and new routes, development of interregional business, use of land around airports, and opening closed airports, making regions an attractive place to live and work, and new logistics opportunities.

This research has a number of limitations. First, due to a small project scale, we have considered just a limited number of transportation types. Second, we have considered only energy used for calculation of CO2 emissions. Third, we have not considered the full life cycle of battery when calculating environmental impact. Fourth, the study is implemented during the COVID-19 pandemic. It affected the number of routes available at the time of analysis. It is possible that a part of regularly available flights, train and bus routes became unavailable or got rescheduled during the pandemic. For analysis of alternative routes, we use those routes that were available on the websites of transport companies (Norrtåg, SAS, Vy.no, Wasaline) as of April 2021.

The report is structured as follows. In the next section, we present the research approach, methodology used, and describe used data collection methods. This is followed by a detailed description of used assumptions and indices. Then we present a summary of comparison of time, distance, travel cost per passenger, and emvironmental impact for identified routes. We conclude this report by discussing expected costs of electric aviation and its other direct and indirect socio-economic effects and provide summary and conclusions.

2 Research approach, methodology, and data collection

Research approach and methodology. In this pre-study, we are focused on the analysis of:

(i) *direct costs and benefits of electric aviation.* We consider such factors as travel time, distance, travel cost per passenger, and environmental impact (CO_2 emissions per passenger) for a trip that would include an electric flight option.

(ii) *indirect socio-economic impacts* (e.g., impact for passengers, impact on regional aviation, municipalities, and regions, etc.).

This research is exploratory in nature. For analysis purposes, we used both quantitative and qualitative research methods. In more detail, they are described below.

The quantitative approach was used to quantify CO_2 emissions, to identify travel time and distance. In the analysis, we considered a few alternative transport modes: electric aviation, traditional aviation, car using gasoline, electric car, a bus, and an train. Used assumptions and formulas are described in more details in Section 3.

There are certain socio-economic effects, which are difficult to quantify. For that reason, we describe them in a text form using qualitative data. This description is based on our collected primary data.

Data collection. In order to analyse socio-economic effect, direct and indirect benefits of electric aviation, we have collected primary data via semi-structured interviews. First, we have developed the interview protocol with formulated interview questions. A sample protocol is provided in *Appendix A. Sample interview protocol*. Discussed topics were related to:

- The overall electric aviation context.
- Costs of traditional and electric aviation.
- Different potential effects of electric aviation for passengers, local airports, environmental effects, domestic aviation, regions, and municipalities.

Secondly, we conducted interviews. Majority of interviews lasted about one hour. Three researchers took part in interviews. All conducted interviews were recorded. These recordings were used for analysis and summarising of research findings.

In order to understand different perspectives on electric aviation, we have interviewed different types of actors. These are representatives and analysts of transport regulation authorities (Trafikverket, Trafikanalys, Svenska FlygBranschen), association of Swedish Regional Airports, regional airports, municipality, project managers of FAIR (Finding Innovations to Accelerate Implementation of Electric Regional Aviation) project, an electric aircraft producer, a consultancy company, and a climate researcher. A list of interviewed actors is summarised in Table 1. Contacted interviewees represent researchers, specialists, experts, consultants, and managers directly involved in the electric aviation industry or working with electric aviation projects. All interviewees were qualified as industry experts having relevant knowledge and expertise for our research.

The interviews were conducted in the period from October to November 2020. The total number of conducted interviews is 15. The total number of interviewed experts is 16. In addition, H. Dunder, a project manager of the projects Green Flyway, has been consulting us during the entire project.

Table 1. A list of interviewees.

Company /organisation	Type of actor	Interviewee (reference in the text)	Position	Interview date
HL Insight	Consultant	Henrik Littorin (HL)	Owner, consultant	20 Oct. 2020
Trafikverket	Regulation authorities	Katarina Wigler (KW)	Aviation strategist	20 Oct. 2020
Svenska FlygBranschen, SFB	Regulation authorities	Fredrik Kämpfe (FK)	Industry manager	23 Oct. 2020 11 Nov. 2020
Trafikverket	Regulation authorities	Malcolm Lundgren (ML)	Strategic advisor	26 Oct. 2020
Svenska FlygBranschen, SFB	Regulation authorities	Nils Paul (NP)	Business policy expert	26 Oct. 2020
Svenska regionala flygplatser	Regional airports	Mari Torstensson (MT)	Project manager of Grön flygplats	29 Oct. 2020
Climate researcher	Researcher	Anneli Kamb (AK)	KTH, PhD student	12 Nov. 2020
Project FAIR	eAviation project	Andreas Å Forsgren (AF)	Project manager, Tyréns AB	13 Nov. 2020
Project FAIR	eAviation project	Lars Westin (LW)	Professor at Umeå university	13 Nov. 2020
Östersund municipality, Green Flyway project	Municipality	Anne Sörensson (AS)	Climate strategist in municipality, Project manager of Green Flyway	13 Nov. 2020
Östersund municipality, Green Flyway project	Municipality	Hans Dunder (HD)	Project manager of Green Flyway	Constant consultation during the course of the project
Trafikanalys	Regulation authorities	Fredrik Brandt Backa (FBB)	Analyst	20 Nov. 2020
Pipistrel aircraft	Electric aircraft producer	Tine Tomažič (TT)	CTO of Pipistrel	20 Nov. 2020
Skellefteå airport, FAIR project	Regional airports	Robert Lindberg (RL)	CEO of Skellefteå airport	23 Nov. 2020
Castellum Säve operating and owning Säve Airport	Regional airports	Ulf Östermark (UÖ)	Head of development	27 Nov. 2020

Used assumptions, indices, and delimitations are described in the next section.

3 Calculation model and assumptions

In this section, we describe assumptions that we have used for analysis.

3.1 Considered types of transport

eFlight. We define electric aviation as an airplane powered by a battery or hydrogen. We have assumed a use of 19-seats electric aircraft for all routes.

Flight. For analysis of traditional flights, we have used aircraft and flight information from official websites of existing airlines (JonAir and SAS) and Wikipedia.

Car. We have considered a medium size car, which is approximately 10 years old (ACEA, 2020). We have calculated CO2 emissions for a car that uses gasoline 95.

eCar. We have considered a new medium size car. A considered electric car uses 1,5kWh/100 km (energuide, 2021).

Bus. We have considered a long-distance bus, which is about 5 years old (Sveriges Bussföretag, 2019), has about 50 seats, and uses diesel fuel (Volvo, 2020).

Electric train. The assumed train is Coradia Nordic X62, an electric train used by Norrtåg (Wikipedia, 2020). For regional trips, we assume a train having 180 seats.

Diesel train. This is a train operating between Östersund – Sveg and Östersund – Strömsund. We assume 180 seats.

Ferry. Ferries were not considered in this pre-study.

3.2 Modelling a trip distance and time

Trip distance. For a trip distance, we have used estimations of *sv.distance.to* and Google maps.

Travel time. Travel times for an electric and traditional flight were estimated using formula:

$$t = D / v, \tag{1}$$

Where, t – travel time (h), D – travel distance (km), v – speed (km/h).

For a car and electric car, we used travel time estimated by *sv.distance.to* for a certain route.

For a bus and a train, we used travel times, which were provided by transport companies operating corresponding routes, for example, Norrtåg, Vy.no, etc.

In order to estimate a duration of a door-to-door trip for trips by an electric flight, a traditional flight, a bus, and a train, we have additionally considered:

- Some additional time needed to travel to and from an airport or a bus / train station (see Table 2).
- Waiting time between different legs or parts of the same trip. This time has been provided by a transport company or was calculated, when building a detailed travel plan based on schedules of different transport operators.

Table 2. Assumed travel times to and from an airport and bus / train station.

Transport mode	Additional time to or from airport or a train/bus station (min)
eFlight	90
Flight	90
Car (Gasoline 95)	0
eCar	0
Bus	30
Train	30

3.3 Modelling a trip cost per passenger

3.3.1. Cost per passenger for an electric and traditional flight

In this pre-study, we were mostly focused on the comparison of electric and traditional flight options. For that reason, we have built a model where we sought to consider the most important cost drivers for flying a plane from airport A to airport B, as listed below:

- Depreciation cost of an airplane.
- Maintenance cost of an airplane.
- Personnel cost.
- Direct operating cost (fuel cost and airport fees).

The cost per passenger per flight was calculated using the following formula:

Cost per passenger per flight = (Depreciation cost + Maintenance cost + Personnel cost + Direct operational cost) / Average number of passengers (2)

Where, 50% of occupancy rate is used to estimate an *average number of passengers*.

Depreciation cost. An aircraft is a very complex machine consisting of different parts. Every part has a different price and lifetime. For example, the aircraft's body or airframe has a lifetime of about 30 years, the lifetime of engine is about 6 000 hours. A report by IATA and KPMG (n.a., p.14) summarises depreciation practices used by different airline companies, which can significantly differ.

In our calculations of depreciation, we have used straight-line method:

Yearly depreciation = Price / Lifetime (3)

Depreciation cost per flight = Yearly depreciation / Number of flights per year (4)

Depreciation cost is a fixed cost and is value is the same for any flight.

In our model, we have considered four types of aircrafts:

1. A 19-seater used for regional aviation (namely, aircraft Beechcraft B1900C).
2. An electric 19-seater (namely, Heart ES-19).
3. A 90-seater used for regional aviation (Canadiar Regional Jet 900).
4. A 180-seater used for international flights (Airbus A320 neo).

Our used assumptions for these aircrafts are provided in Table 3.

Table 3. Assumptions used to calculate depreciation cost.

Type of cost	**Beechcraft B1900C**	**Heart ES-19**	**Canadair Regional Jet 900**	**Airbus A320 neo**
Assumed price	100 000 000 SEK	100 000 000 SEK	398 000 000 SEK	836 000 000 SEK
Lifetime	30 years	30 years	20 years	20 years
Yearly depreciation	3 000 000 SEK	3 000 000 SEK	9 950 000 SEK	41 800 000
Number of flights per year	960 (Assuming 2 trips there and back, 240 days per year)	960 (Assuming 2 trips there and back, 240 days per year)	960 (Assuming 2 trips there and back, 240 days per year)	960 (Assuming 2 trips there and back, 240 days per year)
Depreciation cost per flight	3 125 SEK	3 125 SEK	10 365 SEK	43 542 SEK
Number of seats	19	19	90	180
Average number of passengers (50% occupancy rate)	10	10	45	90

Maintenance cost. Based on the data that we have gathered during interviews with industry representatives[1], maintenance cost in practice is 50% higher than depreciation cost.

*Maintenance cost of traditional aircrafts = Depreciation cost per flight * 1.5* (5)

Maintenance cost of electric aircrafts is expected to be 50% lower in comparison to equivalent jet engine aircrafts (Forslund, 2020) (see Table 4).

Table 4. Assumed maintenance costs.

Type of cost	**Beechcraft B1900C**	**Heart ES-19**	**Canadair Regional Jet 900**	**Airbus A320 neo**
Maintenance cost	4 688 SEK	2 344 SEK	15 547 SEK	65 313 SEK

Personnel cost. The key considered parameter was personnel cost per flight. Our assumptions and formula used to calculate personnel cost are provided in Table 5.

Table 5. Assumptions used to calculate personnel cost.

Parameter	**Beechcraft B1900C**	**Heart ES-19**	**Canadair Regional Jet 900**	**Airbus A320 neo**
Number of flights per year per pilot	800	800	800	800
Salary cost per pilot per year (SEK)	1 000 000	1 000 000	1 000 000	1 000 000
Number of pilots per flight	2	2	5	8
Personnel cost per flight (SEK) = (*Salary cost per pilot per year / Number of flights per year) * Number of pilots per flight* (6)	2 500	2 500	6 250	10 000

[1] Interview with T. Tomažič, Pipistrel aircraft.

Direct operating cost. In the category of direct operating cost, we have only considered the cost of fuel and airport fees. In Sweden, the price of aviation fuel used (kerosene) is not subject to taxation and typically can be obtained for 5 SEK/l or 0.52 SEK/kWh (Dunder, 2021), given the energy content of kerosene equals 9.56 kWh/l (see Table 6). It should be noted that this is about one third of the cost of fuel for land-based transportation, and also considerably lower than the cost of international flight, which is subject to CO2 emission fees.

Today, it is hard to predict the future price of electricity, when its demand will increase with increasing numbers of electric vehicles and plains. At the same time, electricity production is projected to increase in the coming years. Assuming a similar cost of electricity as today is a reasonable approximation. However, the cost of charging infrastructure needed to charge aircraft batteries in reasonable time should be included. In dialogue with the study commitment, we baked those costs into a 4 SEK/kWh electricity cost at quick-charging stations at the airport (Dunder, 2021; Sörensson, 2021). Both fuel cost and electricity cost contain an element uncertainty, especially in the medium-term future.

Table 6. Energy cost by different aircrafts.

Parameter	**Beechcraft B1900C**	**Heart ES-19**	**Canadair Regional Jet 900**	**Airbus A320 neo**
Fuel price (SEK/l)	5		5	5
Fuel energy content (kWh/l)	9.56		9.56	9.56
Energy price (SEK/kWh)	0.52	4	0.52	0.52
Cruise energy need (kWh/km)	9.03	0.75	30.19	37.15
Take-off, landing, taxi energy need (kWh)	301	25	1342	1424
Cruise speed (km/h)	446	307	829	828

In our analysis, we have built upon analysis performed by Hans Dunder and used data on Jet A1 that is using 315 l of fuel for a trip between Östersund and Umeå, with distance 300 km, and that about 10% of that fuel is used for take-off, taxi, and landing. These parameters were scaled up for other JonAir routes by Beechcraft B1900C.

Parameters used to calculate energy use per trip by electric aircraft Heart ES-19 are the following: speed – 330 km/h; energy use – 715 kWh or 0,75 kWh/km. These parameters were scaled up for analysed trips. For other considered types of aircrafts, we used fuel consumption data provided by SAS.

A considered airport fee is 1 000 SEK per flight.

For eFlight and traditional flight, energy per trip is calculated using this formula:

$$Et = E\_cruise * d + E\_to \quad (7)$$

Where, *Et* – energy per trip, *E_cruise* is the cruising energy per km (kWh/km), *d* – distance (km), and *E_to* is the energy used for take-off, taxi, and landing (kWh).

For eFlight and traditional flight, cost of the trip is calculated using this formula:

$$CfE = Et * PE \quad (8)$$

Where, *CfE* – cost of energy for the trip (SEK), *Et* – energy per trip, *PE* – energy price (SEK/kWh).

3.3.2. Cost per passenger for a gasoline and electric car trip

We considered that the maintenance and operational costs of gasoline and electric car are roughly the same because gasoline car has a lower price and more expensive maintenance cost, and electric car has a high price and lower maintenance cost. Thus, we followed ASEK 7.0 (Trafikverket, 2020) recommendations regarding calculation of cost of using personal car for business trips (see Table 7).

Table 7. Parameters used to calculate cost per passenger for a trip by a gasoline or an electric car.

Parameter	**Gasoline car**	**eCar**
Number of passengers (100% occupancy rate)	4	4
Average number of passengers, *ANp* (50% occupancy rate)	2	2
Total cost per km, *Ckm* (SEK/km)	3.86	3.86
Energy used per km, *Ekm* (kWh/km)	0.57	0.15

For a gasoline and electric car, energy needed per trip is calculated using this formula:

$$Et = Ekm * d \tag{9}$$

Where, *Et* – energy per trip, *Ekm* – used energy per km (kWh/km), *d* – distance (km).

A cost per passenger per trip is calculated following the following formula:

$$Cpt = (Ckm * d) / ANp \tag{10}$$

Where, *Cpt* – a cost per passenger per trip, *Ckm* – a total cost per km, *ANp* – an average number of passengers.

3.3.3. Cost per passenger for a bus trip

To calculate a cost per passengers for a bus trip, we have followed ASEK 7.0 model recommendations (Trafikverket, 2020). The parameters are summarised in Table 8.

Table 8. Parameters used to calculate a cost per passenger for a trip by a bus.

Parameter name (Express bus)	**Value**
Number of passengers (100% occupancy)	50
Average number of passengers, *ANp* (50% occupancy)	25
Vehicle-dependent and time-dependant costs, *VTc* (SEK per vehicle hour)	550
Time-dependent costs, *Tc* (SEK per vehicle hour)	359
Distance dependent cost, *Dc* (SEK per scheduled km)	5,29

Distance dependent costs are direct costs that depend on traffic work and distance, and include:

- Costs for fuel, lubricating oil, tires, spare parts.
- Insurance claims.
- A part of administration cost (approximately 10 percent).

Time-dependent costs include both direct costs that vary depending on the volume of operations measured in the number of car hours, and indirect annual costs, which do not depend on time, but are distributed over the number of vehicle hours. The following costs are included:

- Driver salaries.

- Salary for traffic personnel, including service and workshop.
- Part of administration costs (approximately 70 percent).
- Costs of premisses for drivers.

Vehicle-based costs are indirect costs, for example, annual costs associated with vehicle ownership and business. The following costs are considered:

- Insurance costs.
- Vehicle tax, car testing.
- Supplement for wagon reserve (approximately 10 percent).
- Washing and cleaning materials (service).
- Operating cost for parking space.
- Premises costs excluding staff rooms.
- Part of administration (approximately 20 percent)
- Depreciation (depreciation period 10 years).
- Interest expenses (interest of 5 percent).

Cost per passenger per trip is calculated following the following formula:

$$Cpt = (Dc * d + (Tc + VTc) * t) / ANp \quad (11)$$

Where, *Cpt* – cost per passenger per trip, *Dc* – distance-dependent cost, *d* – trip distance, *Tc* – time-dependent cost, *VTc* – vehicle-dependent and time-dependent cost, *t* – time*, ANp* – average number of passengers.

3.3.4. Cost per passenger for a train trip

To calculate a cost per passengers for a train trip, we used parameters used in ASEK 7.0 model (Trafikverket, 2020). Electric trains serve majority of our analysed routes, however, two routes (Östersund – Sveg and Östersund – Strömsund) are served by diesel trains. The parameters are summarised in Table 9.

Operational cost per passenger per trip is calculated following this formula:

$$Ocpt = ((Dbc + Dmc) * d + (Tbc + Tmc) * t) / ANp, \quad (12)$$

Where, *Ocpt* – operational cost per passenger per trip, *Dbc* – distance-dependent basic cost, *Dmc* – distance-dependent marginal cost, *d* – trip distance, *Tbc* – time-dependent basic cost, *Tmc* – time-dependent marginal cost, *t* – time, *ANp* – average number of passengers.

Direct cost per passenger per trip is calculated following this formula:

$$Dcpt = Dtcpk * d, \quad (13)$$

Where, *Dcpt* – direct cost per passenger per trip, *Dtcpk* – total direct cost per passenger km, *d* – trip distance.

Total cost per passenger per trip is calculated following this formula:

$$Cpt = Ocpt + Dcpt \quad (14)$$

Where, *Cpt* – total cost per passenger per trip, *Ocpt* – operational cost per passenger per trip, *Dcpt* – direct cost per passenger per trip.

Table 9. Parameters used to calculate cost per passenger per trip by a train.

Parameter name	Electric train	Diesel train
Number of passengers (100% occupancy)	180	150
Average number of passengers, *ANp* (50% occupancy)	90	75
Operational costs		
Distance dependent basic cost, *Dbc* (SEK per train km)	14,89	26,19
Distance dependent marginal cost, *Dmc* (SEK per train km)	0,09	0,16
Time-dependent basic costs, *Tbc* (SEK per train minute)	50,08	50,08
Time-dependent marginal costs, *Tmc* (SEK per train minute)	0,17	0,17
Direct costs		
Direct costs (SEK per train km)	54,65	66,25
Energy fees (SEK per train km)	0,75	2,02
Track fees (SEK per train km)	2,73	2,73
Overhead (SEK per train km)	9,48	11,58
Total direct cost:	67,61	82,58
Total direct cost per seat km	0.38	0,55
Total direct cost per passenger km, *Dtcpk*:	0.75	1,10

3.4 Modelling the evaluation of CO2 emissions

eFlight and Flight. Car and eCar. For this pre-study, we have only calculated CO2 emission based on energy consumption. This means that we do not consider:

1. The CO2 emissions of building a car, a plane, a bus, or a train.
2. The CO2 emissions related to the live cycle of battery.
3. The CO2 emissions related to production and transportation of fuel.
4. The enhanced effect of emitting CO2 at a higher altitude.

Hence, the CO2 emissions calculated in the report do not catch the full-lifecycle emission of different modes of transport. However, if we are mainly interested in comparing electric vs. combustion engine aircrafts, we can notice that the CO2 emission of the battery life cycle (2), relevant for electric flight, is of the same order of magnitude as the fuel production and transportation (3), relevant for combustion engine flight[2]. Hence, we can expect the difference in CO2 emission between electric and combustion engine car calculated in the report to be not too far from the full life-cycle difference. Similar considerations can be made on land transportation options. However, it would be beneficial to explore this in further detail in a future study.

Formula used for calculation of CO2 emissions per passenger per trip by flight/eFlight and car/eCar is this:

$$CO2ept = Et * CO2e / ANp \quad (15)$$

Where, *CO2ept* – CO2 emissions kg per passenger per trip, *Et* – energy per trip (kWh/trip), *CO2e* – CO2 emissions per energy unit (kg/kWh), *ANp* – average number of passengers.

[2] There are no conclusive studies regarding this, but a good indication is given by a study made on electric-vs-combustion engine cars (ICCT, 2018).

The summary of used CO2 emission parameters is provided in Table 10.

Table 10 Parameters used to calculate energy used per trip and CO2 emissions for trips by eFlight, flight, car, and eCar.

	Fuel type	Energy per fuel unit (kWh/l)	Energy use per km (kWh/km)	CO_2 emissions per energy unit (kg/kWh)
eFlight	Electricity (Nordic mix)	1		0,047
Flight	Kerosene	9,56		0,275
Car	Petrol	8,97	0,57	0,327
eCar	Electricity (Nordic mix)	1	0,15	0,047

Bus and Train. In this pre-study, we build upon assumptions used in the Klimatsmartsemester tool developed by Larsson and Kamb (2018) and use their proposed coefficients of CO2 emissions per passenger. Coefficients used to calculate CO2 emissions when travelling by busses and trains are provided in Table 11.

Table 11 Parameters used to calculate CO2 emissions for trips by a bus and a train.

Transport mode	**CO2 emissions kg per passenger km**	**Reference**
Bus, long distance	0,0324	Larsson and Kamb, 2018
Train, electric	0,010	Larsson and Kamb, 2018
Train, diesel	0,091	Larsson and Kamb, 2018

A formula used for calculations is the following:

$$CO2pt = CO2ekpk * d \tag{16}$$

Where, *CO2pt* – CO2 kg per passenger per trip, *CO2ekpk* – coefficient of CO2e kg per passenger km, *d* – distance.

4 Comparison of time, distance, cost per passenger, and CO2 emissions for identified routes

In this section, we provide a summary of results on time, distance, cost per passenger per trip, and CO2 emissions per passenger per trip for every route described below. In the analysis, we consider only those means of transport that are available today to travel between destinations of the analysed routes, and additionally introduce the option of electric flight. All detailed calculations are provided in the Excel file. Here, we provide a summary of results for all analysed routes.

4.1 Route 1: Östersund – Umeå

This route is procured and financed by the Swedish Traffic Agency (Trafikverket). The base is a connection between the hospital in Östersund and the university hospital at Umeå.

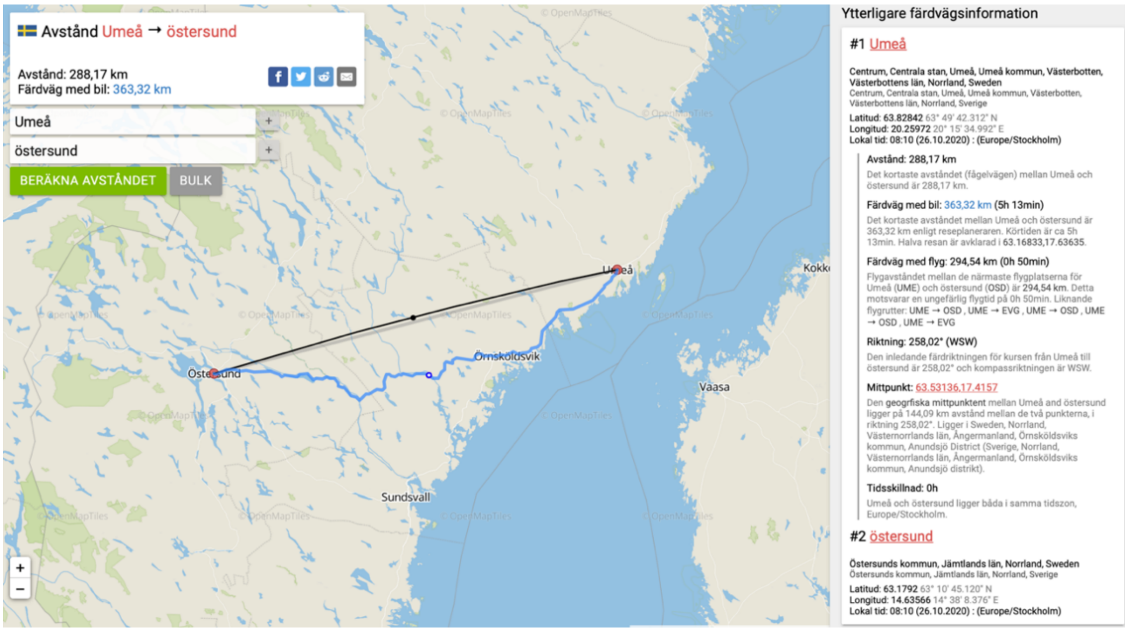

Figure 1. Distance between Östersund and Umeå[3].

Route description

eFlight. A direct flight by an electric airplane. Distance – 300 km. Flight time – 69 minutes. Assumed time to and from airports is 90 min. Aircraft – Heart ES-19.

Flight. A direct flight by a combustion engine airplane. Distance – 300 km. Flight time – about 50 minutes. Assumed time to and from airports is 90 min. Aircraft – Beechcraft B1900C.

Car, eCar. A trip time is 4 h 40 min, distance – 365 km.

Bus. A trip by a bus involves two legs:

1. Umeå – Dorotea. Distance – 247 km. Time to station – 30 min, travel time – 3 h 05 min, waiting time between lines – 30 min.

[3] sv.distance.to, n.a. *Distance between* Östersund – Umeå. Available at: <https://sv.distance.to/Östersund,SWE/Umeå,SWE> [Accessed 13 November 2020]

2. Dorotea – Östersund. Distance – 172 km. Travel time – 2 h 55 min, time from the station – 30 min.

Electric train. A trip by a train involves two legs:

1. Östersund – Sundsvall. Distance – 190 km. Time to station – 30 min, travel time – 2 h 30 min 3 h 05 min, waiting time between lines – 20 min.
2. Sundsvall – Umeå. Distance – 230 km. Travel time – 3 h, time from the stations – 30 min.

Comparison across different transport modes

Direct electric and traditional flights result in the shortest distance (300 km) (see Table 12). Trips by a car/eCar is the second choice with 365 km. Trips by a bus or a train cover the longest distance (418 and 420 km respectively).

The shortest trip duration, considering time door-to-door, is when travelling directly by a traditional aviation (2 h 20 min). The electric aviation is just 20 min longer (2 h 39 min). The next choice is a trip by a car/eCar (4 h 40 min). The longest trip duration is when travelling by a train (6 h 50 min) or a bus (7 h 30 min).

The lowest amount of CO2 emissions is produced when travelling by an electric aircraft or an eCar (1,2 and 1,3 kg CO2 emissions per passenger per trip retrospectively). The next options are trips by a train or by a bus (4,2 and 13,5 kg CO2 emissions per passenger per trip retrospectively). The highest amount of CO2 emissions per passenger per trip is produced when travelling by a combustion engine airplane (82,8 kg).

The lowest cost per passenger is when travelling by a bus (307 SEK per passenger per trip). This cost is higher when travelling by a train (570 SEK per passenger per trip). The cost of the trip by a car/eCar takes a middle position (704 SEK per passenger per trip). The highest cost per passenger is when travelling by a traditional aviation (1 289 SEK per passenger per trip). It needs to be mentioned that the cost of a flight by electric aviation is about one third lower than by a traditional one (997 vs. 1289 SEK per passenger per trip retrospectively).

Table 12. Route Östersund – Umeå: comparison across different transport modes.

Transport mode	Distance (km)	Time door-to-door	CO_2 emissions, kg per passenger per trip*	Cost per passenger per trip (SEK)
eFlight	300	2h 39'	1.2	997
Flight	300	2h 20'	82.8	1289
Car (Gasoline)	365	4h 40'	34.0	704
eCar	365	4h 40'	1.3	704
Bus	418	7h 30'	13.5	307
Train	420	6h 50'	4.2	570

* Energy consumption only

4.2 Route 2: Sveg – Arlanda

This route is procured and financed by the Swedish Traffic Agency. Electrification will give environmental benefits.

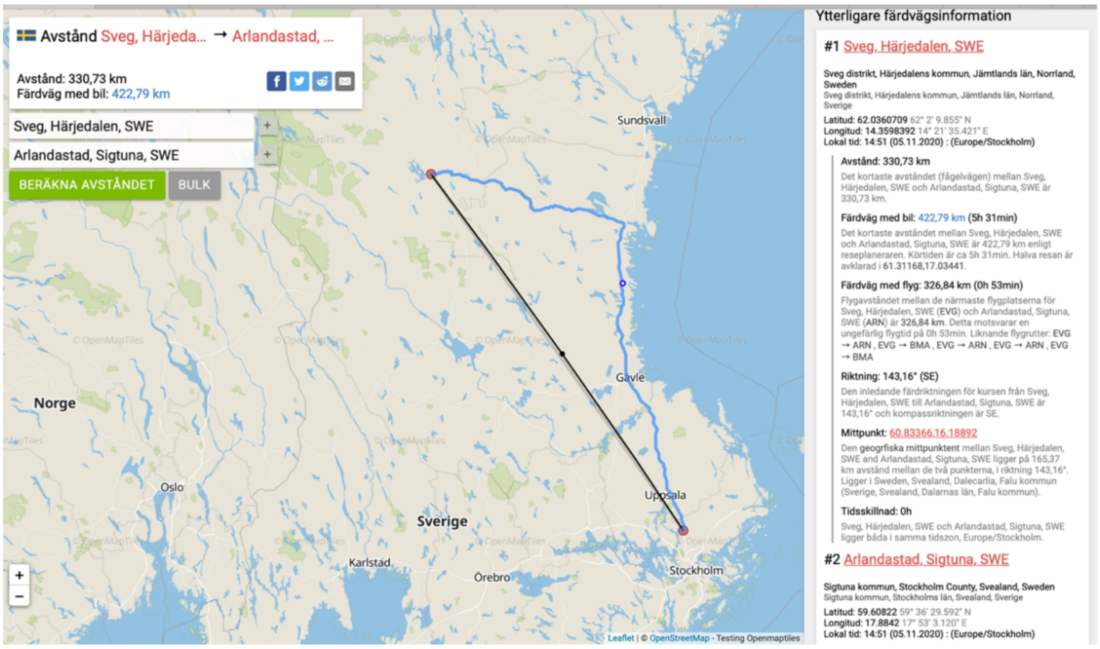

Figure 2. Distance between Sveg and Arlanda[4].

Route description.

eFlight. A direct flight by an electric aircraft. Distance – 327 km. Flight time – 74 minutes. Assumed time to and from airports is 90 min. Aircraft – Heart ES-19.

Flight. A direct flight by a traditional aircraft. Distance – 327 km. Flight time – 54 minutes. Assumed time to and from airports is 90 min. Aircraft – Beechcraft B1900C.

Car, eCar. A trip time is 4 h 45 min, distance – 395 km.

Bus and Electric train. This route involves trip by a bus and a train:

1. The bus trip Sveg – Ljusdal. Distance – 109 km. Time to station – 30 min, travel time – 2 h 05 min, waiting time between lines – 1 h 40 min.

2. The train trip Ljusdal – Arlanda. Distance – 300 km. Travel time – 3 h, time from the station – 30 min.

Comparison across different transport modes

Direct electric and traditional flights will give the shortest distance (327 km) (see Table 13). Trips by a car/eCar and by a combination of a bus and a train will cover the longest distances (395 and 409 km).

The shortest trip duration, considering time door-to-door, is when travelling directly by a traditional aviation (2 h 24 min). Electric aviation is just 20 min longer (2 h 44 min). The trip by

[4] sv.distance.to, n.a. *Distance between Sveg and Arlanda*. Available at: <https://sv.distance.to/Sveg,Härjedalen,SWE/Arlandastad,Sigtuna,SWE> [Accessed 3 November 2020]

a car/eCar is the next choice with 4 h 45 min. The longest trip duration is when travelling by a combination of a bus and a train (7 h 45 min).

The lowest amount of CO2 emissions is produced when travelling by an electric aircraft and by an eCar (1,3 and 1,4 kg CO2 emissions per passenger per trip retrospectively). The next choice is a trip by a combination of a train and a bus (6,5 kg CO2 emissions per passenger per trip). The highest amount of CO2 emissions per passenger per trip is produced when travelling by a combustion engine airplane (90,2 kg).

The lowest cost per passenger is when travelling by a combination of a bus and a train (475 SEK per passenger per trip). The cost of the trip by a car/eCar is 762 SEK per passenger per trip. The highest cost per passenger is when travelling by a traditional aviation (1 303 SEK per passenger per trip). It needs to be mentioned that the cost per passenger by an electric aviation is about one third lower than by a traditional one (1 006 vs. 1 303 SEK per passenger per trip retrospectively).

Table 13. Route Sveg – Arlanda: comparison across different transport modes.

Transport mode	Distance (km)	Time door-to-door	CO_2 emissions, kg per passenger per trip*	Cost per passenger per trip (SEK)
eFlight	327	2h 44'	1.3	1006
Flight	327	2h 24'	90.2	1303
Car (Gasoline)	395	4h 45'	36.8	762
eCar	395	4h 45'	1.4	762
Bus and train	409	7h 45'	6.5	475

* Energy consumption only

4.3 Route 3: Trondheim – Östersund – Sundsvall

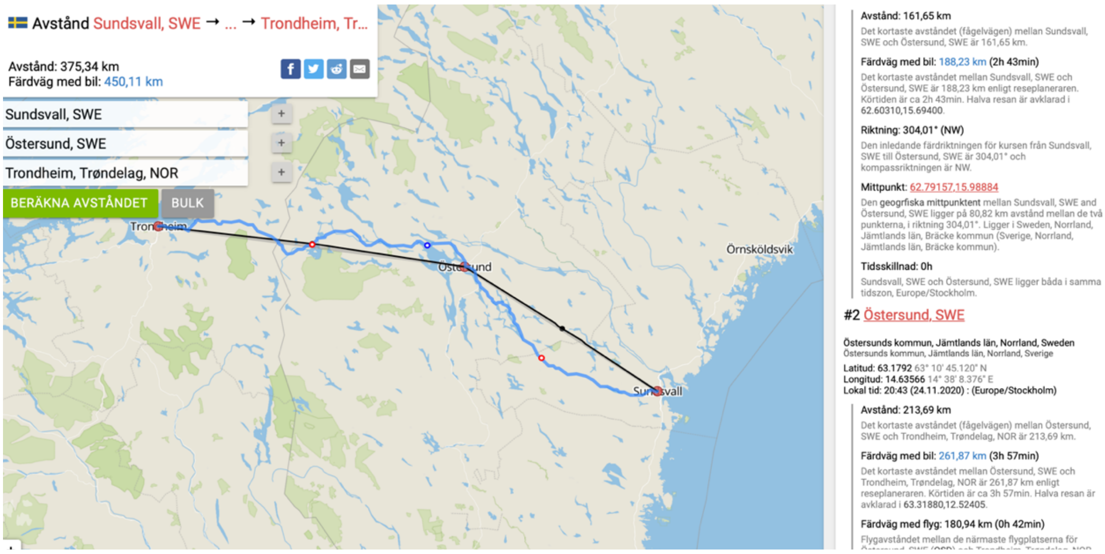

Figure 3. Distance Trondheim – Östersund – Sundsvall[5].

Route description.

eFlight. A trip by an electric aircraft involves two legs:

1. Sundsvall – Östersund. Distance – 172 km. Time to airport – 90 min, flight time – 44 min, waiting time between lines – 30 min. Aircraft – Heart ES-19.
2. Östersund – Trondheim. Distance – 225 km. Flight time – 54 min, time from the airport – 90 min. Aircraft – Heart ES-19.

Flight. Today, there are no routes that would connect Sundsvall, Östersund, and Trondheim directly. Existing routes are either connecting Sundsvall and Trondheim or Östersund and Trondheim.

Route Östersund – Trondheim involves three legs:

1. Östersund – Arlanda. Distance – 431 km. Time to airport – 90 min, flight time –55 min, waiting time between lines – 45 min. Aircraft – Airbus 320 neo.
2. Arlanda – Oslo. Distance – 383 km. Flight time – 60 min, waiting time between lines – 1 h 25 min. Aircraft – Airbus 320 neo.
3. Oslo – Trondheim. Flight time – 1 h 10 min, time from the airport – 1 h 40 min. Aircraft – Airbus 320 neo.

Route Sundsvall – Trondheim involves two legs:

1. Sundsvall – Arlanda. Distance – 319 km. Time to airport – 90 min, flight time –50 min, waiting time between lines – 1 h 10 min. Aircraft – Airbus 320 neo.
2. Arlanda – Trondheim. Flight time – 1 h 15 min, time from the airport – 1 h 30 min. Aircraft – Airbus 320 neo.

Car, eCar. A trip time is 6 h 50 min. Distance – 455 km.

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[5] sv.distance.to, n.a. *Distance between Trondheim – Östersund – Sundsvall*. Available at: <https://sv.distance.to/Sundsvall,SWE/Östersund,SWE/Trondheim,Trøndelag,NOR> [Accessed 13 November 2020]

Bus. No bus options for this trip on Norrtag.se.

Electric train. A trip by a train involves two legs:

1. Sundsvall – Östersund. Distance – 190 km. Time to station – 30 min, travel time – 2 h 50 min, waiting time between lines – 30 min.
2. Östersund – Trondheim. Distance – 270 km. Travel time – 3 h 50 min, time from the station – 30 min.

Comparison across different transport modes

A flight by an electric plane gives the shortest distance (397 km) (see Table 14). Trips by a car/eCar and by a train are nearly the same (455 km and 460 km retrospectively). Currently available flights by a traditional aviation are directed through big hubs (like Arlanda and Oslo). For that reason, flights Östersund – Trondheim (1 175 km) is the longest, and Sundsvall – Trondheim (885 km) is slightly shorter.

The shortest trip duration, considering time door-to-door, is when travelling directly by an electric flight (5 h 8 min). The available flights by a traditional aviation (Sundsvall – Trondheim and Östersund – Trondheim) are longer in comparison to electric flight. Moreover, they are not an optimum solution for this route as they do not connect desired destinations. A trip by a car/eCar is 6 h 50 min. The longest trip duration is when travelling by a train (8 h 10 min).

Table 14. Route Trondheim – Östersund – Sundsvall: comparison across different transport modes.

Transport mode	Distance (km)	Time door-to-door	CO_2 emissions, kg per passenger per trip*	Cost per passenger per trip (SEK)
eFlight	397	5h 8'	1.6	1926
Flight (Östersund – Trondheim, SAS)	1175	7h 35'	148	4277
Flight (Sundsvall – Trondheim, SAS)	885	5h 54'	112	2876
Car (Gasoline)	455	6h 50'	42.4	878
eCar	455	6h 50'	1.6	878
Bus - - - no option - -	–	–	–	–
Train	460	8h 10'	4.6	645

* Energy consumption only

The lowest amount of CO2 emissions per passenger per trip is when travelling by an electric aircraft or an eCar (1,6 Co2e kg per passenger per trip). The next choice is a trip by a train (4,6 kg CO2 emissions per passenger per trip). A trip by a gasoline car produces 42,4 kg CO2 emissions per passenger per trip. The highest amount of CO2 emissions per passenger per trip is produced when travelling by a traditional aviation (112 and 148 kg CO2 emissions per passenger per trip).

The lowest cost per passenger is when travelling by a train (645 SEK per passenger per trip). This cost is higher when travelling by a car/eCar (878 SEK per passenger per trip). Existing routes offered by a traditional aviation have the highest cost (2 876 and 4 277 SEK per passenger per trip). A flight by an electric airplane will be significantly cheaper when compared to a traditional one (1 926 SEK per passenger per trip).

4.4 Route 4: Östersund – Sveg

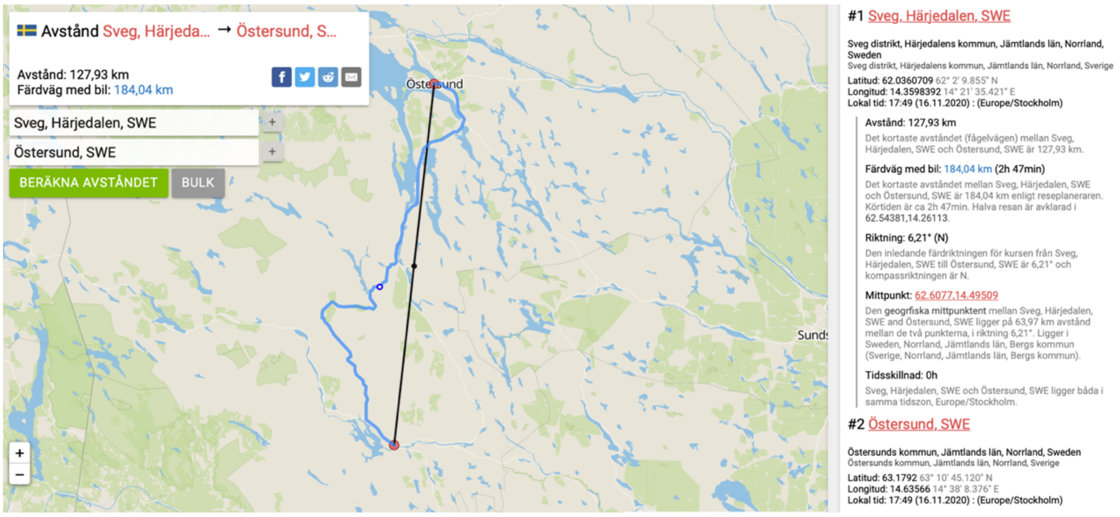

Figure 4. Distance between Östersund and Sveg [6].

Route description.

eFlight. A direct flight by an electric aircraft. Distance – 140 km. Flight time – 38 minutes. Assumed time to and from airports is 90 min. Aircraft – Heart ES-19.

Flight. Currently, there is no flight option for this route.

Car, eCar. A trip time is 2 h 50 min. Distance – 184 km.

Bus. Östersund – Sveg. Distance – 190 km. Time to station – 30 min, travel time – 2 h 50 min, time from station – 30 min.

Diesel train. Östersund – Sveg. Distance – 182 km. Time to station – 30 min, travel time – 2 h 50 min, time from station – 30 min.

Comparison across different transport modes

A direct electric flights gives the shortest distance (140 km) (see Table 15). A trip by a bus covers the longest distance (190 km). A trip by a train and by a car/eCar are just slightly shorter (182 and 184 km respectively).

The shortest trip duration, considering time door-to-door, is when travelling directly by an electric airplane (2 h 7 min). The longest trip duration is when travelling by a bus or by a train (3 h 50 min in both cases). A trip by a car/eCar is in the middle (2 h 50 min).

The lowest amount of CO2 emissions per passenger per trip is when travelling by an electric aircraft or by eCar (0,5 and 0,6 kg CO2 emissions per passenger per trip). A trip by a bus results in 6,2 kg CO2 emissions per passenger per trip. The highest amount of CO2 emissions per passenger per trip is produced when travelling by a train or a gasoline car (16,6 and 17,1 kg CO2 emissions kg per passenger per trip).

The lowest cost per passenger is when travelling by a bus (143 SEK per passenger per trip). The cost per passenger when travelling by a car/eCar or a train is more than two times higher in

[6] sv.distance.to, n.a. *Distance between Östersund – Sveg*. Available at: <https://sv.distance.to/Östersund,SWE/Sveg,Härjedalen,SWE> [Accessed 16 November 2020]

comparison to cost of a trip by a bus (355 and 378 SEK per passenger per trip respectively). The highest cost per passenger is when travelling by an electric aviation (944 SEK per passenger per trip).

Table 15. Route Östersund – Sveg: comparison across different transport modes.

Transport mode	Distance (km)	Time door-to-door	CO_2 emissions, kg per passenger per trip*	Cost per passenger per trip (SEK)
eFlight	140	2h 7'	0.5	944
Flight - - no option - -	–	–	–	–
Car (Gasoline)	184	2h 50'	17.1	355
eCar	184	2h 50'	0.6	355
Bus	190	3h 50'	6.2	143
Train (diesel)	182	3h 50'	16.6	378

* Energy consumption only

4.5 Route 5: Östersund – Strömsund

Not existing regional connections that would offer a better service for passengers (travellers, commuters that use other transport modes or potential new commuters) and saving their time or enlarging the employment market.

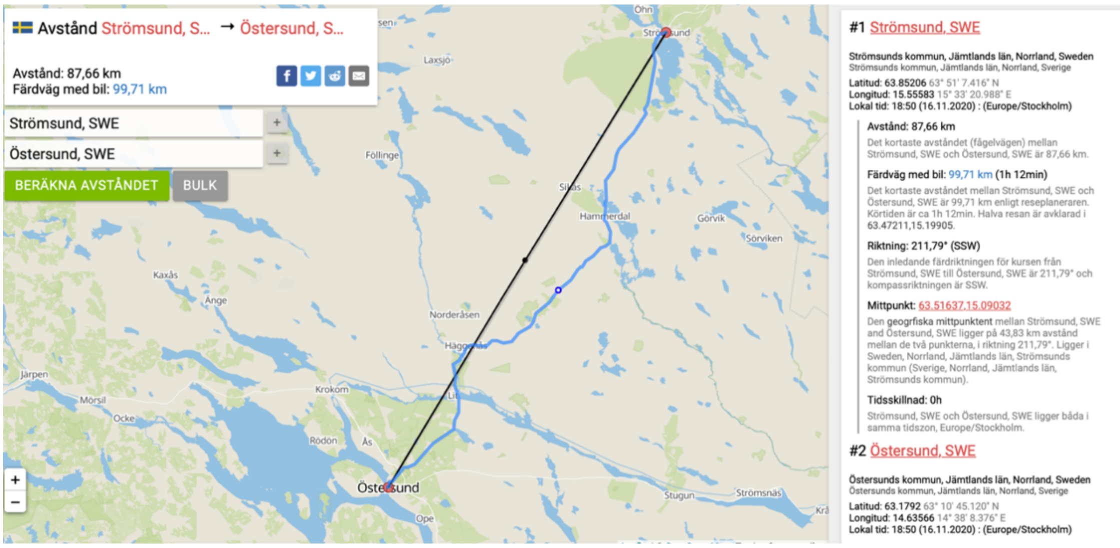

Figure 5. Distance Strömsund – Östersund[7].

Route description.

eFlight. A direct flight by an electric aircraft. Distance – 100 km. Flight time – 30 minutes. Assumed time to and from airports is 90 min. Aircraft – Heart ES-19.

Flight. Currently, there is no flight option for this route.

Car, eCar. A trip time is 1 h 20 min. Distance – 100 km.

Bus. A direct trip by a bus. Distance – 100 km. Time to station – 30 min, travel time –1 h 35 min, time from the station – 30 min.

Diesel train. There were no train options for this trip on Norrtag.se.

Comparison across different transport modes

For this route, the distance is the same for all transport modes (100 km) (see Table 16).

The shortest trip duration, considering time door-to-door, is when travelling by a car/Car (1 h 20 min). A flight with an electric aircraft is 40 min longer (2 h). The longest trip duration is when travelling by a bus (2 h 35 min).

The lowest amount of CO2 emissions per passenger per trip is produced when travelling by either electric aviation or eCar (0,4 kg CO2 emissions per passenger per trip by both options). A trip with a bus is taking the second place (3,2 kg CO2 emissions per passenger per trip). The

[7] sv.distance.to, n.a. *Distance between Strömsund – Östersund*. Available at: <https://sv.distance.to/Strömsund,SWE/Östersund,SWE> [Accessed 16 November 2020]

highest amount of CO2 emissions per passenger per trip is produced when travelling by a gasoline car (9,3 kg).

The lowest cost per passenger is when travelling by a bus (79 SEK per passenger per trip). The second option is a car/eCar (193 SEK per passenger per trip). The highest cost per passenger is when travelling by an electric aviation (930 SEK per passenger per trip).

Table 16. Route Strömsund – Östersund: comparison across different transport modes.

Transport mode	Distance (km)	Time door-to-door	CO_2 emissions, kg per passenger per trip*	Cost per passenger per trip (SEK)
eFlight	100	2h 00'	0.4	930
Flight	–	–	–	–
Car (Gasoline)	100	1h 20'	9.3	193
eCar	100	1h 20'	0.4	193
Bus	100	2h 35'	3.2	79
Train (diesel) – no train	–	–	–	–

* Energy consumption only

4.6 Route 6: Östersund – Örnsköldsvik – Umeå

A safe travel for electric aviation Östersund – Umeå. A technical stopover in Örnsköldsvik makes it possible to charge and come all the way to Umeå. The flight line Östersund – Umeå is 290 km and might be a little too long for electrification, for example, in bad weather. Örnsköldsvik is a partner in the Green Flyway project. This line also increases the connections between Örnsköldsvik and Umeå. Umeå University has a campus in Örnsköldsvik.

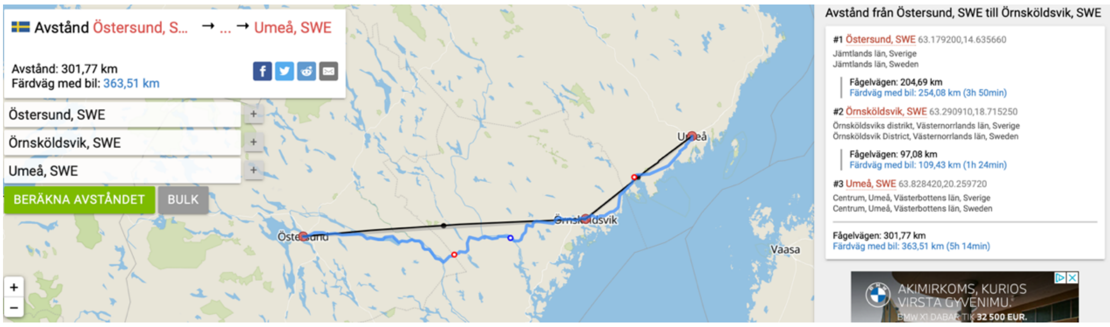

Figure 6. Distance Östersund – Örnsköldsvik – Umeå[8].

Route description.

eFlight. Direct flights by an electric aviation connecting three destinations are:

1. Östersund – Örnsköldsvik. Distance – 226 km. Time to the airport – 90 min, flight time – 55 min, waiting time between lines – 30 min. Aircraft – Heart ES-19.
2. Örnsköldsvik – Umeå. Distance – 110 km. Flight time – 32 min, time from the airport – is 90 min. Aircraft – Heart ES-19.

Flight. Today, there is no direct flights connecting all three destinations (Östersund – Örnsköldsvik – Umeå). A flight, which is available, today is a direct flight Östersund – Umeå:

Östersund – Umeå. Distance – 300 km. Flight time – about 50 minutes. Assumed time to and from airports is 90 min. Aircraft – Beechcraft B1900C.

Car and eCar. A trip time is 4 h 40 min. Distance – 365 km.

Bus and Electric train. This route involves trip by a bus and a train:

1. The bus trip Östersund – Örnsköldsvik. Distance – 270 km. Time to station – 30 min, travel time – 4 h 14 min, waiting time between lines – 15 min.
2. The train trip Örnsköldsvik – Umeå. Distance – 110 km. Travel time – 67 min, time from the station – 30 min.

Comparison across different transport modes

For this route, distances by different transport modes are distributed rather close in the interval between 300 and 380 km (see Table 17). A flight by a traditional airplane has the shortest distance (300 km). However, this is not optimum choice for this route because it directly connects Östersund and Umeå but does not include a stop in Örnsköldsvik. A trip by eFlight

[8] sv.distance.to, n.a. *Distance between Östersund – Örnsköldsvik – Umeå*. Available at: <https://sv.distance.to/Östersund,SWE/Örnsköldsvik,SWE/Umeå,SWE> [Accessed 16 November 2020]

connects all three destinations and is slightly longer (336 km). A trip by a car/eCar is just 30 km longer. A trip by a bus and train covers the longest distance (380 km).

The shortest trip duration, considering time door-to-door, is when travelling by a currently available traditional flight (2 h 20 min). A trip by a car/eCar or an eFlight takes two times longer (4 h 40 min and 4 h 56 min retrospectively). The longest trip duration is when travelling by a combination of a bus and a train (6 h 36 min).

The lowest amount of CO2 emissions per passenger per trip is produced when travelling by an electric aircraft or by an eCar (1,3 kg). A trip by a combination of a bus and a train is taking the second place (9,8 kg CO2 emissions per passenger per trip). The highest amount of CO2 emissions per passenger per trip is produced when travelling by a traditional aircraft (82,8 kg). A trip by a gasoline car results in 34 kg CO2 emissions per passenger per trip.

The lowest cost per passenger is when travelling by a combination of a bus and a train (349 SEK per passenger per trip). The trip by a car/eCar is the second choice. The highest cost per passenger is when travelling by an electric aviation (1 906 SEK per passenger per trip). In this case, a trip by the currently available flight by a traditional airplane is cheaper than by eFlight (1 289 SEK per passenger per trip). However, this flight does not involve a stop in Örnsköldsvik, which would affect the result of cost calculations.

Table 17. Route Östersund – Örnsköldsvik – Umeå: comparison across different transport modes.

Transport mode	Distance (km)	Time door–to-door	CO_2 emissions, kg per passenger per trip*	Cost per passenger per trip (SEK)
eFlight (direct)	336	4h 56'	1.3	1906
Flight (Östersund – Umeå)	300	2h 20'	82.8	1289
Car (Gasoline)	365	4h 40'	34.0	704
eCar	365	4h 40'	1.3	704
Bus and train:	380	6h 36'	9.8	349

* Energy consumption only

4.7 Route 7: Røros – Östersund

Røros is the nearest airport for inhabitants and tourists in west Jämtland. Healthcare service for people living in the western part of Jämtland is provided by Norwegian hospital in Røros. Another possibility is the healthcare service in Östersund with at least 3 h of travel by a bus or 30 min flight time. There is also potential for tourism development in the area with a new flight line.

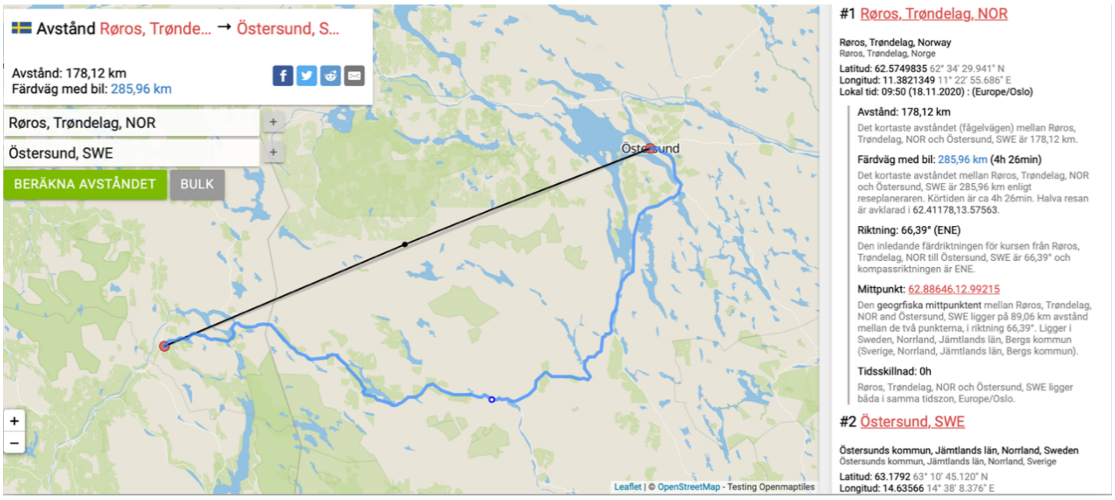

Figure 7. Distance Røros – Östersund[9].

Route description.

eFlight. A direct flight by an electric aircraft. Distance – 190 km. Flight time – 48 minutes. Assumed time to and from airports is 90 min. Aircraft – Heart ES-19.

Flight. Today, there are no routes directly connecting Östersund and Røros. Currently, available routes are directed through big hubs Arlanda and Oslo.

Route Östersund – Røros involves three legs:

1. Östersund – Arlanda. Distance – 431 km. Time to airport – 90 min, flight time –55 min, waiting time between lines – 1 h 30 min. Aircraft – Airbus 320 neo.
2. Arlanda – Oslo. Distance – 383 km. flight time – 60 min, waiting time between lines – 55 min. Aircraft – Airbus 320 neo.
3. Oslo – Trondheim. Flight time – 55 min, time from the station – 90 min. Aircraft – Canadair Regional Jet 900.

Car and eCar. A trip time is 4 h 30 min. Distance – 286 km.

Bus and Electric train. This route involves trips by a bus and a train. A trip planning is provided in Table 18.

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[9] sv.distance.to, n.a. *Distance between Røros – Östersund*. Available at: <https://sv.distance.to/Røros,Trøndelag,NOR/Östersund,SWE> [Accessed 18 November 2020]

Table 18. Røros – Östersund: a trip planning (as of the 5th of April 2021).

	Departure time	Arrival time	30 min - time to station		
	Österund	Stockholm	Trip duration	Waiting for connection	Carrier
Train 1	05:34	10:28	4 h 54 min	1 h	SJ, train
	Stockholm	Göteborg			
Train 2	11:30	14:35	3 h 5 m	1 h 15min	SJ, train
	Göteborg Nils E	Oslo			
Bus 1	15:50	19:20	3 h 20 min	2 h 30 min	Bus4You, bus
	Oslo	Røros		Time from station	
Train 3	22:50	08:14	9 h 24 min	30 min	SJ Nord, night train

Comparison across different transport modes

A direct electric flights give the shortest distance (190 km) (see Table 19). A trip by a car/eCar is the next choice (286 km). A flight by a traditional aviation is directed through big hubs (like Arlanda and Oslo). For this reason, this choice covers much longer distance (1 084 km). A trip by a combination of a bus and a train results in the longest distance (1 860 km), which is almost 10 times longer than a trip by an electric aviation.

The shortest trip duration, considering time door-to-door, is when travelling by a direct electric flight (2 h 17 min). The next choice is a car/eCar (4 h 30 min). A trip duration using the available traditional flights today – via Arlanda and Oslo (7 h 44 min) – is about three times longer in comparison to a direct electric flight. A trip by a combination of a bus and a train gives the longest trip duration (26 h 28 min).

Table 19. Route Røros – Östersund: comparison across different transport modes.

Transport mode	Distance (km)	Time door-to-door	CO_2 emissions, kg per passenger per trip*	Cost per passenger per trip (SEK)
eFlight	190	2h 17'	0.7	960
Flight (Östersund – Arlanda – Oslo – Røros)	1084	7h 44'	158	3701
Car (Gasoline)	286	4h 30'	26.7	552
eCar	286	4h 30'	1.0	552
Bus and train	1860	26h 28'	25.3	2199

* Energy consumption only

The lowest amounts of CO2 emissions per passenger per trip are produced when travelling by an electric aircraft (0,7 kg) or by an electric car (1 kg). Trips by a gasoline car and by a combination of a bus and a train result in a similar CO2 emission (26,7 and 25,3 kg CO2 emissions per passenger per trip respectively). The highest amount of CO2 emissions per passenger per trip is produced when travelling by available traditional aviation flights via Arlanda and Oslo (158 kg).

The lowest cost per passenger is when travelling by a car/eCar (552 SEK per passenger per trip). The second choice is an electric flight (960 SEK per passenger per trip). The cost of travel by a combination of a bus and a train is 2 199 SEK per passenger per trip. A trip by currently available traditional aviation flights via Arlanda and Oslo has the highest cost (3 701 SEK per passenger per trip).

4.8 Route 8: Östersund – Sundsvall – Vaasa

Connections between University cities.

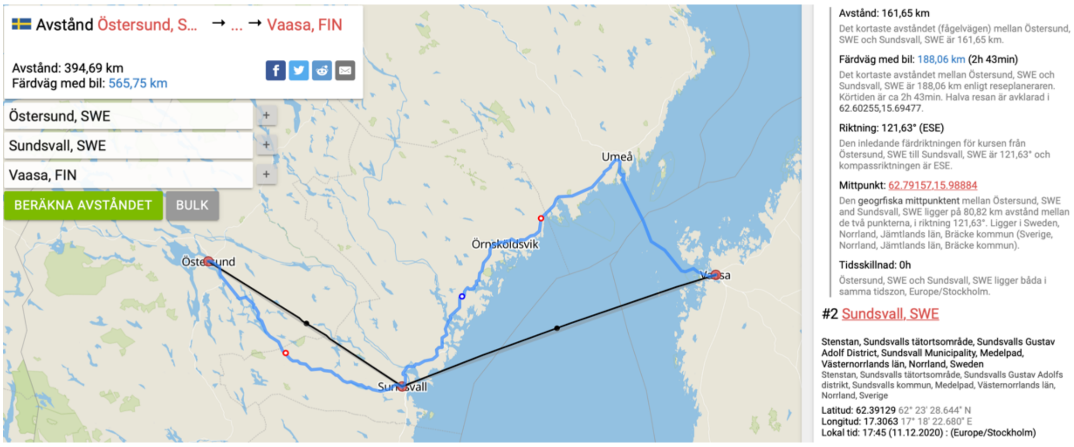

Figure 8. Distance Östersund – Sundsvall – Vaasa[10].

Route description.

eFlight. Direct flights by an electric aviation connecting three destinations are:

1. Östersund – Sundsvall. Distance – 214 km. Time to the airport – 90 min, flight time – 55 min, waiting time between lines – 30 min. Aircraft – Heart ES-19.
2. Sundsvall – Vaasa. Distance – 240 km. Flight time – 60 min, time from the airport – is 90 min. Aircraft – Heart ES-19.

Flight. Today, there are no direct flights connecting all three destinations (Östersund – Sundsvall – Vaasa). Connections available today are the following:

1. Östersund – Arlanda. Distance – 431 km. Time to airport – 90 min, flight time –52 min, waiting time between lines – 1 h 55 min. Aircraft – Airbus 320 neo.
2. Arlanda – Helsinki. Distance – 397 km. Flight time – 55 min, time from Helsinki to Vaasa by train – 4 h 10 min. Aircraft – Canadair Regional Jet 900.

Car, eCar. Time needed to drive from Östersund to Vaasa around the Baltic Sea is 17 h 3 min. Distance – 1 302 km.

Bus. There were no bus options for this trip on Norrtag.se.

Electric train. A trip by a train involves two legs:

1. Östersund – Sundsvall. Distance – 180 km. Time to station – 30 min, travel time – 2 h 29 min, waiting time between lines – 20 min.
2. Sundsvall – Umeå. Distance – 195 km. Travel time – 3 h 3 min, waiting time between lines – 90 min.
3. Ferry: Umeå – Vaasa. Distance – 130 km. Travel time – 3 h 15 min, time from the seaport – 30 min.

[10] sv.distance.to, n.a. *Distance between Östersund – Sundsvall – Vaasa*. Available at: <https://sv.distance.to/Östersund,SWE/Sundsvall,SWE/Vaasa,FIN> [Accessed 19 November 2020]

Ferry. Cost per passenger per trip and CO2 emissions kg per passenger per trip were not considered for a ferry in this pre-study.

Comparison across different transport modes

A direct electric flight results in the shortest distance (454 km) (see Table 20). The second choice is a trip by a combination of a train and a ferry (505 km). Available traditional flights connect through the big hubs (Arlanda and Helsinki) with the length of the trip 828 km to Helsinki. However, this choice is not optimum, as the final destination of this route is Vaasa. There is an additional distance of 440 km between Helsinki and Vaasa. A trip by a car will cover the longest distance (1 302 km).

The shortest trip duration, considering time door-to-door, is achieved when travelling by an electric aviation (5 h 19 min). Currently available flight by traditional aviation through Arlanda and Helsinki takes the second position with 9 h 15 min. A trip by a combination of a train and a ferry takes 11 h 38 min. The longest trip duration is when travelling by a car/eCar (17 h 50 min).

Table 20. Route Östersund – Sundsvall – Vaasa: comparison across different transport modes.

Transport mode	Distance (km)	Time door-to-door	CO2 emissions, kg per passenger per trip*	Cost per passenger per trip (SEK)
eFlight	454	5h 19'	1,8	1945
Flight Östersund – Arlanda – Helsninki)	828	9h 15'	136	2327
Car (Gasoline)	1302	17h 50'	121.3	2513
eCar	1302	17h 50'	4.6	2513
Bus	–	–	–	–
Train + Ferry (distance and time)	505	11h 38'	–	–
Ferry Umeå - Vaasa			not considered	not considered

* Energy consumption only

A trip by an electric aviation produces the lowest amount of CO2 emissions per passenger per trip (1,8 kg). The electric car takes the second place (4,6 kg CO2 emissions per passenger per trip), and a gasoline car is the third (121,3 kg CO2 emissions per passenger per trip). The highest amount of CO2 emissions per passenger per trip is produced when travelling with the available traditional aviation flight via Arlanda and Helsinki (136 kg). In this pre-study, we did not consider CO2 emissions for trips by a ferry. This way, this parameter cannot be compared for a trip by a combination of a train and a ferry.

The lowest cost per passenger per trip is when travelling by an electric aircraft (1 945 SEK). The second choice is travelling by the available traditional aviation flight via Arlanda and Helsinki (2 327 SEK per passenger per trip). This is followed by a trip by a car/eCar (2 513 SEK). In this pre-study, we did not consider cost per passenger per trip for trips by a ferry. This way, this parameter cannot be compared for a trip by a combination of a train and a ferry.

4.9 Route 9: Östersund – Borlänge – Karlstad

These are not existing regional connections that would offer a better service for passengers (travellers and commuters using other transport modes) and saving their time. Borlänge is an important communication node with good connections between south and east in Sweden. The Swedish Transport Administration is situated in Borlänge. Karlstad is very difficult to reach from Östersund. From Karlstad there is a connection to Gothenburg.

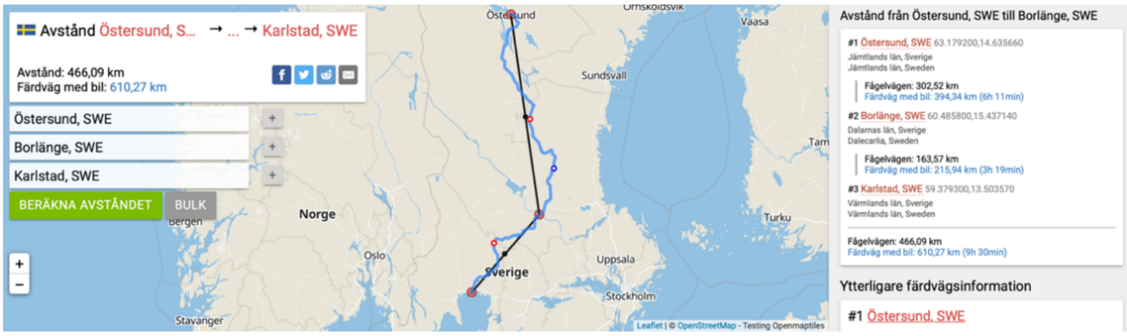

Figure 9. Distance Östersund – Borlänge – Karlstad [11].

Route description.

eFlight. Flights by an electric aviation are the following:

1. Östersund – Borlänge. Distance – 315 km. Time to the airport – 90 min, flight time – 1 h 15 min, waiting time between lines – 30 min. Aircraft – Heart ES-19.
2. Borlänge – Karlstad. Distance – 165 km. Flight time – 45 min, time from the airport – is 90 min. Aircraft – Heart ES-19.

Flight. Today, there are no direct flights connecting all three destinations (Östersund – Borlänge – Karlstad). Flights available today are the following:

1. Östersund – Arlanda. Distance – 431 km. Time to airport – 90 min, flight time – 52 min, waiting time between lines – 45 min. Aircraft – Canadair Regional Jet 900.
2. Arlanda – Gothenburg. Flight time – 60 min, time from Gothenburg to Karlstad by train – 3 h. Aircraft – Canadair Regional Jet 900.

Car, eCar. A trip time is 9 h 31 min. Distance – 615 km.

Bus. There were no bus options for this trip on Norrtag.se.

Electric train. A trip planning by a train is provided in Table 21.

[11] sv.distance.to, n.a. *Distance between Östersund – Borlänge – Karlstad*. Available at: <https://sv.distance.to/Östersund,SWE/Borlänge,SWE/Karlstad,SWE> [Accessed 19 November 2020]

Table 21. Östersund – Borlänge – Karlstad: a trip planning (as of the 5th of April 2021).

	Departure time	Arrival time		30 min - time to station	
	Österund	Gävle	Trip duration	Waiting for connection	Carrier
Train 1	05:34	09:04	3 h 30 min	20 min	SJ, train
	Gävle	Borlänge			
Train 2	09:23	10:47	1 h 24 min	1 h 24 min	SJ, train
	Borlänge	Hallsberg			
Train 3	11:50	14:37	2 h 47 min	27 min	SJ, train
	Hallsberg	Karlstad		Time from station	
Train 4	15:04	16:20	1 h 16 min	30 min	SJ, train

Comparison across different transport modes

An electric flight results in the shortest distance (480 km) (see Table 22). A trip by a car/eCar is the second choice (615 km). The available traditional aviation flight via Arlanda and Gothenburg covers a much longer distance (822 km), and there is still a need to travel by a train to the desired destination (Karlstad). A trip by a train covers the longest distance (855 km), which is nearly twice longer than a trip by an electric aviation.

The shortest trip duration, considering time door-to-door, is when travelling directly by an electric flight (5 h 24 min). The next choice is the available traditional aviation flight via Arlanda and Gothenburg (6 h 54 min). The following option is a car/eCar (9 h 31 min). A trip by a train results in the longest trip duration (12 h 12 min).

The lowest amount of CO2 emissions is produced when travelling by an electric aircraft or an eCar (1,9 and 2,2 kg CO2 emissions per passenger per trip retrospectively). A trip by a train produces 8,6 kg CO2 emissions per passenger per trip. A gasoline car produces 57,3 kg CO2 emissions per passenger per trip. The highest amount of CO2 emissions per passenger per trip is produced when travelling by available traditional aircraft flight (168 kg).

The lowest cost per passenger per trip is when travelling by a train (1 084 SEK). The second choice is a car/eCar (1 187 SEK per passenger per trip). The available traditional aviation flight via Arlanda and Gothenburg is the next option (1 794 SEK), which has a lower cost than a flight by an electric aviation (1 954 SEK per passenger per trip).

Table 22. Route Östersund – Borlänge – Karlstad: comparison across different transport modes.

Transport mode	Distance (km)	Time door-to-door	CO_2 emissions, kg per passenger per trip*	Cost per passenger per trip (SEK)
eFlight	480	5h 24'	1,9	1954
Flight (Östersund – Arlanda – Gothenburg)	822	6h 54'	168	1794
Car (Gasoline)	615	9h 31'	57.3	1187
eCar	615	9h 31'	2.2	1187
Bus - - no bus option - -	–	–	–	–
Train	855	12h 12'	8.6	1084

* Energy consumption only

4.10 Route 10: Östersund – Sundsvall – Åbo/Turku – Tallinn – Riga – Vilnius

This route connects Swedish cities with universities with Åbo that has a university and is the third biggest city in Finland. From Åbo (Turku in Finish), there could be electric flight lines to Tallinn – Riga – Vilnius connecting Baltic countries (Estonia, Latvia, and Lithuania).

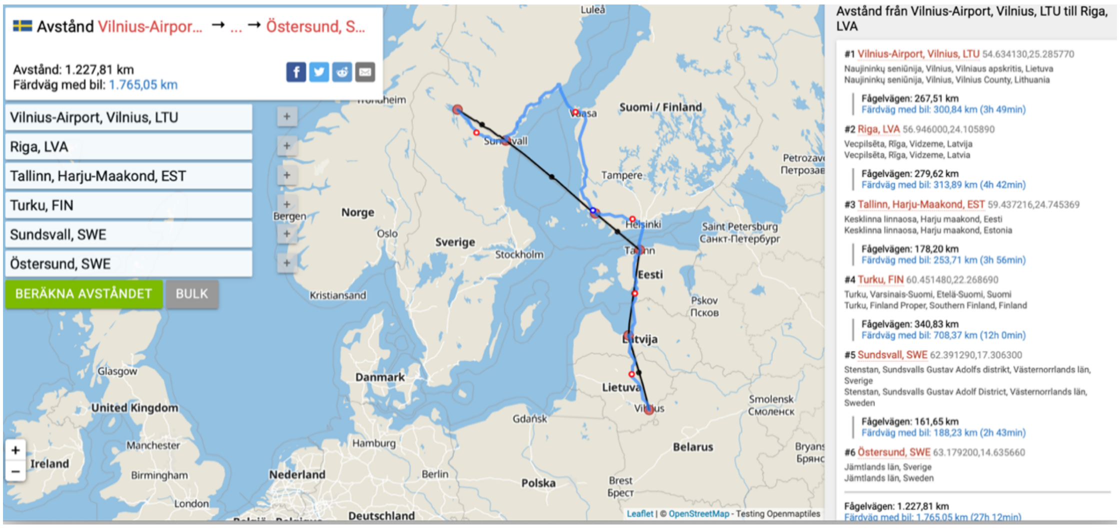

Figure 10. Distance Östersund – Sundsvall – Åbo/Turku – Tallinn – Riga – Vilnius[12].

Electric aviation could lead to a faster and better connection in the Baltic region. This route is an example of such a connection. This route was included in the project assignment. However, in the process of analysis, we found out a high complexity of this route, which includes variety of different interchanging modes of transport. After discussions with the Green Flyway project managers, it was decided to skip this route in this pre-study.

[12] sv.distance.to, n.a. *Distance between Östersund – Sundsvall – Åbo/Turku – Tallinn – Riga – Vilnius*. Available at: <https://sv.distance.to/Vilnius-Airport,Vilnius,LTU/Riga,LVA/Tallinn,Harju-Maakond,EST/Turku,FIN/Sundsvall,SWE/Östersund,SWE> [Accessed 19 November 2020]

5 Expected costs of electric aviation

In this report, we consider electric aviation which is driven by a battery or hydrogen. First electric 19-seater produced by Heart Aerospace is expected to be certified for commercial flights in 2026. Its expected flight distance is 400 km. This aircraft will need a shorter flyway of 750 m (heartaerospace.com, 2020) and for that reason will be suitable for regional airports. In this section, we discuss expected costs related to electric aircraft in comparison to a traditional combustion engine aircraft. These findings are based on the conducted interviews with industry experts.

Production costs. A representative of Pipistrel Aircraft producing a 2-seater electric aircraft, commented that a production of a 2-seater electric aircraft in comparison to the same size combustion engine aircraft requires less labour cost but more material costs. As a result, the production cost of an electric aircraft is about 10–15% lower. These estimations could be projected to the production of a larger aircraft, for example, a 19-seater at least until 2040. After 2040, the supply chain for electric aviation is supposed to become more diverse, more choice will become available, and more similar types of technologies will appear. All this will reduce the price of electric aircraft even more (TT).

Fuel cells at the moment would increase the price by 20–25% mainly because this class of cells fitting requirements of aviation is not produced for other market segments (TT).

The size of a factory producing electric planes could be 50% smaller in comparison to traditional aviation factories. This is due to the fact that production of an electric aircraft does not require use of certain dangerous liquids and oils, which normally have to be separated due to safety requirements and precautions. This means lower rent due to reduced production space or double throughput of production using the same factory size (TT).

Maintenance cost (Maintenance, Repair, Overhaul, MRO). In the airplane maintenance, periodic check-ups are expensive because the aircraft has to stop flying. These check-ups are needed for traditional aircrafts because they do not report on their condition. Hence, the majority of maintenance costs in traditional aviation are related to powertrain and engine maintenance (TT, FK).

In the electric aircraft, the powertrain reports on its condition all the time. The maintenance becomes on demand and the aircraft does not need to stop for check-ups. And it also allows to extend the intervals between the check-ups. For turbo-engines, the intervals are between 1 500 and 3 000 hours, and for electric engines it is 6 000 hours. Only rotating parts – bearings – should be taken care of. However, when there is a time to replace needed details, it is more expensive than with the fuel driven engines. Currently, this is due to a limited choice and lack of economy of scales (TT).

Battery is expected to have from 1 000 to 3 000 cycles of charging. With a faster charging the number of cycles decreases (HL).

Based on Pipistrel Aircraft estimations, today the maintenance cost of electric 2-seater aviation is about 40 – 45% lower than the maintenance cost of a traditional aircraft of the same size and is expected to go down in the future. Forecasted maintenance cost for a 20-seater could be 20% lower because the safety measures and rules are stricter, and there is a need to replace details and make check-ups more often. Heart Aerospace expects maintenance costs to be lower 50% by 2026 (heartaerospace.com, 2020).

Practically, when air companies buy a new aircraft, they assume that they will need to invest 1,5 times of its purchase value as maintenance cost during the lifetime of this aircraft. The total value of the aircraft equals 2,5 of the price. Electric aircraft could be from 20% to 50% cheaper (TT).

Personnel cost. The personnel for an electric aircraft will be the same as for a combustion engine aircraft (TT, Forslund, 2020). An electric 19-seater plane will require two pilots for scheduled commercial flights with passengers. This is due to decision making during the flight and for safety reasons if one of the pilots suddenly feels bad or has issues. Navigation of the electric aircraft is expected to be easier for pilots due to easier ways of monitoring and handling the performance of the electric engine (TT).

Infrastructure cost for airline companies. Aviation infrastructure includes airports and their provided services (air traffic control, terminals, engineering, support, airport buses, duty-free shops, airport ground handling, hangars, etc.). Airports charge airline companies for using airport facilities. Examples of charges are landing, freight fees, fees for using runways and passenger terminals, and so on. These airport utilisation fees will remain the same (TT) or could be differentiated (FBB, Forslund, 2020).

Currently, electric aircrafts are sold with a charger because they are not available today. In the future, this will not be needed as chargers will be widely available (TT).

Direct operating cost. Direct operating cost includes the landing fee, fuel costs, insurance, personnel (pilots) cost, etc. One of the major types of costs for airlines is fuel, which share is more than 20%. In addition, there is a price for CO2 emissions that airlines have to pay. In the future, these costs are expected to increase (FK).

Fuel costs of electric aviation are expected to be 50–80% lower in comparison to combustion engine airplanes (heartaerospace.com, 2020; FK, TT, HL, FBB). However, it will depend on the future changes of electricity price. Currently, we can predict that the demand for electricity will increase in the next 5–10 years as the electrification scale will take a bigger scale in all aspects of society. And the increasing demand may affect prices. However, fuel prices may also change. Some experts expect that airport fees for electric planes might be lower than traditional planes (FBB, Forslund, 2020).

Based on Pipistrel Aircraft estimations, direct operating cost of a turbine-power airplane having 20 seats is around 2 000 €/h. This means about 100 € per passenger per hour. Direct operating cost of a zero-emission hydrogen plane of the same size, the same speed, and the same insurance cost is expected to be around 1 450 €/h (or 25% less). This means about 72 € per passenger per hour. However, it is unknown how the insurance cost will be estimated to electric aviation and which fees airports will set for electric planes.

Heart Aerospace expects that the part of the direct operational costs, which includes fuel and maintenance of the engine and the battery of the plane, of a 19-seater will be about 33% of the direct operating costs of a combustion engine aircraft of the same size (Forslund, 2020). A 19-seater is expected to have the same unit economics cost per passenger as a 70-seater turbine-power airplane (Forslund, 2020).

The comparison between traditional and electric aviation discussed above is summarised in Table 23.

Table 23. Summary of cost comparison between traditional and electric aviation.

Type of cost	Traditional aviation, 20-seater	Electric aviation, 20-seater
Production costs	• A larger factory due to a need to separate dangerous liquids and oils • Higher labour cost • Lower material costs because there are many material providers	• 50% smaller factory space • Lower labour cost • Higher material costs because there is a lack of supply • Production cost is 10–15% lower • Fuel cells would increase the price by 20–25% • Safer work environment for technical staff
Maintenance cost	• Engines are expensive and require a lot of maintenance • Check-ups every 1 500 – 3 000 hours • There is a need to make a lot of constant checks, refill oils, and other dangerous, oil-based, and flammable fluids, replace certain details • Less expensive details	• Much lower maintenance cost, because you do not have to maintain the electric engine and there is a constant monitoring of powertrain • Check-ups every 6 000 hours • Not used dangerous oil-based and flammable fluids, safer work environment for technical staff • More expensive details • 20% to 50% lower maintenance cost • Major risks are related to battery, safety, and redundancy
Personnel cost	• 2 pilots	• 2 pilots • Easier navigation
Infrastructure cost (for airline companies)	• Same airport utilisation fees	• Same or lower airport utilisation fees
Direct operating cost	• Higher cost per passenger (100 € per passenger per hour)	• Lower cost per passenger (about 72 € per passenger per hour) • Fuel cost savings about 50–75% • No data on possible insurance costs and airports fees

6 Other direct and indirect socio-economic effects of electric aviation

In this section, we discuss other direct and indirect socio-economic effects of electric aviation. This analysis is based on the information received during interviews with industry experts.

6.1 The impact of electric aviation for passengers

Ticket price. Price of the tickets will most probably be not much lower because the aircrafts will be smaller, and it will be harder to reach the economics of scale (HL). Currently, there is a wish to use as big aircrafts as possible on certain routes in order to sped out all fixed costs. Prices on electric aviation flights might be lowered due to state subsidies, as it is done for public transport today (FK, AS, FBB).

Time. For regional trips, the major benefit is the time, which could be saved (HL). This is especially important for the Northern regions of Sweden, where there are very long distances between destinations. For example, these are routes between northern Sweden and Norway over the mountains and between northern Sweden and Finland over the sea.

However, in order to save time, a security check procedure should be bypassed. Currently, a security control is necessary for passengers in order to be able to transfer and travel to other destinations abroad. And for domestic trips, it is possible to fly without security control. For that purpose, regional airports might need to arrange a separate entrance for domestic passengers so that they do not mix with other travellers (HL, AS).

Better accessibility. Electric aviation has a potential to provide a better accessibility to remote and sparsely populated regions and completely new destinations via direct flights (HL, AS, FBB). Citizens do not need to travel via Arlanda and can save their time. One example are northern regions of Sweden, which can be easily connected to Norway and Finland by electric aviation. In this case, universities located in Sundsvall, Östersund, and Trondheim would be better connected, which would be beneficial for exchange of academic staff and students (HL, AS, HD). Many people who are driving cars between northern cities today would get an easier, faster, and greener connection.

Lower noise. Passengers will get a better flight experience due to a lower level of noise in the cabin (FK).

Target market segments. The target market segments might be business companies and work-related trips, tourists, passengers going for leisure trips, university professors and students moving between universities, wealthy people (FK, HL, AS, FBB). One example is mining companies, which employees (about 50 people) spend a lot of time travelling from site to site in the cars (RL). Direct flights of 40 minutes might be a more attractive option for them than going two hours and a half (2,5 h) by a car. Another example is driving 7 hours from Skellefteå to Kokkola (Finland) around the Baltic Sea or going by a ferry, while a flight over the sea might take about 20 minutes (RL).

There is a potential for cargo transportation with electric aviation (FK). Zero emission and lower noise aircraft doing directly from one destination to another using the fastest route might be a more preferred option than a train or a road transport, which rarely go straight to the destination. Here are huge opportunities for future unmanned aviation and drones with automatic landing systems (FK, AS). This means new logistics possibilities, especially, in remote areas.

Integration into the public transport system. Electric aviation can be an integrated part of the public transport system opening new destinations (FK, AS, FBB). In this case, it is important who is procuring or subsidising the service (AS). Today this is done by region/county administration.

6.2 The impact of electric aviation on regional airports

Major sources of revenues for airports are: (1) landing fee, (2) duty-free shopping, and (3) commissions from transport to and from the airport. Big airports or hubs perform about one operation per minute (TT).

New business areas and increase in revenues. For small airports, electric aviation is an opportunity to add a new business area with short regional flights to new destinations (HL).

Installation of the needed infrastructure and its cost. Electric aviation needs a charging infrastructure. This means that airports need to invest in charging stations, to install and maintain them. This is a one-time investment cost. And some airports are already looking into this development (RL).

An electric 19-seater (e.g., Heart Aerospace ES-19) will need a charging capacity of about 1 megawatt and can be charged by charges having a charging capacity between 175 and 350 kW (Dunder, 2021). The cost of a charger with a capacity of 175 kW is approximately SEK 800,000 and there are additional SEK 500,000 for an additional 175 kW. This means that the cost for a total of 350 kW is SEK 1,300,000 (Dunder, 2021).

Charging time is expected to be longer than using fuel: about 500 kWh in about half an hour (TT; Dunder, 2021). This gives the equivalent of 1 hour of flight time (Dunder, 2021). It is also possible that airports could offer a few charging options: a faster charging, which might be more expensive; and a slower charging, which might be cheaper (HL).

In addition to the charging infrastructure for heavier electric aircraft, there is also a need to invest into battery solutions needed to outpower loads or to store renewable energy from used solar cells or wind power and maintain these solutions (Dunder, 2021).

It is expected that the price per kWh for the charging infrastructure will be determined by how the fixed cost will be distributed between electric aircraft and land-based heavier vehicles, and how this proportion will look like over time (Dunder, 2021). Due to this reason, it is likely that the charging infrastructure standard for heavy trucks and larger electric aircrafts (e.g., 19-seater the Heart Aerospace ES-19) will be the same (TT; Dunder, 2021). In addition, the number of users is likely to increase over time, which will also affect the price (FK; Dunder, 2021).

A need to meet an increased electricity demand. With the appearance of electric aviation, airports will need to supply electricity in order to meet its increasing demand. Expected demand for a 19-seater is 1 megawatt. Possible solutions would be having contracts with local energy suppliers (RL). Alternative solutions might be using solar energy for their own needs, which requires an investment in building a needed infrastructure (HL, FK, FBB, TT). Potential source of revenues for airports might be selling electricity to the grid (FK), however, this entails a distribution cost (UÖ).

Noise. The electric aircrafts are not producing the same amount of noise as traditional aircrafts. The only certified Pipistrel Velis Electro 2-seater produces 50% less level of noise when compared to similar combustion engine aircraft. Heart Aerospace is also expecting a 50% lower level of noise for a 19-seater (heartaerospace.com, 2020, HD, HL, FK). Reducing the level of noise even by 30% will have a positive effect on the health of people (FK).

However, currently, there are no larger electric aircrafts certified, and it is hard to predict which level of noise there will be (HL). It might be a lower level of noise, but it will add more regional aviation routes. This way, even if the level of noise produced by a single electric aircraft is lower, in general, it might result in more noise (HL).

Use of airports that are not used for commercial aviation today. There are about 40 airports that have commercial air traffic in Sweden today. But there are over 200 airports in total in Sweden. Electric aviation has an opportunity to connect cities having no air connection today because of lack of profitability for big airplanes, lack of economy of scale, noise, and pollution restrictions (FK). Electric aviation having lower operational cost, lower level of noise, and zero pollution may overcome existing obstacles. In addition, electric aviation is expected to use shorter runways (700 – 800 m), which makes it a good fit for smaller airports (FK).

No security checks. For regional flights with fewer passengers, the airports may not require the same level of security (FK). The need for security check depends on aircraft weight, and smaller electric planes might fit into this category (FBB).

6.3 The impact of electric aviation on environment

Emissions. All interviewed experts see the major benefit of electric aviation in its positive impact on the environment with expected zero operational emissions in the long run (HL, FK, HD, AS, FBB, heartaerospace.com, 2020). However, there is a certain pollution related to production and recycling of batteries (AS, FK). In the beginning, the impact of electric aviation will be small because it will be limited to just regional aviation. The major impact is expected between 2025 – 2040, when large electric aircrafts will become available (HL).

6.4 The impact of electric aviation for municipalities and regions

Climate and environmental impact. Municipalities in Sweden have the aim to be energy efficient and fossil fuel free by 2025–2030. This drives a use of electricity at a larger scale in transportation. This reduces emissions and, in addition, electric cars, buses, and planes produce less noise. It also is important to evaluate the cost of emissions and noise (AS).

Environmentally friendly destination and tourism. Use of electric aviation might lead to a perception of the destination as sustainable and environmentally friendly (AS). This is attractive for many citizens concerned about environmental impact and wishing to travel in an environmentally friendly way. In addition, distances between cities in the northern regions of Sweden are rather large and electric aviation would enable a faster connection and increased accessibility (AS).

Better connection in the east-west direction and completely new routes (FK, HL, FBB). With lower price of the engine (meaning the lower price of the aircraft) and with lower operational costs, electric aviation has a huge potential, especially for regional aviation (FK). Regional aviation is currently suffering in terms of air connectivity. One reason is that the majority of aviation routes are going through big hubs (e.g., through Stockholm) having pollution and noise issues, and traffic problems reaching these hubs by transport. This is seen as a more efficient and economically feasible way to offer aviation services to customers. And today, the majority of available routes in Sweden have vertical orientation from north to south via Stockholm, while horizontal orientation from east to west is not so exploited (FK, RL). However, this could result in new destinations that do not exist today not only in Sweden, but also across Swedish, Norwegian, and Finish regions. The network of electric aviation could cover all Baltic region (FK).

Another reason is a reduced number of available small and medium size aircrafts, which makes using big aircrafts for regional transportation commercially not profitable. However, in the remote and sparsely populated areas, it would be much easier, beneficial, and cost-efficient to use electric aviation rather than to invest in building high-speed train infrastructure (KW, FK, FBB). In addition, in such remote and sparsely populated areas there will not be enough demand for high-speed trains. This way, electric aviation can be seen as an addition to the existing public transport system (FK, FBB).

Today, small regional airports have two flights to Arlanda, one in the morning, one in the afternoon. One example of electric aviation use case could be an opportunity to have more flights and to connect them to bigger SAS flights going from Skellefteå, Umeå, Luleå, Sundsvall to Arlanda (Stockholm) (RL).

Interregional business development. Better connection and accessibility between regions could facilitate the interregional business development (RL).

Use of land around airports. There are noise zones around airports, where nothing can be placed. If there are more electric planes, which might produce less noise, then it would be possible to make use of the land around airports (AS). The value of property around airports may also increase (FK). Businesses might be established around airports (FK).

Opening closed airports. There is an ongoing process of closing down small regional airports. Electric flight might create a demand to use them, and they may open again (AS).

Making regions an attractive place to live and work. This could be achieved with a wider penetration of broadband, digitalisation, and increased accessibility due to electric aviation (AS, RL).

New logistics opportunities. Use of drones and smaller electric aircrafts will provide new logistics opportunities not only for transporting people but also cargo. They would help to minimise road transportation (AS).

7 Summary and conclusions

This pre-study is focused on two objectives:

- To develop a simple tool calculating direct costs and benefits, such as environmental impact, travel time, and other related costs (total cost, e.g., personnel cost, energy cost, airport, and infrastructure cost where available) for 10 routes that would include an electric flight option.
- To identify and analyse related indirect socio-economic and environmental impacts.

In order to reach these objectives, we have performed a quantitative and qualitative analysis. Quantitative analysis involved evaluation of environmental impact, travel time, distance, and cost per passenger per trip. We used qualitative analysis to discuss expected costs of electric aviation in comparison to traditional and other direct and indirect effects of electric aviation for passengers, regional airports, environment, municipalities, and regions. This is based on semi-structured interviews with a number of industry experts. Our findings are summarised in this section.

7.1 Comparative analysis across analysed routes

In this sub-section, we summarise the most important results of quantitative analysis provided in Section 4. In order to do this, and see the trends, we compare results for different transport modes in four domains (distance, travel time door-to-door, cost per passenger per trip, and CO2 emissions per passenger per trip) across analysed routes.

In order to do that, we have identified the minimum value within each domain for every route and compared remaining results to this minimum value. The closer to 1 are the coefficients that we have got, the better performance showed corresponding transport mood. The closer to 0 the coefficients are, the worse performance showed the corresponding transport mode in relation to identified minimum value (or the best option). The transport mode has got a value of 0 if it was either not available for certain route or not considered.

Distance

Comparison of the analysed routes by distance is provided in Figure 11 (high score = shorter distance). As we can see, route 5 is unique as all transport modes result in the same distance.

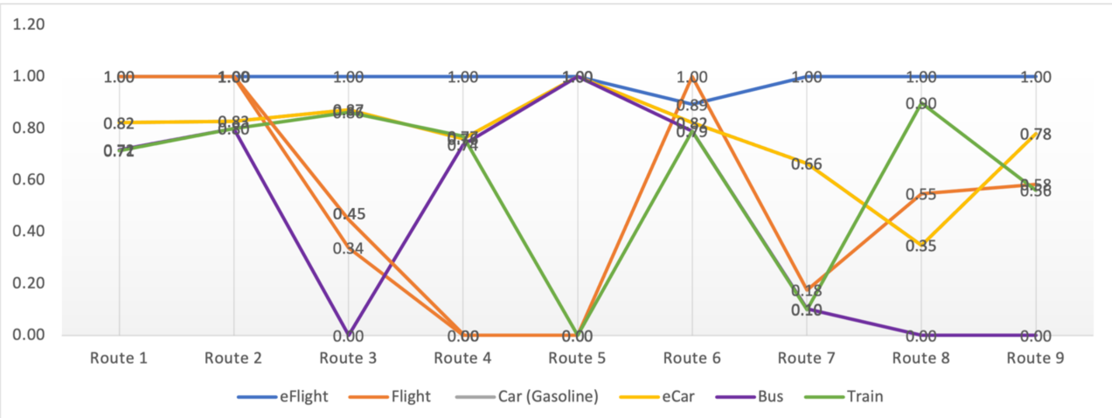

Figure 11. Distance: comparison across analysed routes.

eFlight and Flight. For majority of cases, direct electric and traditional flights (were available) result in the shortest distance. When traditional regional flights are directed via big hubs (such as Arlanda, Oslo, Helsinki), this results in much longer distances (route 3, 7, 8, and 9). Some of traditional flight options are not optimum because they do not connect desired destinations, for example:

- Route 3. Today, there are no flights connecting Trondheim – Östersund – Sundsvall. It is either Trondheim – Östersund or Trondheim – Sundsvall.
- Route 6. There are no flights connecting Östersund – Örnsköldsvik – Umeå. The available flight only connects Östersund –Umeå.
- Route 8. It is not possible to fly between Östersund – Sundsvall – Vaasa. The available flight is Östersund – Arlanda – Helsinki.
- Route 9. There are no flights connecting Östersund – Borlänge – Karlstad. Today's choice is Östersund – Arlanda – Gothenburg.

Car and **eCar**. In the majority of cases (route 1, 2, 4, 6, 7, and 9), a trip by a car/eCar is the next choice after electric and traditional flights.

Bus and **train**. In the majority of cases (route 1, 2, 3, 4, 6, 7, and 9), trips by a bus or a train or by a combination of these, are rarely direct and cover the longest distances.

Time door to door

Comparison of the analysed routes by time door-to-door is provided in Figure 12 (high score = shorter travel time).

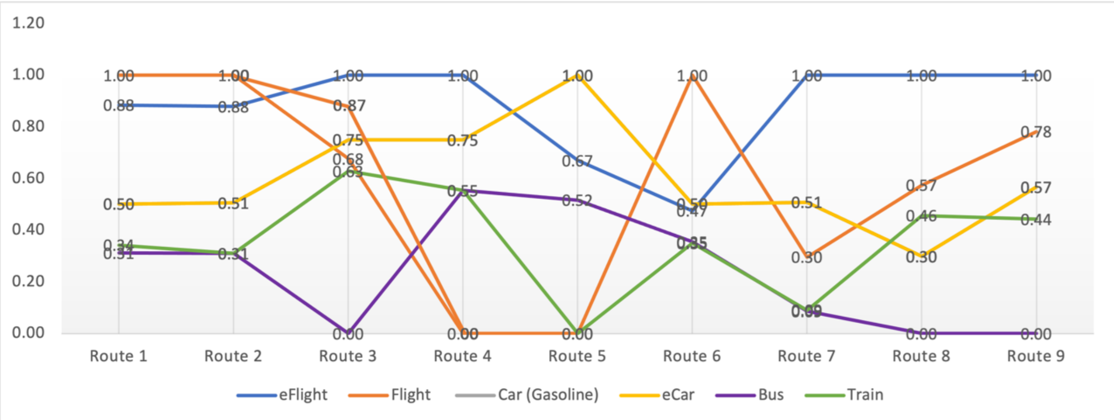

Figure 12. Time door-to-door: comparison across analysed routes.

eFlight and Flight. Available direct traditional aviation flights result in fastest trips considering door-to-door time (routes 1, 2, 6). At the same time, available traditional flights going via big hubs (such as Arlanda, Oslo, Helsinki) require much longer travel time door-to-door (routes 3, 7, 8, 9). At the same time, some traditional aviation flights do not connect desired destinations and passengers additionally need to travel by train (routes 3, 8, 9).

Direct flights by electric aviation would be the fastest choice for routes not connected by traditional aviation today (routes 3, 4, 7, 8, 9). It will be the fastest connection for these routes in comparison to other available transport modes (this is a car/eCar, a train, and a bus). For a short distance (100 km), it is faster to travel by a car/eCar rather than by an electric plane (route 5).

Car and **eCar**. In three cases out of 9 (route 4, 6, 7), the trip by a car/eCar is the second choice and in four cases out of 9 (route 1, 2, 3, 9), it is the third choice in terms of time. In one case, a trip by a car/eCar has the longest durations in comparison to other transport modes (route 8).

Bus and **train**. In the majority of cases (8 out of 9), trips by a bus or a train or by a combination of these resulted in the longest trip duration.

Cost per passenger per trip

Comparison of the analysed routes by cost per passenger per trip is provided in Figure 13 (high score = low cost per passenger per trip).

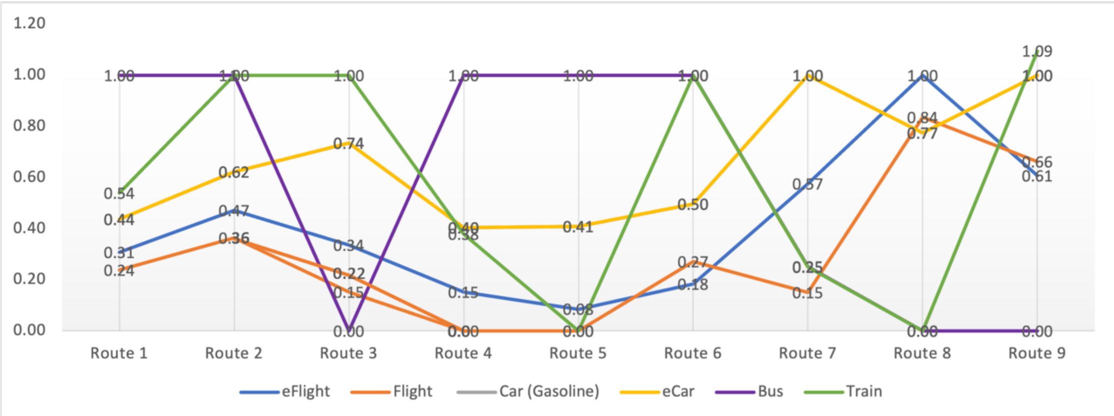

Figure 13. Cost per passenger per trip: comparison across analysed routes.

Bus and **train**. In most cases (7 out of 9), trips by a bus or a train or by a combination of these resulted in the lower cost per passenger.

Car and **eCar**. In 7 cases out of 9 (routes 1, 2, 3, 4, 5, 6, 9), a car/eCar was the next option after a bus and a train or their combinations when considering the cost per passenger.

eFlight and flight. In 5 cases out of 9, eFlight was the fourth choice. Considered electricity price of 4 SEK/kWh makes electric flights rather expensive in comparison to travels by a bus, a train, and a car/eCar.

There are seven routes having a connection by traditional aviation. When analysing these seven routes, electric aviation had a lower cost when compared to a flight by a traditional aviation in 5 cases out of 7 (route 1, 2, 3, 7, 8).

A traditional flight had the highest cost per passenger in 4 cases out of 7. In two cases, a cost of a flight with traditional aviation is lower in comparison to electric flight:

- Route 6. Östersund – Örnsköldsvik – Umeå. In this case, the traditional flight does not include an additional stop in between desired destination, which would make an impact on cost calculation.
- Route 9. Östersund – Borlänge – Karlstad. A currently available traditional flight connects Östersund – Arlanda – Gothenburg, which are completely different destinations from desired ones.

Climate sustainability

Comparison of the analysed routes by climate sustainability, in terms of CO_2 emissions per passenger per trip (high score = low CO_2 emissions) is provided in Figure 14.

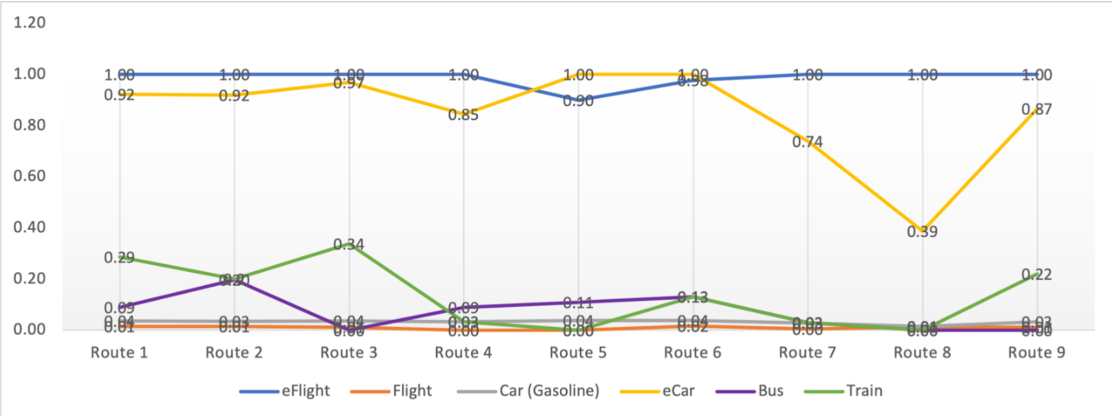

Figure 14. Climate sustainability: comparison across analysed routes.

eFlight. It is a notable trend that electric flights have the least impact in terms of CO_2 emissions in 7 cases out of 9 (route 1, 2, 3, 4, 7, 8, 9).

eCar. An electric car is closely following electric aviation in terms of CO_2 emissions. In 7 cases out of 9, an eCar is option number two, and in 3 cases out of 9, it shares the first position together with electric aviation or is very close to it.

Bus and **train**. Trips by a bus or a train or using their combination are ranked right after an eCar.

Car (gasoline). It is only a flight by a traditional aviation that is producing more CO_2 emissions than a trip by a gasoline car in all cases.

Flight. Direct traditional aviation flights result in the highest amount of CO_2 emissions per passenger per trip for all analysed routes.

7.2 Conclusions

Based on implemented qualitative and quantitative analysis, we conclude this pre-study by an evaluation of analysed factors for electric flight (see Table 24).

Travel time. Electric aircrafts will fly slower than traditional aircrafts, but only marginally so, especially considering ancillary travel times (to and from the airport). Hence, for routes, where regional flights are already procured (Östersund – Umeå and Sveg – Arlanda), traditional aviation is the fastest way to travel, but electric flight adds a pretty small penalty (less than 15%) on door-to-door travel times. For remaining routes, electric aviation can offer the fastest and direct connection between destinations. This is especially beneficial for:

(i) Sparsely populated regions, where development of high-speed railway infrastructure is too costly and will not have enough demand, and

(ii) Trip over natural barriers like mountains or the Baltic Sea (for example, destinations including trips to Vaasa and Turku). Combination of buses and trains results in the longest trip duration.

Another aspect of time saving is bypassing security control procedures when skipping larger hubs like Arlanda.

Table 24. Evaluation of analysed factors for electric flight.

Factor	Effect	
Travel time	Depends on existing alternatives but positive for remote sparsely populated regions	
Distance	Positive	
CO2 emissions	Positive	
Noise	Depends on the general situation at regional airports and number of aviation routes, but positive for electric aircraft	
Cost per passenger per trip	Positive in comparison to traditional combustion engine aviation	
Production costs	Positive	
Maintenance cost	Positive	
Personnel costs	Neutral	
Infrastructure costs for airline companies	Neutral or positive	
Direct operational costs	Positive	
Accessibility	Positive	
Impact on regional airports	Positive	
Impact on municipalities and regions	Positive	

Negative Neutral Positive

Distance. Electric aviation (together with some available direct regional flights by traditional aviation) is a direct way to travel. This results in the shortest travel distance. However, majority of traditional aviation flights are usually directed through big hubs (e.g., Arlanda, Oslo). Because of this, flights between remotely located destinations cover big distances. Trips by buses and trains result in the longest distances because these trips are not direct and require an interchange between different lines (in relation to destinations and routes analysed in this pre-study).

CO2 emissions. Our interviewed industry experts defined the major benefit of electric aviation in low operational emissions. This was confirmed by our calculations. Electric aviation is the transport mode producing among the lowest level of CO2 emissions per passenger per trip, while traditional aviation results in the highest amount of CO2 emissions per passenger per trip.

Noise. Electric aircrafts are expected to produce a much lower level of noise than traditional aircrafts. The level of noise in the cabin will be lower. This will have a positive effect on the health of people and trip experience. At the same time, adding more regional aviation routes might produce more noise in general at airports. Since there are no larger electric aircrafts certified, it is hard to predict today.

Cost per passenger per trip. Based on our modelling, electric flights are expected to have a lower cost per passenger per trip in comparison to traditional flight. Lower cost per passenger per trip makes a base for possible lower ticket prices when compared to traditional flights. However, actual ticket prices will depend on the price strategy of the airline company operating the route, as well as the level of public subsidies. The factors leading to lower cost per passenger are detailed below:

- **Production costs**. Production costs of electric aircraft are estimated to be 10–15% lower in comparison to traditional aircrafts because a smaller factory is needed, and the labour costs are lower. Today, material costs and fuel cells prices are higher due to a lack of supply, however, they are expected to go down with time, and reduce the production cost even more.
- **Maintenance costs**. Maintenance costs of electric aircraft are expected to be 20% to 50% lower in comparison to traditional combustion engine aircraft of the same size. This is due to much cheaper maintenance of the electric engine, longer time between check-ups, absence of work with dangerous oil-based and flammable fluids.
- **Personnel cost**. Personnel costs of electric aircraft are expected to be the same. However, the navigation of electric aircrafts is expected to be easier for pilots due to easier ways of monitoring and handling the performance of the electric engine.
- **Infrastructure cost for airline companies**. From the perspective of airline companies, electric aviation will imply the same or lower airport utilisation fees. However, it is expected that airline companies will need to pay more for using quick-charging stations.
- **Direct operational cost**. Electric aviation is expected to have lower direct operating costs than traditional combustion engine aircraft of the same size due to 50% to 80% percent lower fuel costs. The demand for electricity is expected to increase in the coming 5–10 years. Due to this, electricity prices may increase. However, fuel prices can also go up. In addition, airport fees for electric planes might be lower than for traditional planes.

Accessibility. Electric aviation can provide a better accessibility to remote and sparsely populated regions via direct flights. It can even be seen as an integrated part of the public transport system.

Impact on regional airports. Electric aviation may have a number of positive effects for regional airports. It may result in new business areas, increase in revenues, and opening airports that are not used for commercial aviation today. Airports need to invest in a charging infrastructure, install and maintain it. This one-time investment is about SEK 1 300 000 per one charger with charging capacity of 350 kWh (note, that this was included in the cost estimate mentioned above as a premium on the energy cost). In addition, there may be a need to invest and maintain a dedicated battery solution to store renewable energy coming, for example, from solar panels, and in installation of solar panels themselves.

Impact on municipalities and regions. Electric aviation is an environmentally friendly means of transport. Its use for domestic flights may create a perception of sustainable and environmentally friendly destinations and attract more tourists concerned about environmental impact. Electric aviation can offer a better connection in east-west direction and open completely new routes making remote destinations accessible. Electric aviation may foster interregional business development, new logistics opportunities, which would make remote destinations an attractive place to live and work.

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Appendix A. Sample interview protocol

1. About the overall context

- Why is electric aviation important?

- What are key issues or obstacles for electric aviation currently? Can they be solved?

(e.g., issues related to technology, technical complexity, standards, security, law, financing, unclarity how to organise work, a need for education, etc.)

2. Costs of traditional aviation vs. electric aviation

- What are the principle differences between traditional and electric aviation costs?

- What are the costs related to traditional aviation?

- What are the costs related to e-flight?

  > Production

  > Infrastructure cost

  > Maintenance cost, operational cost, personnel cost

  > Other expected costs

  > Expected ticket price (if possible)

3. Effects of electric aviation

1. What are expected effects for passengers?

Saved time / more attractive life in regions /

2. What are expected effects on local airports?

increase in airport revenues / level of noise / level of particles in the air / waiting time at airports for passengers

3. What are expected environmental effects? (zero CO_2 emissions / lower noise /)

4. What are potential effects for domestic aviation?

5. What are potential effects for local regions and municipalities?

- Which effects can be monetised? And which cannot?

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